Future City 17

Chiara Catalano · Maria Beatrice Andreucci
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Manfredi Leone · Salvatore Pasta *Editors*

Urban Services to Ecosystems

Green Infrastructure Benefits from the Landscape to the Urban Scale

Springer

Future City

Volume 17

Future City Description

As of 2008, for the first time in human history, half of the world's population now live in cities. And with concerns about issues such as climate change, energy supply and environmental health receiving increasing political attention, interest in the sustainable development of our future cities has grown dramatically.

Yet despite a wealth of literature on green architecture, evidence-based design and sustainable planning, only a fraction of the current literature successfully integrates the necessary theory and practice from across the full range of relevant disciplines.

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ISSN 1876-0899 ISSN 1876-0880 (electronic)
ISBN 978-3-030-75928-5 ISBN 978-3-030-75929-2 (eBook)
https://doi.org/10.1007/978-3-030-75929-2

Cover illustration: Zurich-Irchel University Campus, 10 May 2017, Deborah Hasler, Green Space Development Research Group, Institute for Natural Resources Science (IUNR), Zurich University of Applied Science (ZHAW)

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The idea of editing this book arose during the 60th *Symposium of the International Association for Vegetation Science* (IAVS) held in Palermo from the 20th to the 24th June 2017, entitled *Vegetation Patterns in Natural and Cultural Landscapes*.

Initially, the book was meant to collect the contributions of the session *Green Infrastructure and Vegetation Science*, chaired by Riccardo Guarino (editor of this book and organizer of the mentioned IAVS symposium) for the Future City series. The proposal came from Springer, in recognition of the novel and multidisciplinary approaches presented at the session, in which a broad-ranging concept of GI was adopted, from regional ecological networks to urban green roofs, designed as stepping-stones for natural ecosystems.

However, after some reflection, the editors agreed that the book would have lacked its main purpose if it had been open only to scholars of vegetation ecology and related disciplines, in the domain of natural sciences. In fact, the concept of green infrastructure was originally coined in the context of territorial planning and urban design, and responds to the specific aim of ensuring accessibility to a wide range of nature's contributions to people, through a strategically planned network of natural and semi-natural areas, which interpenetrate widely the places where most people live their daily lives.

Therefore, the editors decided to contact and involve other scientists/practitioners, not necessarily having a background in vegetation ecology, namely architects, landscape architects and agronomists. The final book counts 26 contributions and involves 75 authors from 14 countries. All the chapters were blind peer reviewed by the editors as well as by independent parties.

It is still early to say whether this experiment of cultural integration has been successful, but we can already say that the experience of editing this book has been very stimulating, collaborative and truly transdisciplinary. It is hoped that the contributions included in this book will help readers overcome the cultural barriers that lead, at one extreme, to considering the vegetation of green infrastructure as a motionless and indistinct construction material and, at the other extreme, as elements of the natural world that do not need human intervention to continue to exist, thrive and spread.

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Acknowledgements

We thank Dr Valeria Rinaudo, publishing Editor at Springer, who approached us at the IAVS Symposium in 2017 and solicited us to initiate the present editorial project for the Future City Series. The session Green Infrastructure and Vegetation Science organised at the mentioned Symposium was indeed a great opportunity to start the fruitful exchange among vegetation scientists, foresters, agronomists and designers operating in the green infrastructure sector, which eventually developed into this book.

We thank Prof. Luigi Badalucco and Prof. Bruno Massa from SAAF (Scienze Agrarie, Alimentari e Forestali Department of the University of Palermo, Italy), Mr. Gary Grant from Green Infrastructure Consultancy Ltd. (London, UK), Dr Michael Nobis from WSL (Swiss Federal Research Institute, Birmensdorf, Switzerland), and Dr Patrice Prunier from HEPIA (Haute École du Paysage d'Ingénierie et d'Architecture, Jussy, Switzerland) for their helpful comments and constructive remarks while revising some of the chapters.

We hope that this book might enhance the opportunities for scientists and practitioners to cooperate, merging ecological principles into the designing of Urban Green Infrastructure by adopting science-driven Nature-Based Solutions.

Dr Catalano's editorial activity was partially funded by the Institute of Natural Resource Sciences (IUNR) of the Zurich University of Applied Sciences (ZHAW).

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About the Editors

Chiara Catalano, PhD in Technologies for Sustainability and Land Restoration at the University of Palermo (2017) and MSc in Architecture (2008) at the University of Catania. Her eager to travel and to learn different viewpoints took her to live also in London, Zurich, Hannover and České Budějovice where she could alternate professional work, further education, and research activities. From 2017, she got a permanent position as a Researcher at Zurich University of Applied Sciences within the Urban Ecology research group, and currently within the Green Spaces Development. She is engaged in teaching in several BSc modules related to Urban Ecology and Ecosystems Design (in German and English), in supervising both BSc and MSc thesis on these topics, but also in the research and innovation area. Currently, she is leading an international project (DeMo: Design and Modelling of Urban Ecosystems, Switzerland-France), aiming at developing a semi-automatic spatial-based approach to integrate habitats in constructed ecosystems and buildings. Her primary passion as well as the topic of her PhD thesis were near-natural and biodiverse green roof design, construction and monitoring, interests well documented in international peer-review articles and conferences. She landed on the ground of urban green infrastructure inspired by the capability of plants to build dynamic communities able to characterize and reveal specific environmental conditions: plants cannot move, but they give lessons of perfection and slow adaptation, plants cannot speak, but we can observe and study them to plan greener, sustainable and liveable cities.

Maria Beatrice Andreucci, PhD in Environmental Design (Sapienza University of Rome), M.B.A. (INSEAD). She is a registered architect and an economist and focuses her professional activity, research and teaching on the application of environmental technological design and environmental economics theories, principles and methods on urban design, architecture, and landscape architecture projects. Management Committee member of the COST Action “PESFOR-W Payments for Ecosystem Services Forests for Water”. Core group member of the COST Action “Circular City: Implementing Nature-based Solutions for creating a resourceful Circular City”. Co-chair of the European research project “EKLIPSE - Urban

Biodiversity & Mental Health and Well-being", in cooperation with the French Ministry of the Environment and the World Health Organization. Chair of IFLA "International Federation of Landscape Architects Advisory Circle". Member of SITdA "Italian Society of Technology of Architecture", and EDRA "Environmental Design Research Association". In the last decade, she has authored two books, co-edited four books and published more than eighty papers in peer-reviewed journals and conference proceedings. Her design projects have been published in international journals, and have won recognitions and prizes at international levels. Currently, she works as Research Professor of "Environmental Technological Design", member of the Academic Board of the Ph.D. Program in "Planning, Design, Technology of Architecture"; and expert member of the Scientific Didactic Committee of the II level Master in "Environmental Technological Design", at "Sapienza" University of Rome.

Riccardo Guarino is the victim of an insane passion for plants, which led him to devote his restless youth to the floristic exploration of the southern Alpine and Prealpine Region. From the highest peaks, he slipped downstream and, after years as a castaway in the stormy Sea of Precariousness, he landed at the University of Palermo (Sicily), as a lecturer in Applied and Environmental Botany. His research interests include vegetation ecology, vegetation classification, biogeography, floristics, multifunctional agriculture and conservation biology. About these topics, he authored or co-authored more than 150 peer-reviewed contributions, 8 monographs (including the most recent national flora of Italy, in 4 volumes, digital archives and interactive identification tool), and 11 book chapters. His interest in green infrastructure is driven by the desire to offer plants as much space as possible. Plants have an essential smartness, a simplicity lived with serene grace. Silently passing their time on the earth, they glamorize without clamour, they give without demanding. He who loves plants can see how gross it is to hoard without limits; how illusory it is to claim pre-emption over what, in reality, belongs to everyone; how vain it is to spend time just to satisfy needless needs, believing that this is the right way to escape from a status that looks like "poverty" to our blinded eyes. He who really loves plants realizes that we are getting poorer and poorer while we continue this vast and violent exploitation of our planet.

Francesca Bretzel was born in Milan and now lives in Pisa, where she carried out her superior studies obtaining a degree in Agricultural Sciences with a dissertation on Floriculture. Francesca has achieved a MSc in Landscape and Historic Gardens at Versailles, France. Afterwards, she started her working career at the Institute of Soil Chemistry of the Italian National Research Council in Pisa, now Institute of Research on Terrestrial Ecosystems. Her research interest begun with the dynamics of the soil of urban, degraded and anthropized areas, then widen to the spontaneous and planted vegetation of those areas. Recent projects are focused on the circular economy and the recycle of paper sludges to produce a suitable substrate for plantings and green roofs.

Manfredi Leone, PhD in Sustainable Urban Development at the University of Roma Tre (2001) and MSc in Architecture at the University of Palermo (1996). Registered Architect, founding member of the Italian academic society of Landscape Architecture (I-Asla), and currently a member of the Association of Italian Landscapers (AIAPP). He got a permanent position as Professor of Landscape Architecture at the Department of Architecture of the University of Palermo since 2004. He teaches Landscape Architecture and is also a teacher of Historical Gardens and Architectural Design in MSc and BSc courses at the University of Palermo. He has been teaching as visiting professor at QUT University in Australia, offering lectures nationwide and internationally in Universities in China, Iran, Argentina, Cuba, Spain, Czech Republic and France. Currently, he is involved in two international projects funded by the Erasmus program within the European Network of Universities and Education Institutions: SumCuLa focused on Cultural Landscapes Sustainable Management, and NAWA, about Design thinking as a tool for business and design development. He runs research on public spaces of contemporary cities, low-cost landscapes, the recovery of cultural landscapes, the role of urban communities in bottom-up strategies, the landscape in infrastructures and sustainable mobility. He is the author of books and articles published in peer-reviewed journals and conferences, leading and teaching in several workshops worldwide about Landscape and Resiliency. He is the author of low-cost urban landscape projects including Parco Uditore, Giardino Pop-Up / Salita Raffadali, Maredolce Master Plan, all based in Palermo.

Salvatore Pasta, PhD in Plant Biosystematics and Ecology (University of Florence, 1994–1997). Since 2018 he works as a researcher at the Unit of Palermo (Sicily, Italy) of the Institute of Biosciences and BioResources (IBBR) – Italian National Research Council (CNR). His main fields of interest are floristics, plant conservation, forest ecology, biological invasions, vegetation dynamics, sustainable agroforestry, island biogeography, landscape history and ethnobotany. Quite recently, he started to pay increasing attention to urban ecology and to the floristic composition, structure and role of urban plant communities. He is the author or co-author of more than 180 peer-reviewed contributions, 5 monographs and more than 50 book chapters concerning the above-mentioned topics. He is vice-chair of the Mediterranean Plants Specialist Group (MPSG) of the International Union for the Conservation of Nature (IUCN) and has been collaborating with several universities in Italy (e.g., Palermo, Catania and Florence) and Switzerland (e.g., Bern, Fribourg and ZHAW in Wädenswil). As a freelance botanist, he has carried out many vegetation and floristic surveys, censuses and assessments and participated in the writing of the management plans of many protected areas and special conservation areas of European community interest and took part in numerous projects focused on plant species conservation in several Mediterranean countries (mostly Sicily, but also Sardinia, Crete and Tunisia) as well as in NW-Germany.

Chapter 1
Urban Services to Ecosystems: An Introduction

Riccardo Guarino, Maria Beatrice Andreucci, Manfredi Leone, Francesca Bretzel, Salvatore Pasta, and Chiara Catalano

Recent environmental and pandemic emergencies made us more aware that a deep change in our way of living is urgently needed. People are becoming increasingly conscious that substantial social, economic and environmental changes are necessary to reduce the planetary consequences of unsustainable development while acknowledging the failure of adopting pure technological solutions. The last decades of human history led to excessive pressure on natural and seminatural ecosystems

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_1

but, at the same time, life expectancy and global demographic curve increased all over the world at unprecedented rates. People are urged to find new tools to effectively respond to the challenges that await us in this century: on the one hand, the fulfilment of the increasing demand for energy, food and drinking water and, on the other hand, the need to reduce waste and emissions all along the production chains and especially in the urban environment. There is no doubt that change and innovation, through the testing and advancement of new models, have been instrumental in human progress. In the *green city* of the future, digital technologies and the *Internet of things* will represent not only a fundamental management tool, but they will also help in the planning, design and implementation choices of green infrastructure.

In Europe, the concept of green infrastructure was coined in the context of territorial planning and responds to the specific aim of ensuring accessibility to a wide range of nature's contributions to people, through a strategically planned network of natural and seminatural areas, which interpenetrate widely the places where most people live their daily lives. However, the vast majority of people intend the relationship between nature and man as one way and the value of nature as instrumental (as a provider of benefits/services), masking human agency and broader values (Kenter 2018). Unidirectional expressions such as *ecosystem services* or *nature's contribution to people* attest humans' difficulty to abandon the anthropocentric perspective and to accept to be an integral part of ecosystems, *one* of the many species present on earth, whose pressure threatens the survival of *many* others. Giving space to nature in the places where we spend our daily lives can favour the transition to a more *ecocentric*, less utilitarian vision towards nature. Thus, green infrastructure becomes a structural element of *naturally developed* human societies that are capable of using resources responsibly and of preserving and ensuring as much space as possible to the nonhuman elements of ecosystems, with the awareness of being dependent on nature "objectively and subjectively" (Immler 1985).

The *green growth* has been proposed as a promising way to find a new balance between human needs and the exploitation of natural resources. In this context, any form of the multifaceted term *development* can only be *holistic*, thus including ecological and economic sustainability, fair distribution as well as the efficient and effective use of resources. However, making cities *green and healthy* goes far beyond simply reducing CO_2 emissions and pollutants through efficiency measures and energy savings or through sustainable urban transportation. These are fundamental mitigation strategies, but they might be not enough, unless accompanied by an increase in the vegetation cover of our cities.

We need to plan and design green infrastructure so that it is no longer at the service of the city (following the concept of ecosystem services) but that the *new city* is designed in harmony with natural ecosystems, with a complete paradigm shift. Urban green infrastructure can help reconnect society to nature leveraging on environmental awareness and informal education, thus playing a substantial role in improving the attitude of citizens towards natural and seminatural ecosystems. The challenge is to strategically expand urban green infrastructure and provide our societies, including the most vulnerable people, with a more liveable, healthier, safer and fairer environment.

This book wonders precisely what services the city can offer to nature, thanks to a multidisciplinary approach obtained by involving scientists and practitioners from different backgrounds: vegetation ecologists, architects, landscape architects, engineers and agronomists. All those who contributed to this book did so with the intent to test themselves, looking for a common dialogue and striving to recognise an intrinsic value to green infrastructure, well beyond the simple role of a (ecosystem) services provider. The green infrastructure referred to in this book includes urban and peri-urban spaces that humans deliver to other components of natural ecosystems, in order to establish mutually beneficial interactions and synergies.

The commitment of contributors to find a meeting point, on the one hand, led ecologists and vegetation scientists to overcome the idea of green infrastructure as a quasi-synonym of ecological network and, on the other hand, has pushed planners and designers to abandon conventional approaches based on population projections, built infrastructure and architectural objects, unable to meet the challenges and needs of the ecological and sustainable urban form and development.

Despite the effort to converge towards a common and shared idea of green infrastructure, the attentive reader will notice in this book diversity of approaches and writing styles, which to some extent demonstrates that the concepts of vegetation and habitats, as perceived by ecologists, are still far to be corroborated by those who design and build the spaces of our daily life. In fact, the attitude to perceive green infrastructure as a man-made artefact, designed to host vegetation but focused more on its services related to human perceptions and well-being, building energy efficiency, acoustic insulation and carbon fixation, is still the predominant one.

The 26 contributions (excluding the present introductory chapter) of this book are organised in alphabetical order around three thematic pillars, i.e. (a) *green infrastructure, urban ecology and vegetation science*; (b) *planning and implementation of green infrastructure*; and (c) *nature-based solutions and innovative design approaches*.

1.1 Green Infrastructure, Urban Ecology and Vegetation Science

Ecological principles, including vegetation science and soil science, can help in designing, establishing, managing and monitoring green infrastructure (GI) at different spatial scales (Pickett and Cadenasso 2008): from transnational ecological networks down to the small scale of urban green roofs and private gardens, enabling their ecological function as stepping stones for biodiversity and metacommunity dynamics in urban districts (Cameron et al. 2012). From a landscape ecology perspective, in fact, GI can be defined as (Benedict and McMahon 2002, p. 12):

> an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations

In particular, the urban GI (UGI) is characterised by multifunctional patches, corridors and the urban matrix yet connected to the natural and seminatural ecological network (Ahern 2007; Pauleit et al. 2019) in a green-grey continuum (Davies et al. 2006).

Considering green infrastructure in terms of habitats, i.e. in an ecological perspective, may provide some advantages. Living organisms organise themselves in relation to each other, building webs where the single individual development largely depends on its neighbours. The advantage of considering communities, instead of single species, when dealing with the planning, design and managing of UGI, is due to the fact that inside a community the species are more or less adapted to the same conditions, namely, soil and climate, which are the most limiting abiotic factors for plant growth. Similar pedoclimatic conditions, which can hinder the healthy development of many cultivated plants, can be found in urban areas, where ecomimicry can be pursued to inspire the urban plantings (Nash et al. 2019). Cultivated ornamental plants are resource-consuming: they require several inputs such as irrigation, fertilisation and knowledge for successful effect, briefly costs, that municipalities are hardly willing to face in any situation (Hoyle et al. 2019). At the opposite side of the table, there are the many spontaneous urban plant communities, thriving without any specific intervention unless the disturbance due to irregular mowing. In turn, plant communities host wild animals (e.g. birds, insects) and provide beauty (Aloisio et al. 2020). Seminatural plant communities adapted to harsh conditions can be an ideal model to reconstruct habitats within the man-made landscape. Moreover, thinking in terms of *systems* more than *individuals*, when planning UGI, creates dynamic communities where living organisms may coexist and the eventual failure of one species will not represent a miscarriage at the urbanite's eye (Southon et al. 2018).

The works of this section concern the many facets inspired by nature-based solutions and lead to similar key results. For instance, authors pointed out the important role played by the experimental research focused on the composition and the dynamics of natural plant communities that may be mimicked to implement GI (Chaps. 3, 6, 8 and 10). The function of GI in improving the interconnection among habitats suitable for different living beings, such as soil biota, vascular plants, mosses, nesting birds or arthropods, is highlighted (Chap. 2). Functional traits and phylogenetic diversity of plant species contribute to fulfil ecosystem services in urban areas, more efficiently than monospecific plantings (Chap. 4). Urban soil is a habitat and sustains life, mitigating climate, pollution and flash flooding; its important chemical and physical properties interact with the complexity of urban ecosystems, offering opportunities for biodiversity in green infrastructure design, implementation and monitoring (Chap. 11). The study of the urban matrices (water, soil, air) can be pursued through the monitoring of all the organisms living there and, through this study, the use of the nature-based solutions is enabled and the habitat analogues are defined (Chap. 7). The need for a deep reconsideration of the methods and the finalities of applied ecological research and monitoring activities and the tight connection between the degree of naturalness, human health and ecosystem functioning are highlighted, too (Chaps. 5 and 9).

1.2 Planning and Implementation of Green Infrastructure

> Green Infrastructure can be broadly defined as a strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. More specifically GI, being a spatial structure providing benefits from nature to people, aims to enhance nature's ability to deliver multiple valuable ecosystem goods and services, such as clean air or water. (European Commission 2013, p. 7)

Planners consider GI a part of the design skeleton, drawn on maps (thus on land) to cover territories, to create continuous connections, physical but also with relapses on cultural and social life. The main principle is about the protection and enhancement of natural processes, necessarily integrated through planning and development of spaces and lands. For this reason, GI works as opposite to grey infrastructure, which usually focuses on one goal at a time (vs. multifunctional).

GI tries to progress multifunctional targets, enabling the same land system to perform different functions. Planners should aim to improve ecosystem services and goods through nature and environment, improving climate change adaptation and mitigation and thus biodiversity. Planning GI means also to provide and enhance processes in a sustainable and resource-efficient way, especially where spaces are limited. GI is part of the ecological network, be it complex or formed by isolated patches of urban nature, and may significantly contribute to local environmental values. Urban GI may interact and interfere at multiple scales, connecting urban and/or rural areas, being inside or outside protected areas. GI is planned to offer different advantages to human society: food, clean air and water, climate regulation, flood management, recreation and more, especially in urban areas, where most of the people in the world live nowadays (Ahern 2007).

Ecosystems are the matrix of biodiversity, so ecological systems *are* diverse: foodscape is a feasible way to create an integrated system of ecological networks, with local food production as an optimal strategy for recovering abandoned areas. In the wider and more complex meaning of GI, water plays a major role, both in the stormwater regulation and in the vulnerability management, through mitigation of a large number of processes like the urban heat island effect. Drainage systems play a key role here, avoiding flooding risks and ultimately contributing to sustainability (Ahern 2007).

According to some authors, GI as a concept is not coming "out of nowhere" (Wright 2011), but it describes a nonlinear evolution very far from being completed. More recently, innovative planning techniques have been implemented with GIS-based solutions to make places more resilient (Meerow and Newell 2017), offering a new methodology to set and control GI design in complex urban systems, where the Green Infrastructure Spatial Planning (GISP) model has been introduced, a GIS-based multi-criteria approach that integrates six benefits: (1) stormwater management, (2) social vulnerability, (3) green space, (4) air quality, (5) urban heat island mitigation and (6) landscape connectivity.

Green infrastructure is a very wide and, at the same time, precise topic: in the twenty-first-century society, it is no more possible to think of a planning strategy that does not adequately consider the role of GI, in any possible scenario.

This section contains a range of readings illustrating a wide spectrum of GI options and scenarios. Starting with food and agriculture (first group of contributions), an interesting glimpse to GI comes from the Japanese experience in treating farmland (Chap. 12) over a vast area surrounding Tokyo, while the Italian region of Trentino shows how to integrate landscape resources and foodscapes from an ecological network perspective (Chap. 15). Both chapters show great examples on how to contribute to GI, especially in urban and peri-urban areas.

The section includes three chapters with specific focuses on treating GI as *land driven* (second group of contributions): Antalya is one of the sceneries used to describe how to restore and preserve ecological corridors and permeability (Chap. 13), thanks to a set of GI used as a backbone for a wider territorial system; Chap. 14 emphasises the need to focus on multifunctional ecological network to develop framework for landscape and spatial planning, presenting an Italian case study; and Chap. 20 shows the possible links between planning and nature conservation strategies through the example of the Collserola Protection Plan in Barcelona.

A third group of contributions deals with water courses and in particular with water resources management in urban areas in Italy (Chap. 16), geological risk and land restoration throughout Europe (Chap. 17) and opportunities for urban revitalisation in the United Kingdom (Chap. 18) and along the Danube in Eastern Europe (Chap. 19).

All chapters underline that the holistic approach is the best way to keep several actors involved on the same page: public bodies and authorities at different levels, citizens and stakeholders.

1.3 Nature-Based Solutions and Innovative Design Approaches

As cities expand and urban population soars, competition for space from various land uses has become more intense, resulting in green space and nature being squeezed out of many urban areas and marginalised by practitioners and decision-makers.

Growing population density and related urban sprawl have made it harder to justify urban nature, for too long regarded only as an aesthetic nicety rather than a fundamental component of our urban built environment. This attitude has proved hugely detrimental for both people and the environment, with many unsustainably urbanised areas falling apart, due to the effects of climate change and the increasing environmental and socio-economic challenges.

The cornerstones of the development of the evolved paradigm of green infrastructure (GI) – in today’s formulation – are in particular to be traced back to the theories and practices of visionary designers, Frederick Law Olmsted (1822–1903) and Ian McHarg (1920–2001), in the United States, and Ebenezer Howard (1850–1928) and Leberecht Migge (1881–1935), in Europe. It is well known that the work carried out by the Anglo-Saxon masters was inspired by the many long-term benefits of GI, the effectiveness of which is still evident today. The implementation of a new master plan (2001) of the Emerald Necklace parks and wetland system – covering the Charles and Muddy river corridors and the Fens areas of Boston – is still underway according to Olmsted's *green blue infrastructur*e approach (1860) to reduce flood risks, restore natural areas and integrate biodiversity into the urban built environment. Leberecht Migge's multifunctional open space system for the Hufeisensiedlung in Berlin (1925–1931) still stands today as a morphological element structuring the fascinating horseshoe settlement, designed from the model of English garden cities. The neighbourhood still maintains its green infrastructure and, in particular, the pre-existing forest and wetlands to serve the city's resident population and suburban ecosystem.

After a century, urban areas are at the centre of the debate on sustainable development in the age of the Anthropocene. Everywhere, with varying degrees of success, green agendas are experienced, increasingly proving able to respond to the many challenges. The importance of the deep aesthetic value of the urban *nature* is known, but the appreciation of the many, though less obvious, ecological, environmental, social and economic benefits provided by urban biodiversity is less widespread. Trees mitigate the local climate and, together with shrub and herbaceous vegetation, absorb excess nutrients and reduce the flow of urban stormwater. Community gardens primarily use underutilised public spaces, i.e. in addition to producing food and plants, provide meeting places and promote social interaction. In the vegetated public spaces of urban areas, pollinators help to maintain biodiversity, ensuring essential life support services. Green roofs reduce rainwater runoff, increase natural habitat and regulate indoor temperatures, saving energy. In addition to the environmental benefits of nature-based solutions, the potential health and well-being benefits directly linked to them, such as increased life expectancy and better mental and psychological health, are also relevant.

Designing urban green infrastructure implies considering it a critical infrastructure, i.e. an equivalent associated with city energy, water, waste, transport and communication infrastructure. Practitioners consequently need to draw deeply from research findings, monitor GI multifunctional qualities and disseminate the wide-reaching benefits of nature-based solutions in a way that all people can understand. Design should be about what green infrastructure can deliver in terms of quality of life, seeking to create healthier, more socially cohesive and biodiverse urban environments, deeply drawing from research findings, lauding its multifunctional qualities and continuing to communicate its wide-reaching economic, social and environmental benefits in a way that influences decision-makers, politicians and public (Armour 2017).

The contributions included in this section testify to a paradigm shift towards approaches which are more respectful of the natural requirements and *wild* living beings (Chap. 27), take more carefully into account biodiversity and communities' functioning and their benefits (Chaps. 21, 22, 23 and 25), carefully consider health and well-being (Chaps. 22 and 26) and aim at better connecting urbanites with the natural and cultural history of the cities where they live (Chap. 24).

1.4 Concluding Remarks

As the array of definitions reported by Mell (2010) testifies, the term GI does not have a unique meaning, and it changes semantic connotation according to the field of application. However, either from biodiversity conservation or from urban planning and design perspective, the urban green infrastructure (UGI) has a common intent: to make the city more comfortable and liveable while *connecting* people with nature. If, in addition, to fulfil this function, UGI is also beautiful, all the better. One certainly cannot disapprove of those who intend to combine *utile dulci*. The strength of GI is, in fact, its multifunctionality based on the holistic approach adopted when perceiving, planning and designing it.

How UGI should be implemented? Should the use of exotic species be prohibited by law? Of course, in the case of the invasive ones, this has already been achieved in many countries, although other ones (like *Cenchrus/Pennisetum* spp.) are still widely used in Southern European cities despite their well-known invasive attitudes. However, the sustainability of urban greenery cannot and must not go through prohibitions and restrictions.

Perhaps we should first educate people about the *values of sustainability*. We need to realise how useless and unjust it is to think only of human well-being, as if cities were not part of natural ecosystems. An idea of a less energy-demanding society, more respectful of natural dynamics, is already making its way. It is the hope of those who wrote this book that, in the near future, the yellowing of a meadow during the Mediterranean summer dry season will be considered aesthetically acceptable or that the delicate blooms of native species will be preferred to the gaudy ones of many exotic plants.

The success of the revolutions must be sought much more in the psychological and cultural conditions of the rulers than in those of the ruled. Colonialism stopped when the public opinion in colonialist countries understood the absurdity of the colonial system in a modern world. By this, we do not mean that humanity did not have to fight to achieve this goal. In our case, we attribute great importance to every single individual choice in the design and construction of green spaces. At the same time, an improved green literacy should align educational institutions with lifelong ecological stewardship, in order to avoid mistaking reforestation with *Eucalyptus* spp. as a natural forest or *Opuntia* spp. as a typical and essential element of the Mediterranean landscape, as it still frequently happens.

This book opens new perspectives for urban sustainability practices where UGI should be seen as a place to reconciliate people with nature. The design and maintenance of urban ecosystems should therefore foresee and encourage spontaneous colonisation, the dynamics of plant and animal communities and natural cycles, so as to make our cities and landscape better integrated.

UGI designers and planners have to be able to recognise the natural identity of places and to move from the usual anthropocentric design aimed at satisfying human needs towards a systemic and *ecocentric* design (Austin 2014). In other words, professionals involved in the implementation of UGI should be *able to combine the ways of nature to the ways of mankind*, taking into account climate and soil conditions, potential vegetation and interactions within the surrounding ecosystems.

One of the aspects which the authors tried to emphasise is that correct and updated scientific information about the natural wealth (plants, animals, ecosystems, etc.) surrounding cities should represent the key for a more functional, effective and sustainable reshaping of urban spaces and, hopefully, encourage a deep revision of local strategies and policies.

In our opinion, another main issue raised by this book is the need to abandon the old-fashioned distinction between *cultural* and *natural* landscapes, which in many cases, especially in urban and suburban areas that have been prone to human activities since millennia, appears completely meaningless.

As for the *functioning* and the *services* provided by GI, all the professionals involved in the planning, the making and the implementation of GI should not neglect the historical perspective, remembering that until a few decades ago large portions of present-day cities and megacities were still natural and hosted plant communities, as well as wild animals. In many cases, worldwide urban sprawl developed dramatically fast and chaotic: this is true not only for developing countries but also for many Old World and North American cities. In all these contexts, special attention should be paid to the possibility of restoring and connecting the remnant patches of seminatural ecosystems and the populations of living beings within the extant cities. Many of these patches still testify the past texture and identity of the landscape (watersheds, stony ridges, woodlands, pastures, orchards, etc.) and may still be used as stepping stones for nature and life.

Author Contributions R.G. wrote the first draft of the introductory part and of the concluding remarks; R.G., S.P., C.C. and F.B. wrote the first draft of the § Green Infrastructure, Urban Ecology and Vegetation Science; M.B.A. wrote the first draft of the § Nature-Based Solutions and Innovative Design Approaches; M.L. wrote the first draft of the § Planning and Implementation of Green Infrastructure. All authors revised and approved the last version of the manuscript.

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Part I
Green Infrastructure, Urban Ecology and Vegetation Science

Chapter 2
Improving Extensive Green Roofs for Endangered Ground-Nesting Birds

Nathalie Baumann, Chiara Catalano, Salvatore Pasta, and Stephan Brenneisen

Abstract Cities are considered hotspots of biodiversity due to their high number of habitats such as ruderal areas, wastelands and masonry works hosting peculiar biocoenoses. Urban biodiversity represents a challenging and paradigmatic case for contemporary ecology and nature conservation because a clear distinction between nature reserves and anthropogenic lands is becoming obsolete. In this context, extensive green roofs may represent suitable habitat for ground-nesting birds and wild plants, providing suitable conditions occur. In this paper, case studies are used to show how existing extensive green roofs can be improved in order to make them function as replacement habitat for endangered ground-nesting birds. The setup of an uneven topography, combined with hay spreading and seed sowing, significantly enhanced the reproductive performance of the northern lapwing (*Vanellus vanellus*), one of the most endangered ground-nesting birds in Switzerland.

Keywords Hay transfer · Seeds sowing · Green roof vegetation · Breeding success · Ecological compensation

The original version of the chapter has been revised. A correction to this chapter can be found at https://doi.org/10.1007/978-3-030-75929-2_28

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_2

2.1 Introduction

2.1.1 Extensive Green Roofs: An Unexpected Space for Wildlife

The rapid urban population growth and the consequent massive urbanisation are stressing our natural life-support system and negatively affecting global biodiversity. However, integrating conservation goals into urban planning might help to reduce this alarming trend and combat habitat loss and fragmentation (Müller and Werner 2010). Studies of species-habitat relationships of birds occurring in areas lost to urbanisation would inspire ecologically informed design. For example, Stagoll et al. (2010) showed the importance of keeping and implementing habitat structural complexity in urban and peri-urban green space (through tree regeneration, the creation of *stepping-stone* sites, etc.) to support woodland birds.

Green roofs can enhance urban biodiversity by providing suitable habitats for plants and animals, especially for those species which are able to cope with difficult conditions and mobile enough to reach the rooftops (Brenneisen 2003). However, the plant communities growing on green roofs are seldom planted or sown with the specific purpose of supporting biodiversity and plant assemblages and are rarely monitored to see how their composition, structure and functioning change over time (Catalano et al. 2016; Köhler 2006; Ksiazek-Mikenas et al. 2018; Thuring and Grant 2016).

In Switzerland, there are several directives and guidelines which support public administrations (cities, towns, cantons and the Confederation), planners, architects, construction engineers, landscape architects and horticulturalists, in the design and construction of biodiverse green roofs (Brenneisen 2013). Moreover, the building codes of several German-speaking cantons and municipalities explicitly require both new and retrofitted flat roofs to be green. This is for several reasons, as follows: they support and promote plant and animal diversity, reduce the effect of the urban heat island (UHI), regulate water flows, filter pollutants, save energy, represent an aesthetic improvement and increase the longevity of the waterproof layer of the roof by 40 years or more by protecting it (Berardi et al. 2014; Francis and Jensen 2017; Oberndorfer et al. 2007; Partridge and Clark 2018).

From an ecological perspective, urban green roofs can be viewed as green islands embedded in an urban matrix (Blank et al. 2017). In other words, they provide life cycle opportunities for many species and offer therefore a new chance for nature to improve biological diversity in urban areas.

Research carried out by the Research Group of Urban Ecology of the Zurich University of Applied Science (ZHAW) has focused over the last 20 years on the ecological value of green roofs using arthropods as bioindicators (Brenneisen 2003; Pétremand et al. 2018) but also on the identification of key design features which could maximise the ecological value of green roofs (MacIvor et al. 2018). These studies were the origin to what is now more widely known as *biodiverse green roofs*, characterised by an uneven topography, the use of different substrate types (including topsoil), the use of different mixtures of local seeds or hay spreading/transfer and the creation of additional microhabitats, e.g. deadwood piles, stony areas, sand or gravel bands (Brenneisen 2008; Catalano et al. 2018).

2.1.2 The Role of Vegetation Patterns on Green Roofs

The plant assemblages of extensive green roofs must be able to withstand water shortages; for this reason, plant species occurring in naturally dry biomes like ephemeral and ruderal habitats, dry grasslands and the seasonally dry margins of rivers may match the ecological conditions of most extensive green roofs (Catalano et al. 2013; Dunnett 2015; Lundholm 2006; Thuring and Grant 2016; Van Mechelen et al. 2013).

As suggested by several authors, it is possible to create a fairly diverse flora on extensive green roofs in inner cities and peri-urban zones as well as in rural areas (Lundholm et al. 2010). Plant diversity can be even higher if various microclimates (especially sunny and shady areas) are created, initial planting or seeding is enhanced and a minimal amount of irrigation and maintenance are provided during establishment (Buckland-Nicks et al. 2016; Lundholm 2015). The water retention capacity of the substrate affects the speed and the final result of roof vegetation dynamics: the higher the retention, the denser the vegetation (Nagase and Dunnett 2012). Of course, rainfall patterns must also be considered. For example, 3–5 years after planting, a roof subject to average Swiss rainfall conditions with a $\geq$10-cm-thick substrate is likely to support a meadow-like plant community (Nagase and Dunnett 2013). Also, the variability of substrate thickness, particle size and soil type and the percentage of organic matter may strongly influence plant diversity (Chenot et al. 2017; Dunnett et al. 2008).

2.1.3 The Northern Lapwing: An Emblematic Endangered Ground-Nesting Bird

Globally, more than 700 vertebrate animals are confirmed or presumed to have become extinct since 1500, and the same has happened to around 600 vascular plant species. This confirms that humans have increased the global rate of species extinction by at least tens to hundreds of times faster than before they started to impact planetary ecosystems (Díaz et al. 2019).

The northern lapwing (*Vanellus vanellus*, Fig. 2.1) is a wader bird of the plover family. Native to temperate Eurasia, it is highly migratory over most of its range. It sometimes winters further south in northern Africa and India, whilst lowland breeders in the westernmost areas of Europe are resident (Kooiker and Buckow 1997).

Fig. 2.1 Male Northern Lapwing (*Vanellus vanellus*), looking out for predators. (Photo credit: Zurich University of Applied Sciences 2010)

V. vanellus breeds almost exclusively on crop fields and in other low-growing and/or regularly mown or grazed plant communities, such as wet meadows. The first clutch (three to four eggs, Fig. 2.2) is laid in a scrape in the ground. If the first brood is unsuccessful, the adult birds can lay up to seven replacement clutches on a new site or on the same site but several metres away from the first nest. The chicks hatch out after 26–27 days of brooding (Fig. 2.3); they leave the nest early, and after 42 days they are able to fly away. From day one, when they leave the nest, they have to find their food and water by themselves. Food mainly consists of average-sized and not too mobile arthropods, mostly spiders and insects (larvae, nymphs and adults) (https://www.vogelwarte.ch/de/voegel/voegel-der-schweiz/kiebitz, last accessed: 29.05.2020). However, these invertebrate species have been reduced by agricultural intensification (Kooiker and Buckow 1997).

The northern lapwing experienced a significant increase in numbers when it colonised central Switzerland between the 1950s and 1970s. According to the data issuing from last available census (2013–2016), 140–180 pairs of *V. vanellus* currently occur in Switzerland (Knaus et al. 2018).

Following IUCN criteria, *V. vanellus* is currently listed as a critically endangered (CR) bird species in the Swiss Red List (https://www.vogelwarte.ch/de/voegel/voegel-der-schweiz/kiebitz, last accessed: 29.05.2020), mainly because of the loss of its primary habitat, i.e. wet meadows, which were drained for agricultural purposes. This led to a rapid decline in its population, even though the species has adapted to colonise new habitats by breeding in crop fields and even on green roofs. For this reason, lapwing is a high-priority species according to several nature conservation European directives and is considered 'vulnerable' (BirdLife International 2015) and *Spec 1*, i.e. European species of global conservation concern (BirdLife International 2017), thus requiring urgent conservation measures.

Fig. 2.2 A nest with eggs of the Northern Lapwing on an extensive green roof. (Photo credit: Nathalie Baumann 2009)

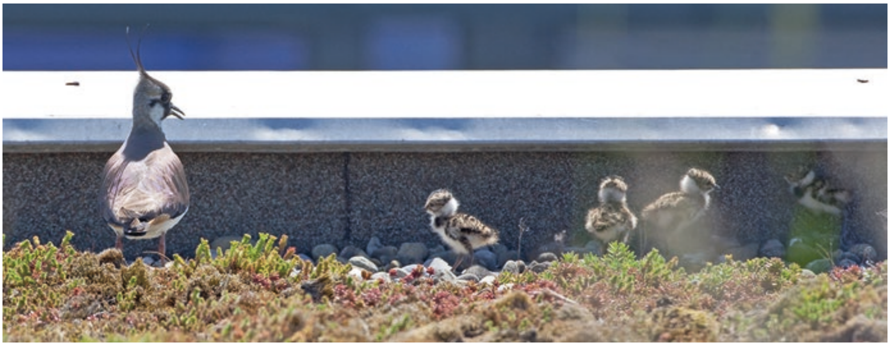

Fig. 2.3 Female Northern Lapwing (*Vanellus vanellus*), with chicks on the extensive green roof in Steinhausen (Hotz AG) with *Sedum* spp. in foreground. (Photo credit: Zurich University of Applied Sciences 2010)

Unfortunately, the intensification of agriculture and the increase of urban sprawl have led to further declines. However, following observations of northern lapwings using flat green roofs as breeding sites (Baumann 2006), there have been several initiatives in Switzerland to encourage ground-nesting birds, for instance by creating suitable replacement habitats on rooftops (Brenneisen et al. 2010).

2.1.4 Aims of the Research

In this work, we review and discuss the results obtained in a project that ran from 2006 to 2010, which had the aim of increasing the reproductive success (from egg-laying to fledging) of the northern lapwing on green flat roofs in the central and eastern Swiss Plateau (Baumann 2006). In particular, the project considered whether or not there was a correlation between the increase of plant species diversity, plant biomass and substrate thickness and the habitat use (behaviour) of the young and adult individuals of the northern lapwing. However, what we present is not a replicated and controlled investigation, but an observational study, like the research carried on in the UK on brown roofs (Bates et al. 2013).

2.2 Material and Methods

The nine green roofs included in the study were located in the suburban and industrial areas of three Swiss cantons: Bern (Schönbühl and Moosseedorf), Zug (Steinhausen, Rotkreuz and Hünenberg) and Lucerne (Emmen) (Table 2.1).

2.2.1 Roof Shaping and Environmental Improvements

The spatial heterogeneity of five out of the six roofs was changed by adding substrate and shaping topography (eventually creating a patchwork mosaic of open and densely vegetated areas; on all of the nine roofs, small shallow containers of water were added (Table 2.2)). The original substrate of four roofs was amended by adding a 4-cm layer of local recycled commercial substrate for extensive green roofs (blend of bark compost, crushed expanded clay and lava-pumice); on one of the other roofs, 4 cm of topsoil (and seed bank) was added from a nearby organic farm (Figs. 2.4 and 2.5).

Three methods were used to increase the species richness and the plant biomass on the roofs, as follows: laying a 2-cm-thick turf, sowing a commercial mixture of wild seeds (Swiss ecotype) for green roofs and distributing overlapping layers of

Table 2.1 Green roof descriptions. The substrate type refers to that existing before intervention

Name of the roof	City	Coordinates	Area [m^2]	YGRC	YGRI	Type of substrate
Hotz AG	Steinhausen	47°11’25.0”N 8°28’57.3”E	240	n.a.	2007	Lava-pumice
3M/Sidler Transport AG	Rotkreuz	47°09’07.9”N 8°25’58.3”E	11’000	c. 1968	2007	Gravel
Migros Aare (Shoppyland)	Schönbühl	47°00’57.3”N 7°29’37.7”E	8’000	c. 2003	2007	Lava-pumice
OBI (Shopping centre)	Moosseedorf	47°00’56.3”N 7°29’24.6”E	9’000	2007	2009	Crushed brick and compost
ALSO I	Emmen	47°04’55.6”N 8°18’20.3”E	2’100	n.a.	2009	Lava-pumice
ALSO II	Emmen	47°04’54.5”N 8°18’18.7”E	4’200	n.a.	2009	Lava-pumice
ALSO III	Emmen	47°04’57.8”N 8°18’16.7”E	3’600	2007	2009	Crushed brick and compost
Bösch I	Hünenberg	47°09’43.7”N 8°26’10.8”E	1’500	n.a.	2009	Lava-pumice
Bösch II	Hünenberg	47°09’46.0”N 8°26’06.7”E	1’400	n.a.	2009	Lava-pumice

n.a. data not available, *YGRC* year of green roof construction, *YGRI* year of green roof improvement

fresh and/or dry hay sourced from nearby dry grasslands. These techniques were applied separately or combined (Table 2.2).

After hatching, the chicks can survive by feeding on the yolk remains just for 3–4 days after their birth; then they need to find enough water and food on the roof. Thus, in 2008, to prevent the stress due to many consecutive days without rainfall and daily temperatures above 25 °C for the nesting birds and chicks, a rainwater irrigation system and two 9 m^2 shallow water containers were installed on each roof. Water availability on the roofs was increased through irrigation to reduce plant stress, to support the survival of soil arthropod fauna and to provide water for both adult and chick lapwings but also, importantly, to create the right conditions to encourage insects, specifically chironomids and other dipterans – an important food source for nidifugous chicks.

2.2.2 *Vegetation Surveys*

Before the interventions, the vegetation was surveyed in order to make a census of the lichens, mosses and vascular plants already present on each roof. Both the floristic composition and the cover of the vegetation on the roofs were regularly monitored and qualitatively assessed over 4 years (2006–2010).

Table 2.2 Interventions on the green roofs and basic information on the nesting and fledging activity of the northern lapwing and on the distance of the roofs from the nearby nesting and foraging sites

Name of the roof	Green roof interventions	FN	FF	MDNS (km)	MDFS (km)
Hotz AG	Substrate/morphology: 4-cm-thick extensive green roof substrate added to form several patches Plants: hay transfer (4 cm) Water supply: two temporary shallow pools	2006	2009	c. 1	0.1
3M/Sidler Transport AG	Substrate/morphology: 11 circles and 6 half-circle patches of 4-cm-thick extensive green roof substrate added on the top of the gravely substrate Plants: turfs and hay mulch (4 cm) Water supply: two temporary shallow pools	2006	none	none	0.1
Migros Aare (Shoppyland)	Substrate/morphology: 4-cm-thick extensive green roof substrate added on two big surfaces Plants: commercial seed mixture (Swiss ecotypes); Water supply: two temporary shallow pools	2006	none	c. 0.8	0.3
OBI (Shopping centre)	Substrate/morphology: topsoil transfer from an organic farmland added on a single large surface Plants: fresh cut hay mulch from a semi-dry grassland + topsoil seed bank Water supply: two temporary shallow pools	2008	2010	0.8	<0.2
ALSO I	Water supply: two temporary shallow pools	2008	none	c. 1	0.1
ALSO II	Substrate/morphology: some mounds of expandable slate added on the top of the lava-pumice substrate Plants: different plugs planted on each of the abovementioned mounds Water supply: two temporary shallow pools	2008	2008	c. 1	0.1
ALSO III	Substrate/morphology: 4-cm-thick extensive green roof substrate added on several patches to form mounds Plants: hay mulch Water supply: two temporary pools	2010	none	c. 1	0.1
Bösch I	None	2008	none	none	<0.1
Bösch II	Substrate/morphology: some structural elements, like wooden boxes, where placed Water supply: two temporary shallow pools	2009	none	none	<0.1

FN year of the first nesting event, *FF* year of the first fledging event, *MDNS* minimum distance from the nearest primary nesting sites, *MDFS* minimum distance from the nearest foraging sites

Fig. 2.4 Setup of uneven topography on a green roof. In order to enhance plant and animal (e.g. arthropod) biomass, the environmental conditions of some of the selected roofs were improved by adding a layer 8–16 mm-thick of expanded slate on the pre-existing substrate (30 mm-thick layer of pumice lava and clay) hosting sparse 'moss and *Sedum* spp.' vegetation. (Photo credit: Nathalie Baumann 2009)

Fig. 2.5 One of the six roofs with a remarkable increase of plant cover following from both sowing and planting carried out between 2008 and 2010. For the first time, in 2010 two young Northern Lapwings, born from two different nesting pairs, fledged from this roof and migrated south. (Photo credit: Nathalie Baumann 2010)

2.2.3 Arthropod Monitoring

The arthropods occurring on two roofs were sampled with ten pitfall traps (plastic cups set into the substrate containing a solution of soap, water and salt) on each roof once the chicks were observed fledging. Sampling was undertaken in 2007 (May–June) on the roof located in Steinhausen and in 2008 (June–July) on one of the roofs located in Emmen. The traps were emptied every two weeks; then the arthropods were counted and sorted to class level, with Carabidae identified to species level (Chinery 1984).

2.2.4 Bird Monitoring

From 2005 to 2010, the use of the roofs by breeding birds was monitored from the end of March until mid-July. From the time of arrival of the breeding pairs, observations were made weekly for 3 h at the same time of the day with binoculars and telescopes. During the breeding period, observations were made three times per week, and when the chicks hatched, the frequency was further increased to 4 h per day at each site. Observations continued until the chicks died, disappeared or fledged. The replacement broods were assessed using the same method. Many parameters concerning bird occurrence on the roofs were regularly monitored. Foraging behaviour, movement patterns, habitat use and other behavioural activities were recorded, and the results of roof enhancements were taken into account and correlated with bird breeding performance. In order to avoid disturbing the birds, observations were mostly carried out from adjacent buildings with a good vantage point. The high fidelity of northern lapwings to their nesting sites facilitated the planning of field surveys, with a focus on the most successful roofs.

2.3 Results and Discussion

2.3.1 Effects of Roof Enhancements and Plant Species Transfer on Vegetation and Invertebrates

Before the interventions, the roofs supported various vegetation types, which ranged from mosses and lichens on gravel to a more or less continuous cover of mosses and *Sedum* spp. on very thin and purely mineral substrates, made of a mixture of lava-pumice and expanded clay with almost no water retention. The most species-rich roofs supported *Dianthus carthusianorum* and grasses, including *Arrhenatherum elatius*, *Holcus lanatus* and *Lolium perenne*.

Our results showed that by using different plant establishment methods or applying them on different parts on the same roof by shaping and varying the topography and the substrate used, a mosaic-like patchwork of vegetation was created. Moreover, the overall length of the flowering season was extended from Spring to Autumn. Since the roofs were not irrigated, plants that can withstand dry periods were favoured.

Plants were able to establish themselves from hay transfer quickly and successfully, probably because the hay mulch prevented the seeds from being blown away or drying out. Consequently, very high vegetation cover rates (90–100%) were recorded on all the studied roofs during the first 2 years after the hay was transferred onto the roof. Additionally, the hay mulch, in comparison with the other plant species transfer techniques (seeding and turfing), significantly improved the seed germination rate, the retention of both rainwater and the maintenance of humidity during the dry season.

Generally, roofs with low plant diversity host very few insects and spiders, which are usually attracted by flowers (Brenneisen 2003). In contrast, the use of hay transfer accelerated the colonisation of arthropods, which represent the main food resource for nesting birds, especially for the chicks. Hence, the increase of both plant species richness and cover facilitated the creation of a rather complex food web, improving the feeding opportunities and the survival rate of young chicks (Partridge and Clark 2018).

Considering the low number of arthropods usually found on green roofs (Schindler et al. 2011), the total amount of spider and insect species recorded after the interventions was remarkable and probably related to the vegetation improvements, which in turn induced a longer flowering season (Table. 2.3). The medium-sized (>5 mm large) arthropods probably represent the best prey for chicks because they provide a higher energy intake.

Table 2.3 Summary of the total and daily numbers of arthropods (spiders, beetles and other insects) collected on two roofs during two different sampling campaigns (from Brenneisen et al. 2010, modified). Ind = individuals

Arthropods	Hotz AG (May–June 2007)	ALSO II (June–July 2008)
Spiders		
Tot. ind.	94	648
Tot. ind./day	0.27	2.09
Tot. ind. >5 mm	52	165
Tot. ind. >5 mm/day	0.15	0.63
Beetles		
Tot. ind.	76	65
Tot. ind./day	0.22	0.22
Tot. ind. >5 mm	28	32
Tot. ind. >5 mm/day	0.08	0.09
Other Insects (e.g. cicads, ants, etc.)		
Tot. ind.	113	150
Tot. ind./day	0.33	0.48
Tot. ind. >5 mm	27	50
Tot. ind. >5 mm/day	0.08	0.16

Table 2.4 Comparison of the total values of some proxies of the reproductive success of northern lapwing on the studied roofs (2005–2010)

Name of the building	City	NPrs	NClt	NRClt	NChk	NFChk
Hotz AG	Steinhausen	10	11	8	38	1
3M/Sidler Transport AG	Rotkreuz	15	18	9	63	0
Migros Aare (Shoppyland)	Schönbühl	6	7	0	16	0
OBI (Shopping Centre)	Moosseedorf	3	6	4	14	3
ALSO I	Emmen	3	5	2	15	0
ALSO II	Emmen	2	2	2	11	6
ALSO III	Emmen	1	1	0	2	0
Bösch I	Hünenberg	2	4	2	7	0
Bösch II	Hünenberg	1	2	2	3	0

NPrs nb. of nesting pairs, *NClt* nb. of clutches, *NRClt* nb. of replacement clutches, *NChk* nb. of chicks, *NFChk* nb. of fledged chicks

Fig. 2.6 Female Northern Lapwing (*Vanellus vanellus*) nesting on *Sedum* sp. tussock surrounded by dense moss cover on an extensive roof which had plant cover improved after the first records of nests in order to increase breeding and fledging success. (Photo credit: Nathalie Baumann 2006)

2.3.2 Trends of the Northern Lapwing Reproductive Performance on Green Roofs

The proxies reported in Table 2.4 provide some clues to the reproductive performance of *V. vanellus* on the nine green roofs monitored between 2005 and 2010. Northern lapwings preferred to lay their eggs on a nest built on low-growing plants, instead of moss, gravel or topsoil (Fig. 2.6). Thanks to the improvement of the green roofs and the sharp increase in vegetation cover, a sudden increase of chicks was recorded on many roofs (Fig. 2.7); unfortunately, most of these chicks did not survive, probably because they did not find enough food or water or simply fell off the roof. This could explain the sharp contrast between the numbers of hatchlings and fledglings on the Holz AG (240 m^2) and 3M (11000 m^2) roofs as well as the high

Fig. 2.7 Trend of several indicators of the reproductive performance of northern lapwings on four of the 9 roofs improved and monitored. *NPrs* number of nesting pairs, *NChk* number of chicks, *NFChk* number of fledged chicks. The black arrow indicates the year of the intervention on each roof

number of replacement clutches. These last two cases suggest that both the roof size and the absence of a parapet to prevent chicks from falling off the roof might have compromised the final success of the intervention (in terms of the total number of fledglings).

Nevertheless, the lessons (from failures) learned from the roofs in 2005 led to technical solutions for the problems by 2009. Ultimately, the two most successful roofs, on the OBI and the ALSO II buildings, were where the first pairs began nesting in 2008, with a total of five chicks being able to fledge in 2010 (Fig. 2.7). Moreover, after the interventions, the chicks recorded on three out the nine roofs experienced an increase in terms of days survived and a decrease on four roofs and remained steady on the other two (Table 2.5).

The improvement of chick performance appears to be linked to the increase of plant species richness and the vegetation cover. Plants attracted spiders and a variety

Table 2.5 Average age (in days) of the chicks before and after roof improvement and success of the improvement in terms of average age (days) of the chicks

	Before improvement	After improvement	
Name of the roof	Chicks age in days (year of the survey)	Chicks age in days (year of the survey)	Success
Hotz AG	4 (2006)	10 (2008)	↑
3M/Sidler Transport AG	4 (2006)	13 (2008)	↑
Migros Aare (Shoppyland)	4 (2006)	3 (2008)	↓
OBI (Shopping centre)	4 (2008)	45 (2010)	↑
ALSO I	6 (2008)	4 (2010)	↓
ALSO II	42 (2008)	42 (2010)	=
ALSO III	8 (2009)	0 (2010)	↓
Bösch I	4 (2008)	0 (2010)	↓
Bösch II	0 (2009)	0 (2010)	=

of insects, with many spending their entire life cycle (including larval stages) on the roofs, constituting the basic food resource for the young lapwings, allowing them to fledge 40 days after hatching.

2.4 Conclusions

Our study shows that it is currently possible and affordable to design and build a green roof of high ecological value providing several ecosystem services. Such green roofs may represent an effective ecological compensation measure, being able to host fully functioning near-natural habitats supporting a diverse flora and fauna. By using a mixture of native annual and perennial herbs, the plant species assemblages created provide an almost continuous vegetation cover and flowering activity from Spring to Autumn, thus combining desirable aesthetic results with a significant increase in animal (arthropods and birds) diversity (Fernández-Cañero and González-Redondo 2010).

In further research, the technical characteristics of the green roofs, including their size and isolation/distance from near-natural habitats (Partridge and Clark 2018), as well as the complex interactions involving the diverse living components of the ecosystems they host, should be more carefully recorded. For example, in order to better fit with the ecological purposes of the intervention, an accurate survey of the initial substrate characteristics should be done. In some cases, data-loggers should be placed on the roofs in order to quantify the daily, monthly and annual variation of several physical parameters such as soil and air humidity and temperature. Moreover, when plant species are transferred by hay and seeds onto green roofs, the local physical features such as aspect, climate (e.g. seasonal and daily thermal range, rainfall seasonality, etc.), the floristic composition of the donor grasslands/meadows, etc., should also be taken into account (Kiehl 2010).

Finally, rigorous, standardised and replicable methods should be adopted to carry out regular monitoring activities, too (Fernández-Cañero and González-Redondo 2010). Vegetation surveys should be carried out *before* soil and vegetation improvements and be repeated on a regular base (i.e. once a year during the first 3–5 years and every 5 years later on) on standard-sized permanent plots (geo-referenced) in order to obtain reliable and verifiable data on the ongoing trends.

Acknowledgements The Open Access of this chapter was funded by the Zurich University of Applied Sciences (ZHAW). The research project presented in this paper was partially funded by the Swiss Federal Office for the Environment (FOEN): *Entwicklung eines neuen Systems von Dachbegrünungen, die die Funktion von Ersatzhabitaten für bodenbrütende Vögel erfüllen (Dachbegrünung für Vögel)* [Improvement of existing green roofs to fulfil the function of substitute habitats for ground-nesting birds (green roofs for birds)], Project Number UTF 189.19.06.

Author Contributions N.B. suggested the topic, provided the raw data and the images, and prepared the first draft of the manuscript; C.C. and S.P. carried out data interpretation, prepared the tables, revised the manuscript, and adapted the final version according to the remarks and suggestions of the reviewers. S.B. supervised the 2006–2010 project and was responsible for the original data analysis. All authors revised the final version of the manuscript.

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Chapter 3
A Plant Sociological Procedure for the Ecological Design and Enhancement of Urban Green Infrastructure

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Abstract Urban green infrastructure could represent an important mean for environmental mitigation, if designed according to the principles of restoration ecology. Moreover, if suitably executed, managed and sized, they may be assimilated to meta-populations of natural habitats, deserving to be included in the biodiversity monitoring networks. In this chapter, we combined automatised and expert opinion-based procedures in order to select the vascular plant assemblages to populate different microhabitats (differing in terms of light and moisture) co-occurring on an existing green roof in Zurich (Switzerland). Our results lead to identify three main plant species groups, which prove to be the most suitable for the target roof. These guilds belong to mesoxeric perennial grasslands (*Festuco-Brometea*), nitrophilous ephemeral communities (*Stellarietea mediae*) and drought-tolerant pioneer species linked to nutrient-poor soils (*Koelerio-Corynephoretea*). Some ruderal and stress-tolerant species referred to the class *Artemisietea vulgaris* appear to fit well with local roof characteristics, too. Inspired by plant sociology, this method also considers conservation issues, analysing whether the plants selected through our procedure were characteristic of habitats of conservation interest according to Swiss and European laws and directives. Selecting plant species with different life cycles and

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_3

life traits may lead to higher plant species richness, which in turn may improve the functional complexity and the ecosystem services provided by green roofs and green infrastructure in general.

Keywords Green roofs · Urban biodiversity · Species introduction · Urban meadows · Data mining · Vegetation

3.1 Introduction

The Natura 2000 ‘Habitats’ Directive 92/43/EEC is the backbone of the European ecological network. It mentions 231 habitat types, 71 of which are designated as priority conservation targets (European Commission 1992, 2007). Despite the huge effort for mapping, surveying, monitoring and implementing conservation measures for the Sites of Community Importance belonging to the Natura 2000 network (the large majority of them falling in national parks and nature reserves), less effort was put to develop sound ecological corridors connecting them (Biondi et al. 2012; Jongman et al. 2011).

In the last decade, the European Commission started to promote nature-based solutions to contrast the erosion of biodiversity, habitat fragmentation and degradation, urban sprawl, resources depletion, the spread of invasive species, the reduction of ecosystem services and climate change (Bauduceau et al. 2015). With this regard, the construction and implementation of green infrastructure is a commonly adopted strategy to restore natural ecological processes and to implement the ecological network (Naumann et al. 2011). In landscape and urban planning, green infrastructure is conceived as (Department for Communities and Local Government 2012: 52):

> […] a network of multi-functional green spaces, urban and rural, which is capable of delivering a wide range of environmental and quality of life benefit for local communities.

In urban areas, the concept of green networks was developed already at the beginning of the twentieth century with the idea to implement green belts to connect cities with the surrounding natural ecosystems and to provide recreational services (Jongman et al. 2004). Nowadays, when more than half of the world’s population lives in cities and urbanisation is considered to be one of the main causes of habitat and species losses, it is necessary to foster species survival but also their chances to move and disperse within the built environment (Müller and Werner 2010; Planchuelo et al. 2019).

Given these premises, on the one hand, urban greenways and urban green infrastructure are gaining more attention by ecologists because of their species conservation relevance; on the other hand, planners and designers are increasingly willing to *design with nature* so to improve cities’ ability to support biodiversity whilst increasing citizens’ awareness and wellbeing (Hunter and Hunter 2008). Scientists and educators conveyed the need to interweave urban biodiversity and design with the Convention of Biological Diversity (CBD) by instituting the International Network in Urban Biodiversity and Design (URBIO, previously CONTUREC or Competence Network Urban Ecology), after the conference *Urban Biodiversity and Design: Implementing the CBD in Towns and Cities* held in Erfurt (Germany) in 2008 (Müller and Kamada 2011; Müller and Werner 2010).

Despite the extensive surveys and monitoring effort to describe the ecology of cities, little attention was given to the role that less disturbed spaces like railways, brownfields, city airports and green roofs can play as steppingstones and corridors within the Natura 2000 network. With this regard, Lundholm (2006) introduced the *habitat template approach* (hereafter: HTA) as a basic concept for the design of green roofs and green walls (see Box 3.1). As a matter of fact, the best way to identify the most appropriate habitat template is to become familiar with the vegetation occurring close to the project area. These preliminary field surveys may be supported by identification tools (see Box 3.2).

In southern France, the HTA was used to select a pool of 142 species adapted to grow on green roofs under Mediterranean climate (Van Mechelen et al. 2014). Plant species were obtained from vegetation relevés in open vegetated areas with shallow soils and limestone pavements but also from published phytosociological literature on the selected areas. The results were refined according to specific functional traits (Raunkiær's life forms and Grime's plant strategies – CSR) obtaining a list of several hemicryptophytes (perennial herbs with buds at soil level), few therophytes (annual plants) and geophytes (perennial herbs with underground buds).

Box 3.1 Habitat Template Approach (HTA)

HTA aims at finding habitat analogues (Lundholm and Richardson 2010) to mimic plant species compositions of natural stands assuming the similarity in terms of environmental conditions (both climatic and edaphic) between natural habitats and man-made ones (novel habitats). Thus, this approach can be adopted to create near-natural patterns, in terms of spatial heterogeneity and substrate properties, but also in the selection of plant species for green roofs and walls, e.g. stress-tolerant species typical to habitats subject to environmental stresses comparable to those imposed by urban ecosystems, like summer drought and periodical floods.

As mentioned by Lundholm (2006), the same principles of the HTA were applied in Switzerland by Brenneisen (2006) at the beginning of the 2000s. The Swiss prototypes are nowadays a mainstream, at least in Central Europe. These are known as biodiverse green roofs: an intermediate type between the simple intensive and the extensive green roofs (Catalano et al. 2018). These roofs were inspired by the surveys focused on species richness and evenness carried out on German green roofs during the 1990s (Buttschardt 2001; Mann 1998; Riedmiller 1994; Thuring and Dunnett in press) and characterised by a fine-grained patchwork of different, contiguous habitats capable of hosting different biocoenoses.

Box 3.2 Online Interactive Tools

Recently, several tools were launched to help planners and designers to select the appropriate species, among pools of native plants, according to the location (often political/administrative boundaries) and the ecological requirements (e.g. light temperature, pH). For example, Menegoni et al. (in press) developed the Italy Anthosart: an online tool based on the Flora of Italy (Pignatti et al. 2017–2019) providing a suitable species list (with pictures) after applying filters like region (e.g. Sicily or Lombardy), altitude (e.g. 0–300 m a.s.l.), infrastructure to be designed (e.g. extensive green roof or rocky garden), plant growth form (e.g. tree or herb), blooming season, size (e.g. <1 m), flower colour (e.g. red, white), climate and soil parameters (i.e. light, temperature, soil humidity, pH and salinity).

Similarly, Staas and Leishman (2017) launched the project *Which Plant Where* to develop an online tool for Australia to select the right species according to the location, whilst Vogt et al. (2017) developed Citree, a tool focused on the selection of urban trees and shrubs suitable for temperate climates by taking into account not only the site characteristics and the species natural distribution but also the ecosystem services, the management and citizens' need.

In addition, identification keys for phytosociological units are available for some regions (see, for instance, Prunier et al. 2014; Schubert et al. 1995) such as the app *Probabilistic Vegetation Key* freely available at https://play.google.com/store/apps/details?id=com.test.tichy.vegkey&hl=en; it was recently developed for Czech Republic to help users to classify the plant communities observed in the field by means of a probabilistic approach based on species identification. This allows to retrieve information concerning the vegetation structure, ecology and characteristic species combination (Tichý and Chytrý 2019) which might be used to implement the HTA (see Box 3.1).

Similarly, in Italy Caneva et al. (2013) proposed a list of 138 species by merging the national lists of species tested on green roofs and the information derived from vegetation studies concerning the following habitat analogues: (1) rocks and screes, (2) grey dunes, (3) perennial grasslands and (4) anthropogenic habitats. The final species list was obtained by applying filters related to chorology, life forms and ecological traits (namely, Ellenberg indicator values) concerning the Italian vascular plants (Guarino et al. 2010, 2012; Pignatti et al. 2005). Quite surprisingly, the paper by Caneva et al. (2013) excluded annual and biennial species (therophytes and short-lived hemicryptophytes), which represent a distinctive feature of Mediterranean landscapes, especially grasslands (Guarino et al. 2020), and proved to perform well on green roofs (Vannucchi et al. 2018).

Going beyond species lists, Catalano et al. (2013) proposed a plant sociological approach for green roofs. More in detail, they explicitly referred to two ranks of the sociological hierarchic system, i.e. classes and alliances, to create *ad hoc* seed mixtures based on real plant species assemblages occurring in natural habitats. Plant sociology, also known as phytosociology (Braun-Blanquet 1964; Dengler 2017; Guarino et al. 2018), was brought to landscape architecture by J. P. Thijsse and A. J. Van Laren in the Netherlands and by R. Tüxen in Germany in the second half of the twentieth century: these applications represent the first attempts to re-think urban parks and gardens according to species adaptations and natural assemblages (Woudstra 2004).

In this paper, we combined the inductive methodology proposed by Caneva et al. (2013) and the phytosociological approach by Catalano et al. (2013) in order to select the most appropriate plant species assemblage for an existing green roof in Zurich. With this aim, by screening the *Flora Indicativa* database (hereafter FI) (Landolt et al. 2010; Nobis 2010), we checked (1) whether the Landolt ecological indicators (hereinafter EIs), concerning the plants growing on the study roof, could be used to address the species selection; (2) whether this approach could implement the connectivity of some rare and endangered (target) Swiss habitats and could be applied elsewhere in the EU, taking into account the Natura 2000 Network; and, finally, (3) whether a shadow analysis on the roof may help to adjust the species assemblage derived from the automatic selection and to answer the question *where to sow (or plant) what?*

3.2 Materials and Methods

3.2.1 Study Case

The extensive green roof of the Technopark building has an area of about 1700 m^2 and was constructed in 2011 in Zurich (47°23’24.9” N, 8°30’56.9” E). According to Köppen-Geiger climate classification, the local climate is warm temperate, fully humid with warm summer (*Cfb*) (Rubel et al. 2017). The green roof at issue was implemented by adopting some of the main key designing features characterising *biodiverse green roofs*: varying substrate thickness (from 10 to 20 cm) and topography (small mounds and flat zones), sowing native plant species, using local substrate (sandy-gravel) and laying random piles of tree trunks (deadwood) on the roof to support arthropod communities (Fig. 3.1). Unfortunately, a comprehensive list of the sown species was not available. The facility manager reported that the roof was visited randomly for the maintenance of the drainages and the air conditioning machineries (max once or twice a year) but no agronomical maintenance (weeding, watering, fertilising) was carried out.

Fig. 3.1 (Left) Perspective view of the Technopark building roof in Zurich (study case). (Right) Aerial photo of the study case (magenta perimeter). (Photo credit: Chiara Catalano 2013; aerial photo: Bing Map 2012)

3.2.2 Vegetation Survey, Preliminary Ecological Assessment and Shadow Analysis

The green roof was visited in September 2013 to write down a list of the plant species (hereinafter: *master species list*) occurring there. This list was used to adjust and choose the values to query the FI database (see next paragraph): the average values of Landolt EIs related to the plant species found there were adopted as a proxy of the environmental conditions on the green roof, related to moisture (F), soil reaction (R), temperature (T), nutrients (N) and light (L) (Diekmann 2003); the indicators of soil aeration (D) and humus content (H) were considered, too. Species abundance and frequency were not recorded; consequently, rare species had the same weight of abundant ones in the calculations. Raunkiær's life forms and Grime's life strategies were used to better characterise the structural pattern of local plant communities. Phytosociological classes (to which the recorded plant species were ascribed) were used to get clues on the plant communities that could potentially be hosted on the roof.

To identify any possible shaded, half-shaded or fully lit surface, a shadow analysis was performed considering the light conditions at summer solstice (21st June) and at autumn equinox (22nd September). The latter simulation was meant to be considered for the microclimatic planting because it represents an intermediate situation at the end of the summer season. Thus, the hours of shade were considered to decide *where to sow (or plant) what* on the roof, according to the light requirements of the selected communities. The simulation was performed on a 3D Model of the Technopark building realised with SketchUp 2020 (Trimble®) and using the plug-in Shadow Analysis for SketchUp (DeltaCode®). Plant ecological information was derived from the FI Software (Landolt et al. 2010; Nobis 2010). Plant taxonomy, phytosociological nomenclature and the affinity of species with phytosociological ranks follow Landolt et al. (2010).

3.2.3 Automatic Plant Species Selection

In order to have replicable results, FI was queried to select the most suitable species and, consequently, to identify the phytosociological units that would match the estimated ecological conditions of the study roof. The whole database included 6472 taxa; discarding species aggregates, the remaining 5614 vascular plants were further processed by applying the following five queries (Figs. 3.2 and 3.3):

1. Conservation status for flora of the eastern Swiss Plateau (MP2), in order to sort out endangered species (i.e. those assigned to the following conservation statuses: VU, EN, CR) and to focus only on the species occurring in the Zurich region
2. Native status and invasiveness level (AE) in order to sort out neophytes (exotic plants naturalised after 1500) and most of the invasive species
3. Life forms (LF) *sensu* Raunkiær
4. Landolt EIs for soil moisture (F), soil reaction (R), soil nutrient content (N), temperature (T) and light (L)

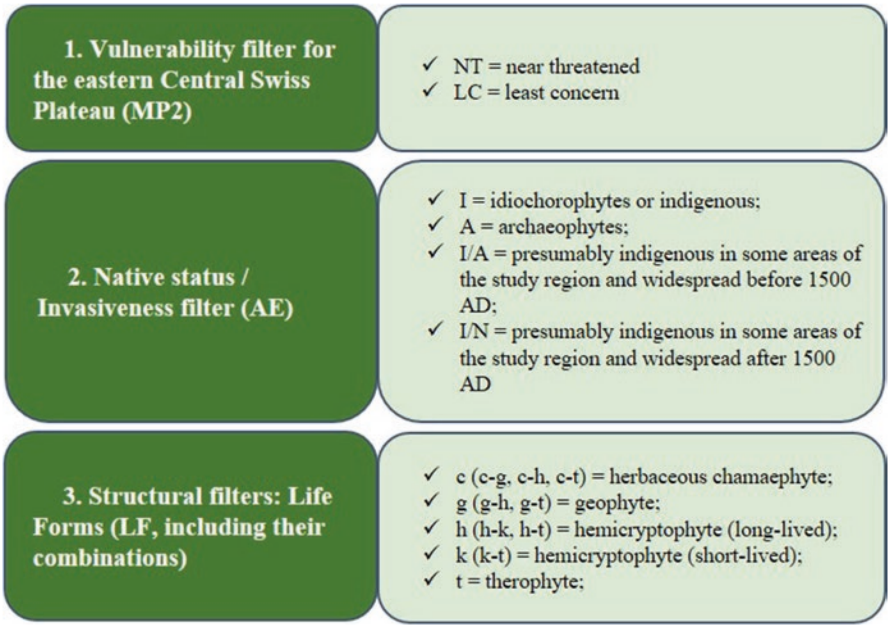


Fig. 3.2 First three steps of the inductive research procedure used to query the Flora Indicativa (FI) Software (Landolt et al. 2010; Nobis 2010). ✓ = queries used for the automatic plant species selection (the other possible choices are not shown)

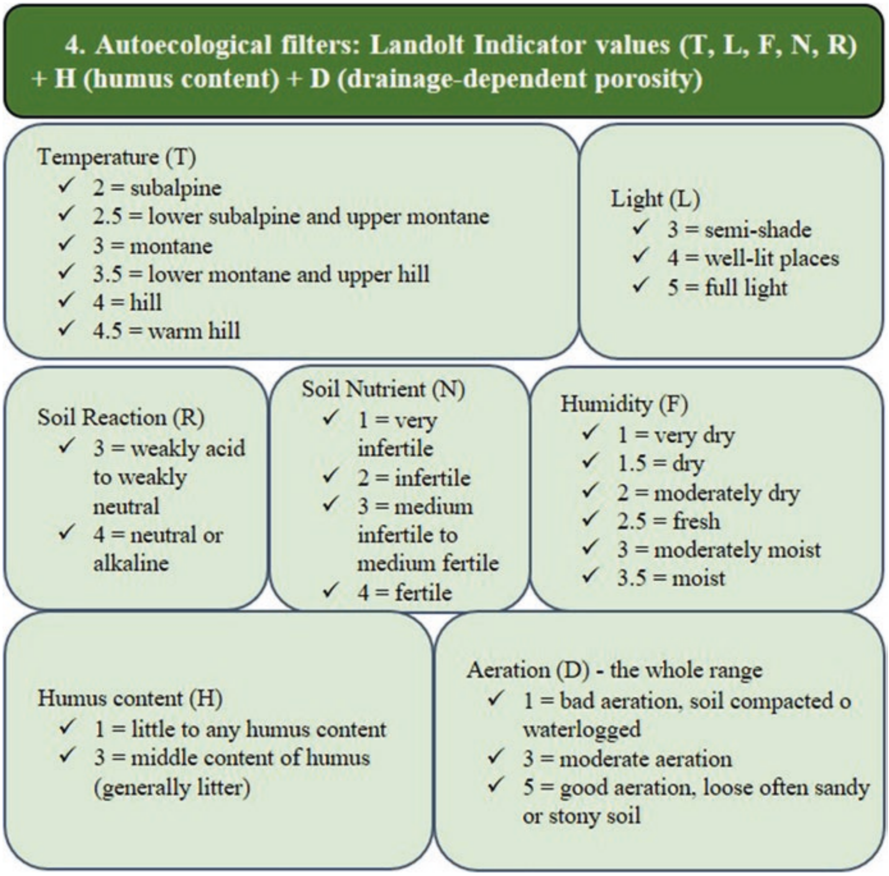


Fig. 3.3 Fourth step of the inductive research procedure used to query the Flora Indicativa Software (Landolt et al. 2010; Nobis 2010): auto-ecological filters encompassing climatic conditions (L and T) and soil conditions (N, R, and F). ✓ = queries used for the automatic plant species selection (the other possible choices are not shown)

5. Indicators of soil aeration (D) and humus content (H)

The values for Landolt EIs as well as those for D and H (queries 4 and 5) were adjusted considering the preliminary vegetation survey (see previous paragraph), i.e. ranging from the minimum and the maximum values of the master species list.

3.2.4 Further Screening and Expert-Based Assessment

The final list issuing from the selection procedure described in the previous paragraph was imported in Excel for Office 365 (Microsoft®). To perform quantitative analysis, we followed a four-step procedure:

1. We discarded (a) the species not recorded in the eastern Swiss Plateau in recent times (Welten and Sutter 1982) and (b) the archaeophytes which only live under cultivation and are not naturalised (infoflora.ch, last accessed: 03.05.2020).
2. The selected species were framed into the phytosociological ranks, i.e. classes (-*etea*), orders (-*etalia*) and alliances (-*ion*) they belong to. We discarded (a) the species not assigned to any phytosociological unit, (b) the classes counting less than three species and (c) the classes whose average value of soil humidity (F) was more than 3 (moderately moist substrates).
3. Expert-based assessment was needed to decide how to handle (a) the classes represented by species which are also ascribed to other classes and (b) the orders and the alliances represented by only one species (c) to obtain the final species list (hereinafter: derived list).

3.2.5 Habitat Connectivity and Microclimatic Design (Where to Sow/Plant What?)

To assess the connectivity of the detected habitats (corresponding to vegetation alliances), we searched for their potential habitat distribution and priority status in Switzerland (Delarze et al. 2015). Additionally, we checked the correspondence of these *syntaxa* with the habitats identified by the 92/43/EEC Directive (http://www.prodromo-vegetazione-italia.org, accessed 19.04.2020). To verify habitat occurrence near the study case at a finer scale, the web-GIS browser of the Canton of Zurich (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020) was consulted, too.

To decide where to sow (or plant) the species issuing from the screening according to the simulated light conditions (shadow analysis), we grouped them according to the following light (L) and soil humidity (F) values:

A. For $L = 4$ and 5 and $1 \leq F \leq 2$ (well-lit, full light areas on dry and very dry substrates)
B. For $L = 4$ and $2.5 \leq F \leq 3.5$ (well-lit areas on fresh to moderately moist substrates)
C. For $L = 3$ and $1.5 \leq F \leq 2.5$ (semi-shade areas on dry to fresh substrates)

3.3 Results

3.3.1 Vegetation Survey and Ecological Assessment of the Green Roof

The 29 *master species* found on the roof during the survey are reported in Table 3.1; most of them were therophytes (t = 13), herbaceous chamaephytes (c = 11) and ruderal strategists (Grime's life strategies *crr*, *crs* and *rrr*). According to the average values of Landolt indicators, the green roof showed the following environmental characteristics: very lit place (L = 4.1), temperature values typical to the deciduous mixed forests of the hill belt (T = 3.8), moderately to fresh soil moisture conditions (M = 2.3), neutral to alkaline soil chemistry (R = 3.6) and medium soil fertility (N = 3.2). At the same time, the species indicated intermediate humus content (H) and moderate aeration (D). Most of the plants belonged to the phytosociological classes *Stellarietea mediae* (nitrophilous therophytic pioneer communities, 15 species), *Koelerio-Corynephoretea* (pioneer communities with therophytes and dwarf succulents typical to well-drained, coarse or sandy substrates, 10 species) and *Festuco-Brometea* (dry grassland and steppe vegetation, 5 species). Other classes were represented by only one species or by species also referred to other classes (Table 3.2), which were considered as a reference for the final species selection and assemblage via expert-based assessment (see next paragraph). It should be noted that some species of wide ecological amplitude can be related to more than one phytosociological class.

3.3.2 Expert-Based Plant Species Selection and Assemblage

The automatic plant species selection gave a total of 283 taxa (*automatic list*) out of the initial 5614 ones, ascribed to 15 phytosociological classes and covering a wide range of habitats (Table 3.2): from open spaces to fringes and open forests (i.e. decreasing light availability), from sandy to sandy-loamy soils (increasing water holding capacity), from oligotrophic to eutrophic soils (rising nutrient content), from anthropogenic ruderal habitats to seminatural grasslands (diminishing disturbance) and from acidic to calcareous soils (pH gradient) (data not shown).

Comparing the phytosociological classes identified by the automatic list with those of the master list (Table 3.2), we decided to keep the classes judged to be compatible with the edaphic conditions of the study roof, i.e. *Festuco-Brometea*, *Stellarietea mediae*, *Koelerio-Corynephoretea* and *Artemisietea vulgaris.*

Within the selected classes, we excluded (i) the segetal annual weeds of the *Stellarietea mediae* that usually grow on base-rich soils in crop fields, vineyards and gardens subject to regular soil tillage (orders *Papaveretalia rhoeadis*, *Centaureetalia cyani, Eragrostietalia* and some species of the *Sisymbrietalia*) and (ii) the ruderal

Table 3.1 Life forms (LF), life strategies (LS) and Landolt ecological indicators (EIs) of the species found on the roof (*master list*) of the Technopark building in Zurich. H humus content, D drainage soil aeration, T temperature, L light, F soil moisture, R soil reaction, N soil nutrients. Species followed by an asterisk * are commonly used in Switzerland for extensive green roofs

						Landolt EIs				
	Taxon	LF	LS	H	D	T	L	F	R	N
1	*Acinos arvensis**	c-t	rrs	1	5	4	4	1	4	1
2	*Arenaria serpyllifolia*	t	rrs	1	5	4	4	2	4	4
3	*Buddleja davidii*	n	ccr	1	3	4.5	4	2	4	3
4	*Chaenorhinum minus*	t	rrs	3	3	4	4	2.5	4	4
5	*Chenopodium album*	t	rrr	3	3	3	4	2	3	4
6	*Conyza canadensis*	t	crr	3	3	4	4	2.5	4	3
7	*Echinochloa crus-galli*	t	crr	3	1	4	4	3.5	3	4
8	*Epilobium ciliatum*	c-h	crr	3	3	5	4	3	3	3
9	*Galinsoga ciliata*	t	crr	3	3	4	4	3	3	4
10	*Gypsophila repens**	c	crs	1	3	2	5	3.5	5	2
11	*Panicum capillare*	t	crr	3	3	4.5	4	2	3	4
12	*Petrorhagia saxifraga**	c	crs	1	5	4.5	4	1.5	4	2
13	*Polygonum aviculare*	t	rrr	3	3	4	4	3.5	3	4
14	*Polygonum persicaria*	t	crr	3	1	3.5	4	3	3	4
15	*Portulaca oleracea*	t	rrr	3	1	4.5	4	2.5	4	4
16	*Prunella grandiflora**	h	crs	3	1	3.5	4	2	4	2
17	*Salix caprea*	n-p	ccc	3	1	3	3	3	3	3
18	*Sedum acre**	c	rss	1	5	3	5	1	3	2
19	*Sedum album**	c	sss	1	5	3	4	1	4	2
20	*Sedum hybridum**	c	css	3	5	4	4	2	4	3
21	*Sedum rupestre**	c	sss	3	3	4.5	4	1.5	3	2
22	*Sedum sexangulare**	c	sss	1	5	3.5	5	1.5	4	3
23	*Sedum spurium**	c	css	3	5	4	4	2	3	3
24	*Setaria viridis*	t	crr	3	3	4	4	2.5	4	4
25	*Solanum nigrum*	t	rrr	3	3	3.5	4	3	4	4
26	*Sonchus oleraceus*	t	crr	3	3	3.5	4	3	4	4
27	*Taraxacum officinale s.l.*	h	crs	3	3	3	4	3	3	4
28	*Thymus pulegioides**	c	css	3	3	3	4	2	3	2
29	*Trifolium repens*	c-h	crs	3	1	3	4	3	3	4
Average				-	-	3.7	4.1	2.3	3.6	3.2
Min				1	1	2	3	1	3	1
Max				3	5	5	5	3.5	5	4

LF: c, herbaceous chamaephyte; h, long-lived hemicryptophyte; n, nanophanerophyte; p, phanerophyte; t, therophyte; KS: ccr, competitive ruderals; ccs, stress-tolerant competitors; crr, competitive ruderals; crs, C-R-S strategists. T: 3, montane; 3.5, lower montane to upper hill; 4, hill; 4.5, warm hill. L: 3, semi-shade; 4, well-lit places; 5, full light. F: 1, very dry; 1.5, dry; 2, moderately dry; 2.5, fresh; 3, moderately moist; 3.5, moist. R: 3, weakly acid to weakly neutral (pH 4.5–7.5); 4, neutral or alkaline (pH 5.5–8.5); 5, alkaline, high pH (pH 6.5>8.5). N: 1, very infertile; 2, infertile; 3, medium infertile to medium fertile; 4, fertile. D: 1, bad aeration, soil compacted o waterlogged; 3, moderate aeration; 5, good aeration, loose often sandy or stony soil. H: 1, little to any humus content; 3, middle content of humus (generally litter); 5, high humus content (generally row humus turf) and nitrophilous herbs and forbs growing on deep soils (alliance *Arction lappae*, order *Onopordetalia acanthii*) referred to the class *Artemisietea vulgaris*.

The above-described procedure allowed to identify the following 10 alliances (habitats) suitable for the study roof: *Mesobromion*, *Xerobromion* and *Stipo-Poion* (*Festuco-Brometea*); *Polygonion avicularis*, *Panico-Setarion* and *Sisymbrion* (*Stellarietea mediae*); *Dauco-Melilotion* and *Onopordion acanthii* (*Artemisietea vulgaris*); *Alysso-Sedion albi* and *Sedo-Scleranthion* (*Koelerio-Corynephoretea*).

3.3.3 Habitat Connectivity

At the scale of biogeographic units, we verified the potential distribution and the vulnerability status of the detected habitats within the eastern Swiss Plateau (Fig. 3.4): five of them resulted to be vulnerable (VU), four near threatened (NT) and one, i.e. *Onopordion acanthii*, endangered (EN). Five of the identified alliances corresponded to the following habitats of the 92/43/EEC Directive: 6110 (*Alysso-Sedion albi*), rupicolous calcareous or basophilic grasslands; 6210 (*Mesobromion* and *Xerobromion*), seminatural dry grasslands and scrubland facies on calcareous substrates; 6240 (*Stipo-Poion*), sub-Pannonian steppic grasslands; and 8230 (*Sedo-Scleranthion*), chasmophytic vegetation of calcareous rocky slopes. Habitats 6110, 6120 and 6240 are of priority interest according to the abovementioned directive. Excluding the habitats not occurring in the eastern Swiss Plateau and/or represented by only one species (*Onopordion acanthii*, *Sedo-Scleranthion*, *Xerobromion* and *Stipo-Poion*), we finally obtained a list of 139 species (derived list).

At the scale of the Zurich urban matrix, according to the cantonal web-GIS open data browsers (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020), the closest habitat type and the most similar to the target green roof are the ruderal communities living along the rails of the Zurich main station (Fig. 3.5). With this regard, many of the selected species belonged to the class *Stellarietea mediae*, characterised by ruderal (*rrr* = 20) and competitive ruderal (*crr* = 16) life strategy (data not shown).

3.3.4 Microclimatic Planting (Where to Sow/Plant What?)

The species of the derived list were grouped according to three combinations of light and moisture, hence suitable for different microenvironmental conditions (Table 3.3):

A. 52 species for well-lit areas on dry and very dry substrates (L = 4 and 5 and $1 \leq F \leq 2$)

Table 3.2 Phytosociological classes (Landolt et al. 2010) obtained by the preliminary survey of the extant flora of the study roof (*master list*, N = 29) and by means of the automatic species selection (*automatic list*, N = 283). The classes are listed first according to the decreasing species number of the master species list and then alphabetically. The species names are reported only for the master list, whilst the humidity values refer only to the automatic species list (F-a)

	Phytosociological classes	N-m	N-a	F-a	Ass.
1	*Stellarietea mediae*: annual, ephemeral, weed ruderal nitrophilous and sub-nitrophilous vegetation found throughout the world except for warm tropical regions	15	78	2.6	✓
	Arenaria serpyllifolia, *Chaenorhinum minus*, *Chenopodium album*, *Conyza canadensis*, *Echinochloa crus-galli*, *Galinsoga ciliata*, *Panicum capillare*, *Polygonum aviculare*, *Polygonum persicaria*, *Portulaca oleracea*, *Setaria viridis*, *Solanum nigrum*, *Sonchus oleraceus*, *Taraxacum officinale* s. l., *Trifolium repens*				
2	*Koelerio-Corynephoretea*: dry grasslands on sandy soils and on rocky outcrops of the temperate to boreal zones of Europe, the North Atlantic islands and Greenland	10	16	1.8	✓
	Acinos arvensis, *Arenaria serpyllifolia**, *Petrorhagia saxifraga*, *Sedum acre*, *Sedum album*, *Sedum rupestre*, *Sedum sexangulare*, *Sedum spurium*[N], *Thymus pulegioides*				
3	*Festuco-Brometea*: dry grassland and steppe vegetation of mostly base- and colloid-rich soils in the sub-Mediterranean, nemoral and hemiboreal zones of Europe	5	64	2.2	✓
	*Arenaria serpyllifolia**, *Petrorhagia saxifraga**, *Prunella grandiflora*, *Sedum acre**, *Thymus pulegioides**				
4	*Asplenietea trichomanis*: chasmophytic vegetation of crevices, rocky ledges and faces of rocky cliffs and walls of Europe, North Africa, Middle East, the Arctic archipelagos and Greenland	3	10	2.6	x
	Gypsophila repens[R], *Sedum album**, *Sedum hybridum*[N]				
5	*Molinio-Arrhenatheretea*: anthropogenic managed pastures, meadows and tall-herb meadow fringes on fertile deep soils at low and mid-altitudes – rarely also high altitudes – of Europe	3	107	2.9	x
	*Polygonum persicaria**, *Taraxacum officinale* s. l.*, *Trifolium repens**				
6	*Artemisietea vulgaris*: perennial (sub)xerophilous ruderal vegetation of the temperate and sub-Mediterranean regions of Europe	2	48	2.9	✓
	Epilobium ciliatum[N], *Taraxacum officinale* s. l.*				
7	*Rhamno-Prunetea*: scrub and mantle vegetation seral or marginal to broad-leaved forests in the nemoral zone and the sub-Mediterranean regions of Europe	2	8	2.6	x
	Buddleja davidii[N], *Salix caprea*[R]				
8	*Elyno-Seslerietea caeruleae*: alpine and subalpine calcicolous swards of the nemoral mountain ranges of Europe	2	22	2.7	x
	Gypsophila repens[R], *Prunella grandiflora**				
9	*Thlaspietea rotundifolii*: vegetation of scree habitats and pebble alluvia of the temperate, boreal and oromediterranean Europe and the Arctic archipelagos	2	11	2.4	x
	Gypsophila repens[R], *Sedum album**				

(continued)

Table 3.2 (continued)

	Phytosociological classes	N-m	N-a	F-a	Ass.
10	*Juncetea trifidi*: acidophilous grasslands in the alpine belt of the nemoral zone of Europe, the Caucasus and in the boreo-arctic and arctic zones of Northern Europe and Greenland	1	7	2.4	x
	*Thymus pulegioides**				
11	*Quercetea pubescentis*: Mixed deciduous oak and conifer open forests of warm regions in the cool-temperate nemoral zone of central and southern Europe and in the supramediterranean belt of the Mediterranean, Asia Minor and Middle East	1	36	2.3	x
	*Prunella grandiflora**				
12	*Agropyretea intermedii-repentis*: not recognised as class in Mucina et al. (2016) (synonym of *Artemisietea vulgaris*, see description above)	-	10	2.4	x
13	*Epilobietea angustifolii*: tall-herb seminatural perennial vegetation on disturbed forest edges, nutrient-rich riparian fringes and in forest clearings in the temperate and boreal zones of Eurasia	-	14	2.9	x
14	*Erico-Pinetea*: relict pine forests and related scrub on calcareous and ultramafic substrates of the Balkans, the Alps, the Carpathians and Crimea	-	16	2.4	x
15	*Trifolio-Geranietea sanguinei*: thermophilous forest fringe and tall-herb vegetation in nutrient-poor sites in the sub-Mediterranean to subboreal zones of Europe and Macaronesia	-	35	2.2	x

N-m species number of the master list, *N-a* species number of the automatic list, *F-a* average value for Landolt EI soil humidity for the species of the automatic list, *Ass.* expert-based assessment. ✓ classes kept according to the Ass., *x* class rejected by the Ass., [R] species not growing in the eastern Swiss Plateau or belonging to a life form not compatible with extensive green roofs (e.g. phanerophyte), * species occurring also in more species-rich classes, [N] neophyte. The ecological description of the classes follows Mucina et al. (2016)

B. 59 species for well-lit areas on fresh to moderately moist substrates (L = 4 and $2.5 \leq F \leq 3.5$)
C. 28 species for semi-shade areas on dry to fresh substrates (L = 3 and $1.5 \leq F \leq 3.5$)

Finally, the shadow analysis showed that during the autumn equinox (22th September), almost the whole roof is shaded at least for 1 h, with a variation from 3 to 6 h closer to the staircase blocks and to 7–9 h close to other elements of the building higher than the roof. According to the solar radiation map, the plant communities of the derived lists that might fit the sun exposure are shown in Fig. 3.6.

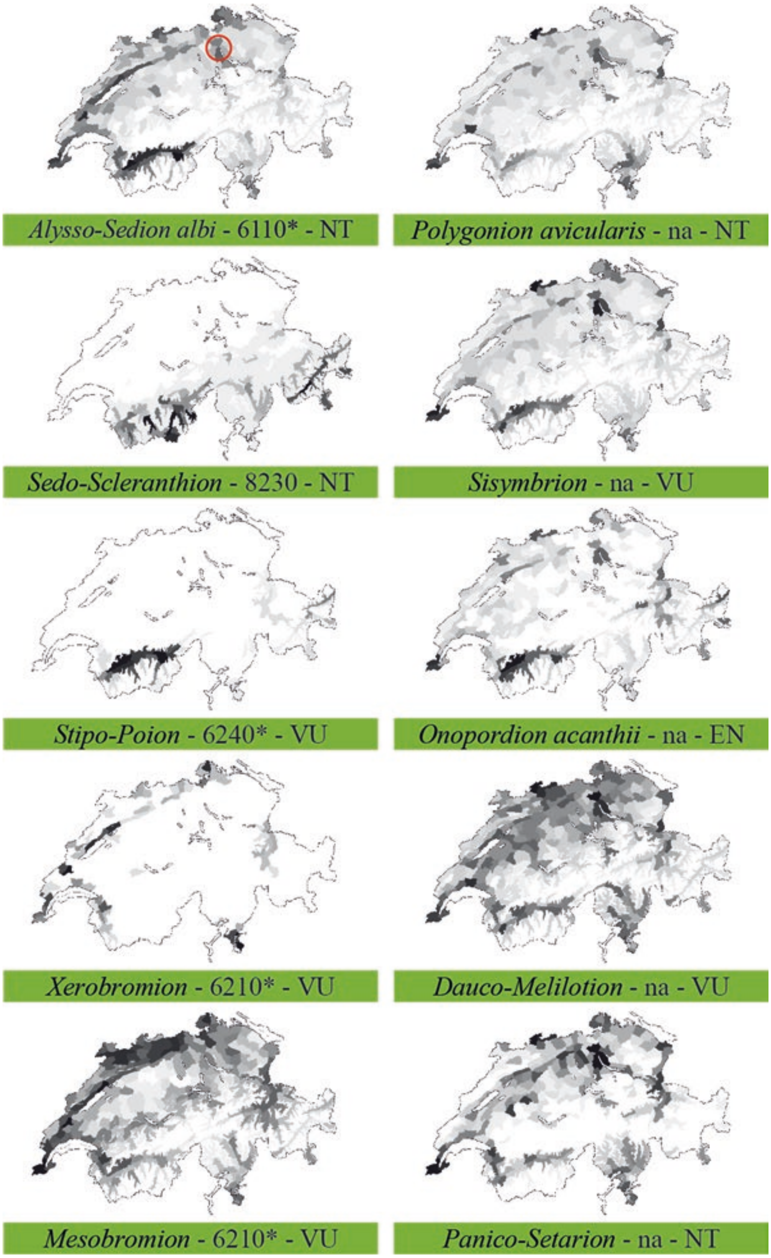


Fig. 3.4 Potential distribution maps and Red List-CH status - as in Delarze et al. (2015) – of the alliances (habitats) obtained combining the automatic screening process and the expert-based assessment. For each map, the legend shows, in order: the alliance name (e.g. *Alysso-Sedion albi*), the correspondence to Natura 2000 habitat code (e.g. 6110*) and the red list status (e.g. VU). The probability of occurrence is expressed by using a scale of greys (from white = 0% to dark grey = 100%); the red circle envelops the Canton of Zurich. The correspondence with the habitats of 92/43 *Habitats* EU Directive was checked in the Italian Vegetation Prodrome (http://www.prodromo-vegetazione-italia.org, last accessed 19.03.20). * priority habitats, na = not applicable. (Maps reprinted with permission from Ott-Verlag, Schweiz)

Fig 3.5 Swisstopo map of Zurich (Nature and Landscape Conservation Inventory https://maps.zh.ch/s/joodwjme accessed on 20.3.2020). The cross indicates the Technopark building, the hatched area the nearby ruderal sites (Zurich railway, main station)

3.4 Discussion

3.4.1 Ecological Assessment of the Green Roof

The green roof was surveyed in 2013, i.e. just 2 years after its construction. Not surprisingly, it was characterised by a very poor vegetation cover, except for the mounds and the shaded areas (both between 10 and 20 cm thick) near the access room (Fig. 3.1).

Of the 29 identified plants, 11 were probably brought intentionally, as they usually figure among those adopted for Swiss commercial seed mixtures, whilst the remaining 18 species probably colonised the roof through wind and animal dispersal. Most of them resulted to be ruderal species belonging to the class *Stellarietea mediae* (Table 3.1). Yet, the species that almost certainly derived from direct seeding, i.e. *Acinos arvensis*, *Petrorhagia saxifraga*, *Sedum acre*, *S. album*, *S. rupestre*, *S. sexangulare* and *Thymus pulegioides*, are reported as characteristic to the classes *Koelerio-Corynephoretea* and *Festuco-Brometea*, *Asplenietea trichomanis* (vegetation of crevices, rocky cliffs and walls faces) and *Thlaspietea rotundifolii* (vegetation of screes and pebble alluvia). *Sedum spurium* and *S. hybridum* were probably brought accidentally together with the other *Sedum* spp. sprouts; in fact, these *Sedum* species are commonly used for green roof installations (Zheng and Clark 2013). Most of the species probably sown on the roof were stress-tolerant (*sss*, *crs*, *css*), wind-dispersed and propagating by creeping shoots aboveground (Table 3.1).

A weak point in our study was certainly the small number of species in the master list of the studied roof. One single roof, also without knowing the species composition of the original sowing, could be insufficient to set up and test a novel approach. However, the results obtained from basic data analysis agreed pretty well with those obtained from several phytosociological studies on flat sandy-gravel

Table 3.3 Derived list obtained for (A) well-lit, full light areas on dry and very dry substrates (L = 4 and 5 and 1 ≤ F ≤ 2); (B) well-lit on fresh to moderately moist substrates (L = 4 and 2.5 ≤ F ≤ 3.5); and (C) semi-shade areas on dry to fresh substrates (L = 3 and 1.5 ≤ F ≤ 3.5)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Festuco-Brometea	12	*Festuco-Brometea*	1	*Festuco-Brometea*	8
Brometalia erecti	7	*Brometalia erecti*	1	*Brometalia erecti*	1
Mesobromion	11	*Mesobromion*	12	*Mesobromion*	9
Festuco-Brometea	**31**	***Festuco-Brometea***	**14**	***Festuco-Brometea***	**18**
Achillea millefolium, *Anthyllis carpatica*, *Arabis hirsuta*, *Arenaria serpyllifolia*, *Briza media*, *Bromus erectus*, *Campanula farinosa*, *Campanula rotundifolia*, *Carlina vulgaris*, *Centaurea scabiosa*, *Erigeron acer*, *Festuca guestfalica*, *Hieracium pilosella*, *Hippocrepis comosa*, *Koeleria pyramidata*, *Lactuca serriola*, *Malva moschata*, *Muscari racemosum*, *Ononis spinosa*, *Pimpinella saxifraga*, *Plantago media*, *Poa angustifolia*, *Potentilla neumanniana*, *Prunella grandiflora*, *Ranunculus bulbosus*, *Salvia pratensis*, *Sanguisorba minor*, *Scabiosa columbaria*, *Sedum acre*, *Thlaspi perfoliatum*, *Thymus pulegioides*		*Carex caryophyllea*, *Centaurea jacea*, *Euphorbia verrucosa*, *Galium verum*, *Helictotrichon pubescens*, *Knautia arvensis*, *Leucanthemum ircutianum*, *Lotus corniculatus*, *Ononis procurrens*, *Plantago lanceolata*, *Senecio jacobaea*, *Silene vulgaris*, *Trifolium campestre*, *Trifolium pratense*		*Ajuga genevensis*, *Allium oleraceum*, *Aquilegia vulgaris*, *Brachypodium pinnatum*, *Calamagrostis varia*, *Campanula rapunculus*, *Carex flacca*, *Carex humilis*, *Carex montana*, *Linum catharticum*, *Euphorbia cyparissias*, *Medicago lupulina*, *Origanum vulgare*, *Peucedanum cervaria*, *Sanguisorba muricata*, *Silene nutans*, *Veronica chamaedrys*, *Viola hirta*	
Stellarietea mediae	11	*Stellarietea mediae*	19	*Stellarietea mediae*	8
-	-	-	-	-	-
-	**-**	*Polygonion avicularis*	9	-	-
Panico-Setarion	1	*Panico-Setarion*	2	-	-
Sisymbrion	2	*Sisymbrion*	1	-	-
Stellarietea mediae	**14**	***Stellarietea mediae***	**31**	***Stellarietea mediae***	**8**

(continued)

Table 3.3 (continued)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Achillea millefolium, *Arabidopsis thaliana*, *Arenaria serpyllifolia*, *Capsella bursa-pastoris*, *Chenopodium album*, *Erodium cicutarium*, *Hordeum murinum*, *Lactuca serriola*, *Myosotis arvensis*, *Oxalis corniculata*, *Papaver rhoeas*, *Setaria pumila*, *Sisymbrium officinale*, *Vicia angustifolia*		*Anagallis arvensis*, *Atriplex patula*, *Carum carvi*, *Cerastium glomeratum*, *Chaenorhinum minus*, *Digitaria ischaemum*, *Digitaria sanguinalis*, *Elymus repens*, *Fagopyrum esculentum*, *Geranium pusillum*, *Lamium purpureum*, *Leontodon autumnalis*, *Lolium perenne*, *Malva sylvestris*, *Matricaria chamomilla*, *Plantago major*, *Poa annua*, *Polygonum aviculare*, *Polygonum persicaria*, *Portulaca oleracea*, *Potentilla anserina*, *Potentilla reptans*, *Sagina procumbens*, *Senecio vulgaris*, *Setaria viridis*, *Solanum nigrum*, *Taraxacum officinale* s. l., *Trifolium repens*, *Valerianella locusta*, *Verbena officinalis*, *Veronica serpyllifolia*		*Cirsium arvense, Euphorbia peplus, Euphorbia platyphyllos, Geranium columbinum, Raphanus sativus, Stellaria media, Veronica arvensis, Viola arvensis*	
Koelerio-Corynephoretea	6	*Koelerio-Corynephoretea*	2	-	-
-	-	*Sedo-Scleranthetalia*	1	-	-
Alysso-Sedion albi	3	-	-	-	-
Koelerio-Corynephoretea	**9**	***Koelerio-Corynephoretea***	**2**		
Acinos arvensis, *Arenaria serpyllifolia*, *Bromus tectorum*, *Herniaria glabra*, *Saxifraga tridactylites*, *Sedum acre*, *Sedum album*, *Sedum sexangulare*, *Thlaspi perfoliatum*		*Erophila verna*, *Hypochaeris radicata*, *Trifolium campestre*		-	
Artemisietea vulgaris	**-**	*Artemisietea vulgaris*	7	*Artemisietea vulgaris*	2
Onopordetalia acanthii	4	*Onopordetalia acanthii*	6	*Onopordetalia acanthii*	1
Dauco-Melilotion	1	*Dauco-Melilotion*	2		
Artemisietea vulgaris	**6**	***Artemisietea vulgaris***	**15**	***Artemisietea vulgaris***	**3**

(continued)

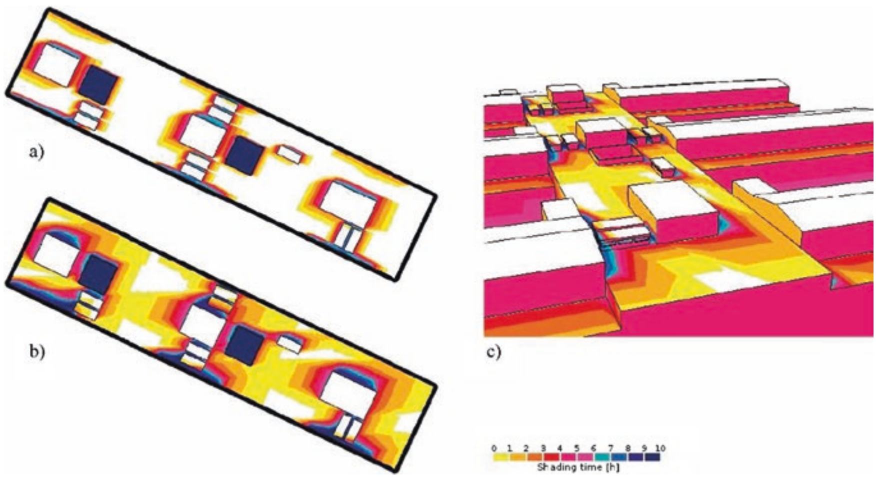
Table 3.3 (continued)

A		B		C	
Phytosociological units and plant species	N	Phytosociological units and plant species	N	Phytosociological units and plant species	N
Echium vulgare, *Lactuca serriola*, *Linaria vulgaris*, *Potentilla recta*, *Reseda lutea*		*Cichorium intybus*, *Cirsium vulgare*, *Dactylis glomerata*, *Daucus carota*, *Malva alcea*, *Malva sylvestris*, *Melilotus albus*, *Melilotus officinalis*, *Pastinaca pratensis*, *Picris hieracioides*, *Plantago major*, *Poa annua*, *Senecio erucifolius*, *Silene pratensis*, *Tanacetum vulgare*		*Geranium pyrenaicum*, *Stellaria media*, *Saponaria officinalis*	

Species are grouped per habitat types, phytosociological classes (-*etea*), orders (-*etalia*) and alliances (-*ion*) following Landolt et al. (2010). N = number of species characteristic to the different phytosociological ranks; in bold is indicated the sum of the species characteristic to each class. * = alliances (habitats) not occurring in the study areas but with characteristic species occurring in it.

roofs (Bornkamm 1961; Thommen 1986) and those issuing from long-term monitoring of both flat extensive and sloped simple intensive green roofs (Catalano et al. 2016; Thuring and Dunnett 2019). Basing on literature data, it seems that during the first 2–5 years of biological succession, green roofs with little to no management are first colonised by ruderal plant species dispersed by wind and animals visiting the roofs and only in a more mature stage (after more than 10 years) by stress-tolerant and competitive ones (Martini et al. 2004). In the case of sandy-gravel roofs, the substrate thickness, the shade and the fine earth percentage proved to influence the speed and final result of local vegetation dynamics (Bornkamm 1961; Thommen 1986): from the early ephemeral ruderal assemblages (*Panico-Galinsogetum*, currently framed into the alliance *Panico-Setarion*) to ruderal perennial communities shifting towards *steady* perennial grasslands of nutrient-poor soils (*Alysso-Sedion* and, if the substrate is deep enough, *Festuco-Brometea*) over more than 50 years. In shaded areas, the progressive succession might be faster (about 30 years) and, in the long run (over 45 years), eventually allow the encroachment of pioneer shrubs (*Crataego-Prunetea*).

Several species of *Alysso-Sedion*, whose seeds were intentionally brought on the roof, proved to be able to thrive also at the very early stage (after 2 years). This fact suggests that by carefully selecting the plant species and by creating different ecological niches, it might be possible to foster plant succession processes and diversify species assemblages. This opportunity was confirmed by recent experiences on urban-industrial grasslands. In fact, just 3 years after combining seeding and hay layering, Kövendi-Jakó et al. (2019) observed plant communities whose species composition and richness were similar to that of 30-year-old grasslands.



Shading time (h)	Derived lists	L	N	Phytosociological classes (for the plant species see Tab. 3)
0 - 3	A	4 - 5	52	*Festuco-Brometea* > *Stellarietea mediae* > *Koelerio-Corynephoretea* > *Artemisietea vulgaris*
4 - 6	B	4	59	*Stellarietea mediae* > *Festuco-Brometea* > *Artemisietea vulgaris* > *Koelerio-Corynephoretea*
7 - 9	C	3	28	*Festuco-Brometea* > *Stellarietea mediae* > *Artemisietea vulgaris*

Fig. 3.6 Shadow analysis performed on the Technopark building in Zurich by means of SketchUp Pro 2019 version 19.0.685 (Trimble Inc.®) and the plug in Shadow analysis (DeltaCode®). On the left the shadow analysis for (**a**) the Summer solstice (21st June) and (**b**) the Autumn equinox (22nd September); (**c**) 3D perspective of the shadow simulation for Summer solstice. L Landolt EI for light, N number of species

3.4.2 Plant Species Functional Traits: A Comparison Between the Master and the Derived List

As regards the functional composition of the species included in the master list, the species sown were mostly herbaceous chamaephytes and stress-tolerant strategists, whilst the spontaneous ones were therophytes and ruderal strategists. As for the derived species, they were mostly therophytes (42 species), hemicryptophytes (55 species) and few geophytes (4 species) whilst showing prevailing *crs* (46 species) and ruderal (*crr* and *rrr*, 51 species) life strategies. All these features fit well with the early stages of succession observed in the first studies on spontaneous sandy gravel green roofs (see previous paragraph) and extensive green roofs. Accordingly, recent research recommended to select for extensive green roofs annual and biennial species mixed with succulents, perennial herbs and geophytes (Van Mechelen et al. 2015).

In commercial seed mixtures for green roofs, herbs and grasses are preferred to short-lived plants to obtain more stable communities and higher and more long-lasting plant cover within a shorter time and to be less dependent from the seed germination success of annual species (Caneva et al. 2013). However, even if this choice may offer advantages in the short term, unwanted consequences might occur in the long run, because empty niches will be eventually occupied by unwanted annuals/biennials (often alien, invasive or both). In fact, few years after, the expected *nice* green effect provided by perennial species is overtaken by *messy* ruderals not necessarily considered appealing by customers (Dunnett 2015). However, in the long run, some empty niches could also be occupied by spontaneous vulnerable species, including many orchids, especially in the case of nutrient-poor substrates.

3.4.3 Plant Species Assemblages

Recently, Lundholm and Walker (2018) reviewed the application of the habitat template approach (HTA) 10 years after its definition (Lundholm 2006). The authors concluded that the main limits of HTA were (1) the underestimation of the environmental conditions on green roofs, which are often more extreme than in their habitat analogues and (2) the overestimation of abiotic limiting factors for plants' survival (ignoring the biotic factors). Green roofs are novel ecosystems (artificial habitats) often characterised by additional (both abiotic and biotic) stress if compared with their habitat analogues. In fact, the plants growing on green roofs must adapt not only to the chemical and physical characteristics of artificial substrates and to air pollution, but they must also face herbivores and pathogens typical to urban environment or the absence of specific pollinators, symbiotic/facilitating organisms and substrate micro-organisms (plant microbiota) typical to habitat analogues.

In this chapter, we suggest basing the selection of species for urban infrastructure on plant sociology. Phytosociological associations represent distinct and recurrent species assemblages, selected by distinctive environmental drivers (e.g. edaphic and climatic conditions and disturbance regime); hence, trying to mimic their composition may allow to incorporate also the complex species assemblage rules regulating the plant species co-occurrences in natural habitats. Paying further attention to plant traits (life forms) and physiological requirements (Landolt indicators values) and focusing on the species pool (native to central Swiss Plateau) enabled us to perform a coherent species selection.

A significant percentage of the derived species, as well as many of the plants which spontaneously colonised the study roof, belong to the *Stellarietea mediae*, a class which almost certainly was not represented among the sown species. This result underlines the high colonisation performance of annual pioneer ruderal and/or competitive species on green roofs. Additionally, the plant communities belonging to *Stellarietea mediae* might have high potential for biodiversity conservation in Swiss urban areas; in fact, to this class also belong some phytosociological alliances corresponding to habitats of conservation interest. Among them, one is vulnerable (ruderal communities of *Sisymbrion*), and two result to be near-threatened (communities of trampled sites, framed into *Polygonion avicularis*, and thermophilous summer annuals of *Panico-Setarion*). Interestingly, the spontaneous arrival of species linked to trampled areas (*Polygonion avicularis*) and to generic disturbance (*Sisymbrion*) was probably the direct consequence of the occasional visits by people working on the roof; the same was observed by Bornkamm (1961) in Göttingen on similar sandy-gravel roofs. On the one hand, the ruderal and competitive species belonging to latter class may be able to outcompete some of the neophytes with similar colonisation and survival strategies (e.g. *Buddleja davidii*, *Epilobium ciliatum*, etc.); on the other hand, some of them, like *Cirsium arvense*, behave as noxious weeds; hence, their intentional introduction on green roofs located near crop fields must be avoided (Dierauer et al. 2016).

3.4.4 Habitat Connectivity and Spatial Planning

According to the real and potential habitat distribution in Zurich region (Delarze et al. 2015), most of the habitats identified showed good potential in terms of habitat connectivity (e.g. *Sisymbrion*, *Panico-Setarion*, *Polygonion avicularis*), with the exception of *Sedo-Scleranthion*, *Xerobromion* and *Stipo-Poion* (Fig. 3.4). These habitats came out from the automatic screening procedure because we included near-threatened species in the queries but were eventually discarded on the base of their geographical distribution. Nevertheless, several native species contained in standard seed mixtures are indiscriminately used all over Switzerland even if they grow wild only in certain biogeographic regions and show a narrow distribution range (e.g. *Festuca guestfalica*, *Cytisus nigricans*, *Dianthus sylvestris, Nepeta cataria*). The biogeographic approach, instead, should be more carefully considered by seed producers and green roof designers.

Unfortunately, the GIS portal of the Canton Zurich does not provide any information on the species occurring in the ruderal habitats characterising the rails near Technopark. However, according to literature (Kovář and Lepš 1986), species of *Stellarietea mediae* (e.g. *Atriplex patula*, *Sisymbrium* spp.) and of *Artemisietea vulgaris* (*Verbascum* spp., *Melilotus* spp.) are very common along railways. Hence, green roofs could be used to enhance the populations of these species and may play an important role as steppingstones for the vegetation of the abovementioned syntaxa.

Generally, flat green roofs are fully exposed to sunlight and are subject to intense daily and yearly irradiation; however, shading from building structural elements (e.g. parapets, roof hatches, skylight walls, ventilation supplies, solar panels), surrounding buildings, nearby trees and other features (e.g. deadwood piles and shading structures) designed on purpose may improve the microclimatic conditions on green roofs. Moreover, in a study run in Stuttgart region (southern Germany), plant species growing on conventional extensive flat roofs did not show maximal values of L (light) as it was expected (Thuring and Dunnett in press). In general, the spatial heterogeneity, also in terms of substrate thickness variation, influences plant growth, their cover, their survival and their living together (Bates et al. 2013; Brown and Lundholm 2015; Buckland-Nicks et al. 2016; Gedge and Kadas 2005; Heim and Lundholm 2014; Köhler 2006; Walker and Lundholm 2017). For this reason, the best *modus operandi* is to avoid the use of only one seed mixture for the whole roof but to adopt different mixtures according to varying light/shade and moisture (substrate thickness) conditions (see Fig. 3.6).

3.4.5 Limits of the Method and A Posteriori Remark

The method proposed here could be strengthened through the application to a representative number of different types of flat roofs, so to obtain general species lists for individual cities or even regions, which could represent a good starting point for selecting the habitat templates and related phytosociological units basing on a larger number of ecological indicators.

The most important limit of sorting seed mixtures based on phytosociological units is that many wild species are not available in the market and that their germination rate in controlled experiments is still unknown (Nagase and Tashiro-Ishii 2018). Nevertheless, transferring vascular plants (but also lichens and mosses) with racked material from a sandy dry grassland hosting *Koelerio-Corynephoretea* communities proved to be a very promising technique to establish local wild species otherwise difficult to find in the market (Schröder and Kiehl 2020).

During the vegetation survey aimed at compiling the master species list, we neglected to group the species according to homogeneous habitats and taking into account the existing gradient of light (from well-lit to shaded places), substrate thickness (from shallower to thicker areas) and disturbance (from more to less visited and trampled areas). As a result, the range we applied to sort the species was extremely broad. Instead, when considering the plant species as bioindicators, it would be recommended to use a phytosociological approach, thus making distinct surveying on different habitat patches (when existing).

The present study suggests that the indicators related to soil aeration (D) and humus content (H) are good limiting factors to consider for species screening. By contrast, the rating scale proposed by FI (three values for H and five for D) resulted to be too rough. Further research should address plant-soil relationships and amend the existing plant trait databases. This will allow a more effective species screening based on plant traits and tailored to the type of substrate used. Also, flower colour and the blooming time (season, months, duration) should be considered to fulfil aesthetic issues relevant to designers and people acceptance (see also Menegoni et al. in press) but also to support pollinators.

The expert-based assessment needed to decide which species to leave or to discard from the species list obtained through the automatic selection procedure may be supported by statistically robust datasets issuing from real vegetation surveys carried out in the surroundings. These data, stored in databases like EVA (Chytrý et al. 2016), could help to point out the highest fidelity of each selected species to one preferred vegetation unit/class (Bruelheide et al. 2020).

3.5 Conclusions

This work aimed at identifying a standard, site-specific and replicable procedure to support the selection of the most suitable species and assemblages for green infrastructure. Our selection procedure was inspired by plant sociology: a branch of vegetation science describing extant habitat types by recording and classifying plant species co-occurrences on standard plots. The phytosociological classification proved to be a helpful guidance to tailor plant species mixtures for green infrastructure by mimicking nature. As a matter of fact, plants do coexist because they fulfil similar or complementary requirements (e.g. avoiding the same predators, resisting to the same stress factors, responding to the same disturbances, benefitting of shared facilitation mechanisms, exploiting the same resources, enjoying the same symbiotic organisms, etc.). Moreover, we wanted to overcome both the aesthetic predominance in choosing the plant species (Cameron and Blanuša 2016) and the temptation to use ready-made seed mixtures which are not always place-specific (Prasse et al. 2010).

Further research should test plant communities instead of single species, because species in monoculture might not be able to survive in certain environments. This purpose is related to the concept of niche complementarity: more co-occurring species sharing the same resources are more resilient and can offer a wider array of ecosystem services than uniform monocultures (Lundholm et al. 2010; Tran et al. 2019). The creation of patchy environments hosting many small niches could be a planning strategy not only to increase green roof biodiversity but also to create rescue zones for the species populating green roofs during exceptionally dry seasons. These islands, where the initial planting and sowing might be more successful already in the first year, can serve also as pools of diversity and effective seed banks for the spontaneous cyclic colonisation of other neighbouring niches on the same roof.

Seed mixtures should contain either widespread pioneer annual species, able to colonise roofs at the very early stages of succession (1 to 5 years), or target species able to prevail on the roofs during the following stages, when the edaphic conditions will be more favourable (5–10 years and more than 10 years). This *uncoupled-timing* sowing approach might guarantee a higher ecosystem resilience and require a lower maintenance (but not a lower monitoring) effort over the whole lifetime of a living roof that might reach even one century of glorious survival (Bornkamm 1961; Kreh 1945; Landolt 2001). However, according to the seed longevity of the target species, under severe conditions, it might be necessary to sow the roof more than once. In other cases, when higher budget is available, combining the sowing of annuals and biennials with the planting of propagules of vegetative-dispersing species and perennials should be encouraged.

In the specific case of acting on existing green roofs, the site analysis plays a crucial role to choose the appropriate plants and/or seed mixture. Besides the shadow analysis, both the roof topography and the main wind intensity/direction should be considered to know *where to sow (or plant) what*: the first as a proxy of the soil moisture and the second to boost the colonisation on the roof by species dispersed by wind gusts. The minimum substrate thickness is a major challenge and focus for future applied research: a huge amount of experiences showed that 5-cm-thick substrates only allow the survival of few stress-tolerant species. If we want a higher number of species to establish and spread on the roofs, forming more steady and resilient communities, we should better design roofs and choose more suitable substrates. If the roofs must connect habitats, then we must build them accordingly.

The analysis and the comparison of distribution maps, databases, regulations and risk assessments at different scales (regional, national or international) showed some incongruences. For instance, some neglected vegetation units may correspond (or not) to priority habitats according to the Swiss law; some species of least concern in Europe may be critically endangered in the eastern Swiss Plateau; and some habitats which are very common and not threatened in Canton Zurich may be severely menaced on the international scale or *vice versa*. Also, this work highlighted the need of creating interactive tools (such as online platforms or plug-ins) based on freely accessible databases containing detailed information on species and habitat distribution and adopting a standardised nomenclature for plant names, habitat types, growth and life forms and ecological and biogeographical traits.

In conclusion, the ecologically informed design approach presented in this work represents only a starting point, and it would need the cooperation of vegetation ecologists, horticulturalists and designers to be developed, eventually creating new opportunities for professional figures, able to adopt and implement this approach in dialogue with several specialists.

Acknowledgments The Open Access of this chapter was funded by the Zurich University of Applied Science (ZHAW).

Author Contributions C.C. and R.G. proposed the topic; C.C. performed data analysis, prepared all the iconographic material (figures and tables) and wrote the first draft of the whole manuscript; S.P. and R.G. critically revised the dataset to analyse, the discussion and the conclusions; C.C. and S.P. adapted the final version according to the remarks and suggestions of the reviewers. All authors were involved in data interpretation and revised the last version of the manuscript.

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Chapter 4
Functional and Phylogenetic Characteristics of Vegetation: Effects on Constructed Green Infrastructure

Amy Heim, Garland Xie, and Jeremy Lundholm

Abstract Constructed green infrastructure consists of artificial ecosystems designed to produce specific services. Vegetation in constructed ecosystems such as bioretention strips (rain gardens), water treatment wetlands, living roofs and walls generally results from conscious design. The choice of plants can make a large difference with regard to the ecosystem services provided by green infrastructure. We review the literature on constructed green infrastructure and vegetation characteristics, specifically addressing the role of plant functional types, traits and evolutionary relatedness among species in the vegetation in driving ecosystem services. Each type of constructed green infrastructure involves different but consistent preferences in the functional types of plants used, but studies using general plant trait approaches including manipulations of functional or phylogenetic diversity are only just beginning. Empirical studies have identified key plant traits that drive ecosystem services in each type of constructed ecosystem. Experimental studies that manipulate plant functional or phylogenetic diversity in green infrastructure are still uncommon but, in some systems, show that service provisioning can improve with more diverse vegetation. In other cases, selection of the top-performing monocultures seems to optimize provision of a single service. Future work may yet reveal a role for diverse vegetation in constructed ecosystems to provide a variety of services simultaneously.

Keywords Plant ecology · Urban green spaces · Functional traits · Phylogeny · Biodiversity · Urban ecology

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_4

4.1 General Introduction

Plant species differ in anatomy, physiology, morphology and phenology. These differences, in turn, drive their interactions with other organisms and their effects on the environment. In the quest to make vegetation science more generalizable, ecologists have sought commonalities between plant species to increase our predictive ability for various phenomena including species composition along environmental gradients and the functioning of ecosystems (Keddy 1992). Easily measurable variables that relate directly to plant fitness or ecological interactions are usually called *functional traits*. Measurable traits, however, pose limitations for predictive ecology due to the great number of traits that may impact species interactions and ecosystem functioning. Phylogenetic relationships can assist with these limitations as functional traits can be conserved evolutionarily such that species within a family share similar traits, and modern phylogenetic techniques can result in efficient determination of relationships among large assemblages of species.

In urban areas, green infrastructure is overwhelmingly important due to the encroachment of hard surfaces and the subsequent reduction in services provided. Constructed ecosystems represent a subset of green infrastructure, defined by their purposeful engineering and artificial components (Lundholm 2015). While green infrastructure can include remnant natural vegetation or highly managed systems like urban parks or street trees, constructed ecosystems are built de novo and usually placed within grey infrastructure to provide specific services, often related to the ability of vegetation to mediate physical fluxes of energy and materials (e.g. Lundholm and Williams 2015) or treat waste (Kadlec and Knight 1996). While many kinds of constructed ecosystems employ natural vegetation communities, their reliance on artificial structures, containers or growing media and their small size and isolation breed novelty that prevents reliance on the knowledge garnered from natural vegetation to predict their ecosystem functions and services (Lundholm 2015). Further, some services produced by constructed ecosystems, such as green roofs reducing heat flux through building membranes, are not typically studied in natural ecosystems.

This chapter will review the role of functional and phylogenetic characteristics of vegetation in constructed ecosystems including green roofs, living walls, rain gardens, and water treatment wetlands (Fig. 4.1). While vegetation characteristics are important in determining ecosystem service value of all kinds of green infrastructure, we will only cover constructed ecosystems that can be considered completely artificial.

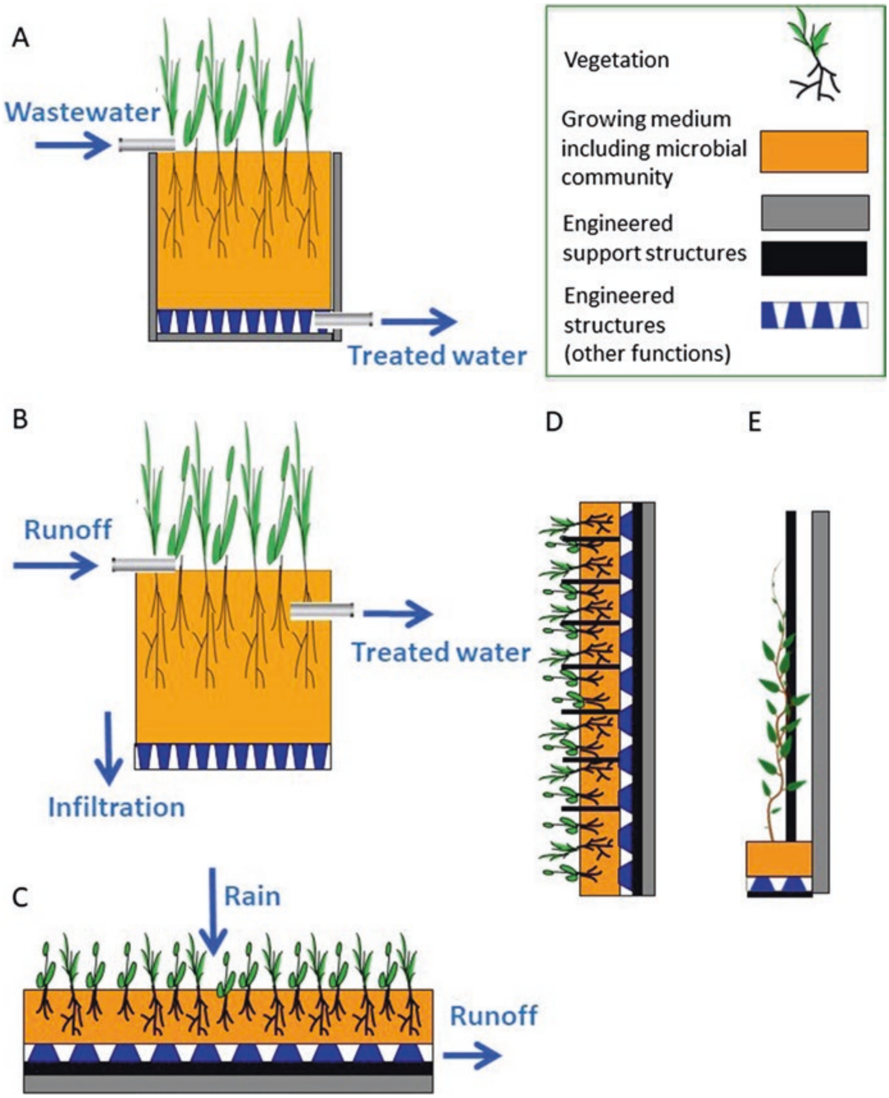

Fig. 4.1 Scheme showing different constructed ecosystems that represent green infrastructure. (**a**) water treatment wetland; (**b**) rain garden; (**c**) green roof; (**d**) living wall; E) green facade

4.2 Application of Functional Traits and Phylogenetics to Green Infrastructure

Functional traits are the morphological, physiological and phenological features expressed in the phenotypes of individual organisms (Díaz et al. 2013; Garnier et al. 2016; Violle et al. 2007). Increasingly, they are being used to understand the underlying relationships between individuals and their surrounding environment. By measuring specific functional traits for individual species, researchers can understand which environments a plant species can persist in, how a species will react to changes in its environment and how an individual plant will impact ecosystem function. Applying functional trait research to constructed ecosystems could lead to an increase in the available species pool, help designers predict how their plant community could change over time and enhance ecosystem services.

Plant species have evolved specific traits that allow them to persist in specific ecosystems (Maire et al. 2012). This pattern can be utilized to inform plant selection in constructed ecosystems. Specifically, species naturally growing in a habitat with similar conditions to a constructed ecosystem should be able to survive in this novel habitat (i.e. habitat template) (Lundholm 2006). This method does not require detailed knowledge of the traits common to the species selected. Additionally, designers can select species with traits considered necessary to persist in a constructed environment. For example, green roofs require species with traits enabling drought tolerance, so plants containing those traits should be able to persist on a green roof (Van Mechelen et al. 2014). Although this method can help select candidate species, it does not necessarily mean the selected species will be able to coexist.

In order to create stable and biodiverse plant communities, the selection of species with complementary traits is recommended. Theory predicts that coexistence can occur if species have functional traits that encourage dissimilar resource use in space and/or time (Bartelheimer et al. 2010; Chesson 2000; Chesson et al. 2004; Fargione and Tilman 2005; Maire et al. 2012; Tilman 1982). For example, differences in the timing of germination in different species of desert annuals allow coexistence as the limiting resource is being used at different times (Chesson et al. 2004). In terms of complementary resource use, grassland species with different resource strategies (e.g. associations with nitrogen fixers or mycorrhizae) have also been observed to coexist stably (Fargione and Tilman 2005; Mamolos 2006). When constructing an engineered ecosystem, designers should incorporate species with different phenology and resource requirements.

In constructed ecosystems, a species' ability to influence the surrounding environment contributes to the ecosystem services provided. A species' potential to alter the local environment depends on its traits (Chen et al. 2016; Lundholm et al. 2015; Weerakkody et al. 2017; Winfrey et al. 2018). For example, species with unpalatable leaves can discourage the presence of herbivores, which in turn provides protection to neighbouring vegetation (Moser and Greet 2018). Further, plant species with a high relative growth rate can increase transpiration leading to improved water retention and lower stormwater runoff (Lundholm et al. 2015). Additionally, plants with hairy and waxy leaves have been shown to be more efficient at capturing airborne particulate matter (Sæbø et al. 2012). By selecting plant species with specific traits, engineers can encourage specific ecosystem services from their constructed environment.

In contrast to natural ecosystems, constructed ecosystems inherently have (1) ecological novelty (e.g. horticultural planting with non-native species), (2) small population sizes, (3) strong spatial boundaries between ecosystems, (4) a lack of biological legacy and (5) conscious human design (Lundholm 2015). This additional complexity poses a potential issue: which traits or combination of traits are relevant to optimize an ecosystem service? In some cases, the solution may be simple, but some functional traits are particularly difficult to measure, such as those derived from belowground systems (e.g. specific root length) or from a physiological nature (e.g. stomatal density). A compelling view of phylogenies is that evolutionary distances can act as a proxy for differences in unmeasured functional traits (Cadotte 2013; Webb et al. 2002). As a result, phylogenies can be a useful tool for practitioners to quickly select appropriate candidates from a wide range of possible plant species (MacIvor et al. 2016). When applied to constructed ecosystems, phylogenetic diversity can be used to select species associated with specific functions, such as habitat provisioning in rain gardens (e.g. planting different plant species to attract butterflies at multiple ontological stages), thermal cooling in green roofs (e.g. species contribution to transpiration and shading) and pollution mitigation (e.g. selecting different species to remove specific pollutants) (MacIvor et al. 2016).

4.3 Green Roofs

Green roofs (Figs. 4.1 and 4.2), or vegetated rooftops, typically include a substrate layer, a water retention layer and a vegetative community exposed to harsh environmental conditions such as wind stress, drought, solar radiation and for many green roofs a shallow soil depth (<15 cm – extensive green roofs) (Oberndorfer et al. 2007). This set of environmental filters often constrains the regional flora to a subset of drought-tolerant species which need to survive and maintain coverage over consecutive growing seasons (Catalano et al. 2016). A popular plant group on green roofs are species from the genus *Sedum*, which are succulent, low-growing and drought-tolerant perennials. Additionally, forbs, graminoids and shrubs have the potential to establish on green roofs, with many providing certain ecosystem services equal to or better than *Sedum* species (Lundholm et al. 2010).

Green roofs can provide multiple beneficial services that can be divided into two distinct categories: primary services (i.e. thermal benefits, stormwater retention) and secondary services (i.e. reduced air pollution, carbon sequestration, habitat provisioning, aesthetics, recreation) (Table 4.1). While current green roof research emphasizes plant selection for survival and propagation, designers can also manipulate the vegetative layer either through a trait-based approach or phylogenetics.

The vegetative canopy on green roofs can contribute to lower roof temperatures through evapotranspiration, increased shading and increased albedo (Del Barrio 1998). Four key traits regulate these processes: (1) specific leaf area (SLA), (2) leaf thickness, (3) plant height and (4) leaf colour (Table 4.1). Resource-acquisitive plants can optimize thermal performance as high SLA is correlated with greater gas exchange (Wright et al. 2004) and evapotranspiration. Multiple studies have shown that SLA is correlated with lower roof temperatures, with thinner leaves more efficient at dissipating heat (Farrell et al. 2013; Lundholm et al. 2015; Monteiro et al.

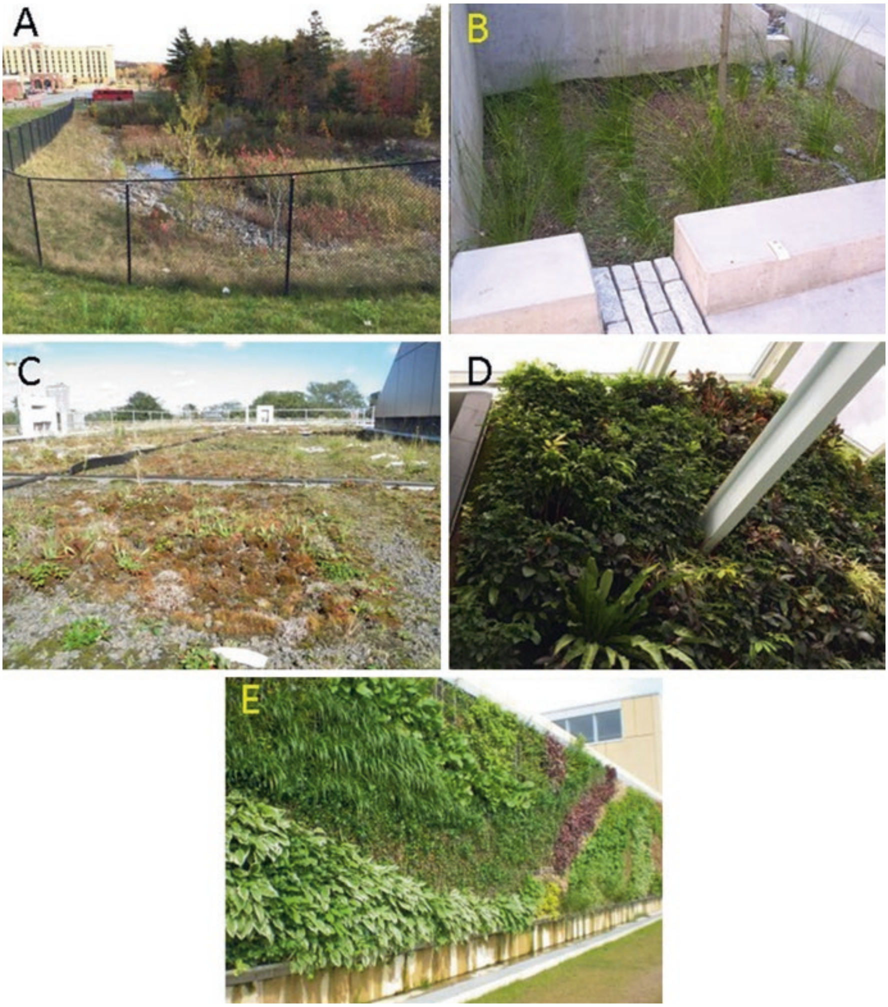

Fig. 4.2 Examples of different constructed ecosystems: (**a**) treatment wetland; (**b**) rain garden; (**c**) green roof; (**d**) indoor living wall; (**e**) outdoor living wall

2016). Additionally, taller stature can lead to increased shading through absorption and reflection of radiation from the plant canopy (Farrell et al. 2013). Finally, leaf colour may reduce temperatures through an increase in short-wave reflectance (Billings and Morris 1951). Monteiro et al. (2016) found that compared to purple-coloured leaves, yellow-coloured leaves reduced leaf temperatures by 2–3 °C.

Green roof vegetation intercepts incoming rainfall and uptakes water through roots, with water losses to the system via transpiration. Key traits associated with these mechanisms are plant height, SLA and root biomass. Lundholm et al. (2015) found that tall plants with high SLA were more efficient at stormwater retention, as

Table 4.1 Plant traits and phylogenetic groups linked with ecosystem services provided by green roofs

Green roofs		
Ecosystem service	Traits, phylogenetic and functional groups	References
Thermal benefits	High specific leaf area, light-coloured leaves, tall plant stature	Farrell et al. (2013); Lundholm et al. (2015); Monteiro et al. (2016)
Stormwater retention	Tall plant stature, high root biomass, high specific leaf area	Lundholm et al. (2015); Nagase and Dunnett (2012); Zhang et al. (2018)
Airborne pollution	High specific leaf area, leaf ridges	Speak et al. (2012)
Habitat provisioning	Phenological complementarity	Kratschmer et al. (2018)

these traits are associated with greater water demand. A study by Nagase and Dunnett (2012) found that green roof vegetation with dense fibrous roots (e.g. *Silene uniflora* Roth) retained 60% more stormwater than those with shallow roots (e.g. *Sedum acre* L.). Additionally, plant height and root biomass both predicted stormwater retention, indicating that large root aggregates may act as an additional water retention layer to mediate greater resource demand and water uptake (Nagase and Dunnett 2012; Table 4.1). On the other hand, Zhang et al. (2018) found no relationship between root biomass and stormwater retention among four plant species (i.e. *Sedum dasyphyllum* L., *Dianella revoluta* R. Br., *Stypandra glauca* R. Br., *Lomandra longifolia* Labill.). Rather, the authors suggested that the variation in root architectural traits created specific preferential pathways for substrate flow (Ghestem et al. 2011). For instance, a highly branched root architecture of a heather shrub (e.g. *Calluna* spp.) could increase the rate of water flow through the soil substrate compared to the dense and fibrous roots of a grass species (e.g. *Eriophorum* spp.) (see Holden 2005). In this case, fibrous root systems may be more beneficial in reducing stormwater runoff as there are less pathways for substrate water to flow through (Table 4.1).

The vegetative layer on green roofs can capture airborne pollutants by physically trapping particulate matter on plant surfaces. Speak et al. (2012) found that within a single growing season grass species (e.g. *Festuca rubra* L.) captured 156% more particulate matter (PM10) than *Sedum* species on green roofs. This substantial difference may be explained by the dense arrangement of thin blade-like leaves, which alters the near-surface airflow to increase the efficiency of pollutant deposition. Alternatively, leaf ridges may capture pollutants at a finer scale, suggesting an additional suit of traits to be explored (Table 4.1).

In addition to individual functional traits, the combination of species with different functional traits can improve the provision of ecosystem services. For stormwater retention, the integration of species that differ in resource-uptake strategies presents two advantages (Table 4.1). First, species combinations containing high and low water users allow a degree of stormwater retention to occur even when the high water users are dormant (i.e. due to drought stress). Second, this combination can lead to a facilitative effect, allowing less drought-tolerant species (i.e. high water users) to survive unfavourable conditions. This facilitative effect has been observed between *Sedum* spp. and high water-uptake plants (MacIvor et al. 2018).

Phylogenetic diversity, which acts as a proxy for unmeasured traits, has been shown to affect substrate cooling in multiple green roof systems (MacIvor et al. 2018; Xie et al. 2018). MacIvor et al. (2018) conducted an experiment that explicitly manipulated phylogenetic diversity (PD) across 35 plant species (belonging to 23 genera) that ranged from closely related (i.e. low PD) to distantly related species (i.e. high PD). The findings from this experiment showed that high-PD communities reduced minimum substrate temperature by 0.5 °C. A possible explanation could be that phylogenetically diverse communities can efficiently intercept (or reflect) light due to a structurally complex canopy (Givnish 1987) and subsequently reduce roof surface temperatures during the day.

In regard to habitat provisioning, increased phenological diversity can lead to an increase in the quantity of pollinator resources available throughout the growing season (Table 4.1). Kratschmer et al. (2018) conducted one of the first surveys of wild bee species on nine different green roofs and found higher bee diversity and abundance in a subset of wildflowers compared to *Sedum* species within a given green roof mixture. The findings suggest that phenological complementarity or other effects of plant diversity can play a key role in optimizing habitat provisioning in green roofs and should warrant further research to support biodiversity objectives in green roof policies.

Current plant selection for green roof ecosystems mainly consists of succulent plant species from the *Sedum* genus, with recent research demonstrating the success of other life forms (i.e. graminoids, forbs and shrubs). A specific combination of functional traits, or at least their evolutionary relatedness, could further optimize services (i.e. thermal benefits, stormwater retention, airborne pollution, carbon sequestration and habitat provisioning). Key traits associated with ecosystem services include tall plant stature, SLA, phenological complementarity and high root biomass. Moreover, further research is required to explicitly manipulate both functional and phylogenetic diversities in green roof experimental ecosystems to unravel the optimal plant combination for a particular service.

4.4 Green Walls

Green walls are usually divided into two categories, green facades and living walls (Fig. 4.1). The construction of green facades involves establishing climbing species in growing media at the base of, or on, a vertical surface. Living walls, on the other hand, contain cells or modules with growing media that extend the full height of the designated surface (Cameron et al. 2014; Cuce 2017; Vox et al. 2018). Unlike green facades, living walls are not just limited to climbing species (Weerakkody et al. 2017) and can be constructed with higher phylogenetic diversity (e.g. ferns, shrubs, forbs, mosses, bromeliads). Green walls can be constructed both inside and outside depending on aesthetics and the desired ecosystem services (Fig. 4.2).

The two main reasons for constructing green walls are their ability to reduce air pollution (mainly indoors) and for the thermal benefits they provide (mainly outdoors) (Table 4.2). However, outdoor green walls can also extend wall life, reduce noise pollution, improve property values, reduce stormwater runoff, increase carbon sequestration and increase biodiversity (Cameron et al. 2014; Collins et al. 2017; Cuce 2017; Djedjig et al. 2017; Pettit et al. 2017; Prodanovic et al. 2017; Vox et al. 2018). Vegetation can contribute to enhancing these ecosystem services through insulation, evapotranspiration, shading and resource uptake (Cuce 2017; Koyama et al. 2013). Additionally, the specific functional traits possessed by a species will influence the extent a species can enhance the desired ecosystem services.

Leaf traits, such as size, shape, orientation, rigidity, hairiness, roughness and waxiness, play an important role in capturing particulate matter (Pettit et al. 2017; Weerakkody et al. 2017; Table 4.2). Additionally, leaves that have more contact with particulate matter will capture more of it than leaves that have less contact. A study by Weerakkody et al. (2017) found that rigid leaves allowed greater airflow through the canopy than floppy leaves, resulting in increased particulate matter accumulation (Weerakkody et al. 2017). These authors also found that small and complex (e.g. hairy, waxy, rough) leaves were better suited to reducing particulate matter than their corresponding opposites, with the best performing small leaf species capturing 45.03 mean particulate matter density per 1 mm^2 and the worst performing large leafed species capturing 3.01 mean particulate matter density per 1 mm^2.

Stem traits are another aspect that can influence the capture of particulate matter (Table 4.2). Stem gravitropism in green wall vegetation can affect leaf orientation, which in turn influences how much airflow a leaf is exposed to. For example, Pettit et al. (2017) found that species with stronger stem gravitropism grew leaf lamellae parallel to wall airflow. Conversely, species with lower stem gravitropism had a more horizontal growth form which resulted in greater contact with particulate matter.

Root traits can play an important role in capturing particulate matter in indoor living walls where air is drawn through the growing medium and rhizosphere (Table 4.2). Pettit et al. (2017) found that rhizomatous roots with a shallow root

Table 4.2 Plant traits and phylogenetic groups linked with ecosystem services provided by green walls

Green wall		
Ecosystem service	Traits, phylogenetic and functional groups	References
Airborne pollution	Leaves: coniferous, hairy, waxy, rigid, dense and rough	Pettit et al. (2017); Weerakkody et al. (2017)
	Roots: coarse, dense, rhizomatous	
Thermal benefits	High percent cover, high leaf solar transmittance	Cameron et al. (2014); Koyama et al. (2013)

structure performed best at capturing particulate matter. The authors reasoned that this may have been due to dense root concentration increasing filtration efficacy and decreasing pressure. However, it is important to keep in mind that species that are efficient at reducing pressure may not be ideal for green wall systems that recycle airflow. In fact, reduced pressure could decrease the amount of airflow entering the system, thus reducing contact with particulate matter.

Designers interested in enhancing the thermal properties of their outdoor green wall can use plant traits to select vegetation that may excel in this purpose (Table 4.2). Cameron et al. (2014) examined the thermal performance of six species and found that those with a dense vertical leaf canopy (*Hedera helix* L. and *Stachys byzantina* K. Koch) provided greater cooling than species with a thin canopy. This occurrence was likely due to increased shade and evapotranspiration. They also observed that plant stems were cooler than adjacent leaves, suggesting that species with multiple stems may increase thermal benefits; however, further research on this topic is needed to confirm this observation. A similar trend was observed by Koyama et al. (2013), who found that high percent cover, multistemmed species and high leaf solar transmittance were associated with reduced wall temperature.

For green walls, research examining the role functional diversity and phylogenetics can play in the design process is still in its infancy. However, several studies point to the benefits of green wall biodiversity. For example, Weerakkody et al. (2017) found that the leaves of the shrub *Hebe albicans* Cockayne captured the greatest particulate matter and the leaves of the fern *Blechnum spicant* L. captured the lowest amount of particulate matter. However, previous studies found that ferns were efficient at removing formaldehyde and volatile organic compounds. Therefore, the authors reasoned that the combination of both these species on a green wall may improve overall air quality (Weerakkody et al. 2017); thus, increased biodiversity can improve multifunctionality. Cameron et al. (2014) also found that two of the best performing species for reducing wall temperatures contributed to wall cooling in different ways, one through shade and the other through shading plus evapotranspiration. If these species are combined in one green wall system, their co-occurrence may lead to greater thermal benefits.

The use of functional plant traits to inform species selection could help enhance the ecosystem services produced by green walls. Specifically, research shows that specific leaf and root traits impact the capture of particulate matter and thermal regulation. When compared to the research concerning other constructed ecosystems, the plant ecology of green walls is still in its infancy. Research is needed to determine how biodiverse plantings may impact ecosystem services and how these services may change over time.

4.5 Rain Gardens

Rain gardens (i.e. biofilters, bioswales, biofiltration systems) are composed of a vegetation layer and filter media (Figs. 4.1 and 4.2). They are constructed at ground level and designed to capture stormwater flowing from adjacent impervious surfaces (e.g. parking lots, roads, sidewalks) (Winfrey et al. 2018). During rain events, water is diverted into the rain garden where it pools. After pooling, the water permeates down through the filter layer and, depending on construction, enters the soil, is collected for reuse or is released into drainage systems (Read et al. 2010; Payne et al. 2015). Due to fluctuating soil moisture and water levels, the vegetation used in rain gardens needs to survive both saturated and dry conditions (Read et al. 2008; Payne et al. 2015). Therefore, the plant species commonly used in rain gardens include rushes, sedges, grasses and shrubs (Levin and Mehring 2015). A study by Winfrey et al. (2017) found that across three Australian cities the majority of rain gardens contained plants belonging to Cyperaceae, Juncaceae, Poaceae and Myrtaceae, with 19 families identified overall. This indicates that the creation of rain gardens with high phylogenetic diversity is possible.

Rain gardens are popular with many consumers due to their flexibility, small footprint and high aesthetic value (Hatt et al. 2009). Rain gardens are primarily built to retain stormwater and improve water quality through the capture of sediment, nitrogen, phosphorus and heavy metals (Bratieres et al. 2008; Ali et al. 2013; Levin and Mehring 2015; Table 4.3). However, rain gardens have also been associated with carbon sequestration, urban heat island mitigation, food production and increased biodiversity (Trowsdale and Simcock 2011; Levin and Mehring 2015; Payne et al. 2018; Winfrey et al. 2018; Table 4.3).

The type of plant species used in rain gardens can significantly impact the ecosystem services provided. In terms of stormwater capture, large fast-growing species and those with a long root length are desired (Richards et al. 2017; Winfrey et al. 2018). Respectively, these traits encourage greater water use and greater access

Table 4.3 Plant traits and phylogenetic groups linked with ecosystem services provided by rain gardens

Rain gardens		
Ecosystem service	Traits, phylogenetic and functional groups	References
Stormwater retention	Large plants, high relative growth rate, long root length (grasses, sedges, rushes)	Payne et al. (2015); Richards et al. (2017); Winfrey et al. (2018)
Water infiltration	Deep roots	Levin and Mehring (2015)
Conductivity	Deep roots	Levin and Mehring (2015)
Remove nitrogen and phosphorus from the water	Long roots, large root mass, extensive and fine roots	Read et al. (2010); Levin and Mehring (2015); Payne et al. (2015)
Prevent/reduce clogging in rain garden system	Thick roots	Le Coustumer et al. (2012)

to total aquatic resources (Table 4.3). For example, a rain garden study by Richards et al. (2017) found that the largest plant species growing there retained ~25% more rainwater than the smallest. Additionally, plants with deep roots can improve water infiltration and conductivity (Levin and Mehring 2015). This in turn can lead to greater water uptake by plant roots and increase soil permeability (Table 4.3).

The functional traits that improve stormwater retention have also been associated with increased nutrient removal (Table 4.3). For example, large fast-growing species with a deep rooting system absorb more water than their counterparts. As this absorption can also filter the water, these traits help reduce target nutrients (Read et al. 2008, 2010; Levin and Mehring 2015). A study conducted in Australia found that the deep-rooted shrub *Melaleuca ericifolia* Sm. was able to filter stormwater over longer periods of time when compared to short rooted species. Additionally, they found that the graminoid *Carex appressa* R. Br., which has a relatively high growth rate and long fine roots, was more efficient at nitrogen removal. The authors suggest that planting both species in one rain garden should lead to increased stormwater capture and nutrient removal (Winfrey et al. 2018). Another study by Bratieres et al. (2008) found that in addition to the traits mentioned above, a dense root system and arbuscular mycorrhizal associations can also increase nutrient removal. The authors found that the dense root system in *Carex appressa* resulted in increased surface area allowing the roots to uptake and filter more water. The arbuscular mycorrhizal species, *Melaleuca ericifolia*, was able to absorb nutrients which are usually unavailable, thanks to the symbiotic relationship that increased the absorptive surface of its roots.

In constructed ecosystems, it is important to remember that vegetation will change over time, either through age or variation in environmental and climatic conditions. For this reason, rain garden engineers should include a diversity of vegetation to encourage strong ecosystem service provisioning throughout the lifespan of the rain garden. For example, research has found that plants with a high growth rate are more efficient at reducing nutrients than those with a low growth rate. However, as species with a low growth rate are better adapted to surviving dry cycles (Read et al. 2008), the use of both may enhance ecosystem services during favourable conditions and ensure some ecosystem services are continued under unfavourable conditions. Additionally, fast-growing species with short-lived leaves may absorb more nutrients than their conservative-growth counterparts. However, they can also return nutrients to the soil faster than long-lived leaves (Read et al. 2008). These changes over time partially explain why young rain gardens excel at different ecosystem services than older rain gardens, with greater water infiltration associated with the former and habitat provisioning associated with the latter (Levin and Mehring 2015).

Rain gardens are ecosystems where both the flora and fauna contribute to ecosystem services. For example, pollinators support plant reproduction, earthworms help aerate the soil, plants provide resources for local biota and their thick roots can alleviate clogging (Le Coustumer et al. 2012; Levin and Mehring 2015). To encourage biodiverse rain gardens, the inclusion of species that shade the soil and species that produce leaf litter could be included. These plant traits can facilitate neighbouring species by cooling the surrounding environment and reduce evapotranspiration (Levin and Mehring 2015).

Current rain garden guidelines encourage the use of biodiversity, and even functional plant traits, to inform plant selection (Oversby et al. 2014; Wettenhall et al. 2014; Payne et al. 2015). For example, guidelines created for Australian cities recommend the inclusion of a diversity of species with specific functional traits to improve overall function. For stormwater retention and pollution mitigation, they recommend the use of vegetation with extensive and fine root systems. For designers interested in supporting local fauna, they recommend the inclusion of flowering species (Payne et al. 2015).

4.6 Treatment Wetlands

Treatment wetlands are constructed to mitigate various water quality issues. They consist of areas of wetland vegetation, rooted in a substrate; wastewater enters the system, passes through the vegetated area and then flows out. There are several main variations in the structure of the system (e.g. horizontal vs. vertical subsurface flow) (Vymazal 2009) and presence and spatial configuration of open water vs. vegetated areas (Vymazal 2014). A new variant, using the same kinds of macrophytes as traditional, sediment-based systems, is hydroponic systems where macrophytes are established in floating mats with their roots extending into the water below (Ladislas et al. 2015). The main vegetation types used are highly productive wetland vegetation consisting mainly of emergent wetland graminoids (Brix 1997) or floating aquatic plants (Nahlik and Mitsch 2006). Many of the early systems engineered to remove nutrients from water supply as a tertiary treatment approach have focused on monocultures of *Phragmites australis* (Cav.) Trin. ex Steud. or *Phalaris arundinacea* L. or mixtures of both species (Brisson and Chazarenc 2009; Březinová and Vymazal 2014). Phylogenetic diversity of the vegetation, in general, tends to be low because both species belong to the same family (Poaceae). Other tall graminoids are used in emergent wetland systems too, including species belonging to the genera *Typha*, *Juncus* and *Scirpus* (Vymazal 2014), as well as forbs (e.g. *Lythrum salicaria* L.; Ge et al. 2015).

We can divide the ecosystem services provided by water treatment wetlands into the primary engineering functions targeted by the designers of the system and indirect benefits that come from the presence of the vegetation and interactions with other components of the urban landscape (Table 4.4). Primary services include increasing water quality, indicated by several variables including reduced biological and chemical oxygen demand (Chen et al. 2013; Kadlec and Knight 1996), reduction of nutrient concentrations (Coleman et al. 2001; Ge et al. 2015), removal of suspended solids (Vymazal 2009), removal and degradation of contaminants (e.g. Liu et al. 2016) and reduced pathogen loads (Vymazal 2009). Treatment wetlands have been deployed to treat wastewater from municipal sources but also industries such as meat processing, wine making, tanneries, intensive farming and

Table 4.4 Plant traits and phylogenetic groups linked with ecosystem services provided by water treatment wetlands

Water treatment wetlands		
Ecosystem service	Traits, phylogenetic and functional groups	References
Nutrient removal from water column	High growth rates	Carballeira et al. (2016)
	Tall emergent wetland species (mainly grasses and other monocots)	
	Aerenchyma in plant roots increases oxygenation of rhizosphere	Paranychianakis et al. (2016)
Retention of metals	High growth rates/productivity	Liu et al. (2016)

aquaculture, as well as runoff from farms, highways and airports (Vymazal 2009, 2014). More recent works examine the ability of constructed treatment wetlands to remove or biodegrade pharmaceuticals, endocrine disrupting chemicals and other contaminants in the wastewater stream (Vymazal 2009; Ladislas et al. 2015; Li et al. 2015).

Recent research has explored additional benefits of treatment wetlands, as this ecosystem is becoming more popular across urban municipalities (Table 4.4). Given that most treatment wetlands use large, perennial plants, there is potential for carbon capture and net sequestration (Mitsch et al. 2014; Moore and Hunt 2012). Treatment wetlands are usually planted with just a handful of plant species, but they can also support many plant species over time due to spontaneous colonization, approaching the levels of diversity recorded in corresponding natural wetlands (Mitsch et al. 2014). Treatment wetlands can also provide habitat for wildlife, including birds, amphibians and invertebrates (Drayer and Richter 2016; Fleming-Singer and Horne 2006; Hickman 1994), although some studies report trade-offs between the optimization of water treatment processes and provision of habitat for wildlife (Murray and Hamilton 2010). Duckweed-based constructed wetlands can also be harvested for animal feed as duckweeds (*Lemna* spp.) are high in protein and nutrients (Zirschky and Reed 1988). There is also some recent work on using vegetation-based treatment wetlands as microbial fuel cells for electricity generation (Corbella et al. 2015). Aesthetic benefits could also be provided by treatment wetlands, especially those that use attractive flowering species, e.g. *Iris* (Carballeira et al. 2016). In larger treatment systems, several studies have quantified the extent of cultural ecosystem services offered (Moore and Hunt 2012; reviewed in Ghermandi and Fichtman 2015), including recreational (e.g. birdwatching, hiking) and educational uses (e.g. guided tours). Constructed ecosystems can thus be incorporated into comprehensive green infrastructure just like other kinds of parks or publicly accessible green spaces, with estimated economic values of over 10,000 €/ha/year for the facilities with more infrastructure related to education and recreation.

Many treatment wetland studies involve comparisons of different species, typically in monoculture, where indicators of the primary ecosystem services are the key dependent variables (reviewed by Brisson and Chazarenc 2009). Relationships between the performance of ecosystem services and plant functional traits are sometimes reported; for example, productivity is a driver of nitrogen uptake in some constructed wetland systems, so high relative growth rates would be the trait that predicts nitrogen uptake (Carballeira et al. 2016). Another common finding is that the species that perform different ecosystem services best may differ, such that no one species is optimal for all services. For instance, Carballeira et al. (2016) found that *Juncus effusus* L. was the most productive species of the five they tested, leading to the highest rate of nitrogen uptake, but *Phragmites australis* had the highest rate of organic matter removal. A study on the ability of 15 plant species to tolerate and accumulate cadmium revealed a 10x difference among plant species in Cd accumulation and that plant biomass was the main driver of these differences (Liu et al. 2016). One of the key traits governing the effects of plants on nitrogen transformation in constructed wetlands may be the rate at which plant roots release oxygen, affecting microbial metabolism (Paranychianakis et al. 2016; Table 4.4). Plants with high relative growth rates lead to rapid production of biomass, improving carbon sequestration functions and other functions related to resource acquisition (Moore and Hunt 2012; Tanner 1996; Table 4.4). Root surface area has also been suggested as a potentially important trait that might influence constructed wetland ecosystem functioning but has been little investigated in constructed wetlands (Brisson and Chazarenc 2009).

Phenological complementarity between plant species occurs when different species perform ecological services at different times of the year. In constructed ecosystems, we can engineer ecosystems to show greater year-round performance of ecosystem services by including species that perform best at different times of the year (Heim and Lundholm 2016). In constructed wetlands, this has been little examined, but one study compared cold and warm season species with warm season only and found that the mixture of cold and warm season species reduced chemical oxygen demand and total nitrate better than the other treatments (Chen et al. 2013). This represents a kind of functional diversity: phenological diversity. Chen et al. (2013) represent a relatively new trend in treatment wetland: testing species mixtures designed with the incorporation of knowledge of functional trait differences among species, in other words, specifically using functional diversity to enhance ecosystem function.

Along these lines, one novel approach has been to test increasing species diversity, not by increasing the number of species or functional groups within a single type of vegetation but implementing a two-stage treatment process where water flows into a container planted with one vegetation type (a monoculture of *Phragmites* or *Phalaris*) and then into a separate container with the other (Button et al. 2016). Such a system not only incorporates the separate effects of different plant species on water flowing through the system but also supports higher overall microbial activity (Button et al. 2016). This *mixture of monocultures* approach may be useful in types of constructed green infrastructure where useful species, which might be outcompeted in mixtures of interacting species (Březinová and Vymazal 2014; Zheng et al. 2016), could be retained in the system. Spatial separation of species with different functional traits via engineered infrastructure may optimize service provision by preventing competitive exclusion.

While most of the engineering of treatment wetlands so far has emphasized the primary functions of the system for wastewater or runoff treatment, attention to indirect benefits, such as habitat for biodiversity, reveals possible design solutions where a more diverse plant palette could be incorporated. One example would be to add forbs with floral resources to provide services to pollinators without compromising the main *mission* of the system. On the other hand, a study of a large constructed wetland (37 Ha) initially planted with a *Phragmites* monoculture accumulated over 200 plant species that spontaneously colonized and persisted over 10 years since the system was established (De Martis et al. 2016). Approximately 75% of the species that colonized were native and included ten species of conservation concern and six endemics; thus, these ecosystems can support important biodiversity in urban areas.

Plant selection for treatment wetland vegetation relies on wetland species, mainly emergent and floating leaf macrophytes. Plant traits sought by designers of constructed treatment wetlands tend to be rapid growth, clonal propagation and high root biomass (Rodriguez and Brisson 2016), and most treatment wetlands still rely on just a handful of species. There are many examples of experiments where increasing species or functional group diversity has been tested as a means to improve ecosystem functioning. Many larger treatment wetlands also spontaneously gain plant species over time. Functional or phylogenetic diversity have, as yet, been little examined as an explicit factor in improving or explaining constructed wetland ecosystem services. Some attempts to test whether diversity of functional groups can improve function are promising (Zhu et al. 2010), and yet other studies suggest that functionally different species, especially those showing phenological complementarity, can be combined to improve ecosystem services (Rodriguez and Brisson 2016).

4.7 Conclusions

Functional traits and phylogenetics are informative approaches used to understand the underlying coexistence mechanisms operating in natural plant communities. Recently, researchers have begun applying these fields to constructed ecosystems to inform plant selection, enhance biodiversity and improve the provisioning of ecosystem services. Although different constructed ecosystems have unique objectives and community structures, similarities do exist. Just as researchers apply the principles observed in natural environments to constructed ecosystems, the inferences revealed though one type of constructed ecosystem could advance the knowledge of another.

The primary reasons for constructing the ecosystems we examined in this chapter include stormwater retention (green roof, rain garden), improved water quality (rain garden, constructed wetland), thermal benefits (green roof, green wall) and capturing particulate matter (green wall). However, the presence of vegetation in these systems means that each also provides habitat for local fauna and sequesters carbon.

The functional plant traits associated with improved water quality include fast-growing species (usually associated with high SLA) and species with a dense root structure (Levin and Mehring 2015; Lundholm et al. 2015; Payne et al. 2015; Richards et al. 2017; Winfrey et al. 2018). Parallel to the traits associated with improved water quality, growth, SLA and height are associated with hydraulic demand, with SLA also linked to transpiration (Lundholm et al. 2015). Additionally, species possessing a deep root structure can access water at different depths in the soil column, which can result in increased water uptake (Levin and Mehring 2015). However, not all traits are acceptable for all systems as each has a unique design that must be considered. For example, extensive green roofs are constructed with shallow substrate depths, so deep-rooted species may not be suitable.

Vegetation can insulate buildings, provide shade and release moisture back into the atmosphere. Both green roofs and green walls are constructed in part for the thermal benefits they provide, and this ecosystem service is considered a secondary benefit of rain gardens. Researchers working with green walls and green roofs have found that high SLA, multistemmed species, tall species, high percent cover and tissue colour are traits that can influence the temperature of the surrounding environment. In terms of which traits should be applied across systems, SLA would be applicable to multiple constructed ecosystem types. However, height would likely not play a major role on green walls as their inherent design encourages vertical plant growth. Additionally, the finding on green walls concerning multistemmed species would be an interesting area to investigate on green roofs as both systems aim to provide thermal benefits.

Vegetation can reduce airborne particulate matter through absorption via stomata and by intercepting particulate matter as it travels over plant surfaces (Currie and Bass 2008). The capture of particulate matter is one of the primary reasons for constructing green walls. However, builders of green roofs and rain gardens consider this outcome to be a secondary benefit. Research has found that hairy, waxy, rigid, dense and rough leaves can intercept more particulate matter than their corresponding counterparts. Additionally, species with a coarse root structure have increased filtration efficacy likely due to decreased pressure and greater root-to-air ratio (Pettit et al. 2017). The leaf traits mentioned here could be applied to any system with similar results. However, the root traits are more complicated. Unlike the other constructed ecosystems, air passes over the roots of the plants on green walls (depending on construction) increasing their contact with particulate matter. Therefore, root traits from other systems would likely rely on a different mechanism to reduce air particulate matter.

The use of phylogenetics has only recently been applied to constructed ecosystems, with green roof research playing a dominant role in the application of this technique. Phylogenetic diversity can be used as a proxy for functional diversity when trait data are lacking. Studies conducted on green roofs have found that high phylogenetic diversity resulted in greater substrate cooling than mixtures with low phylogenetic diversity (MacIvor et al. 2018). As with the previously discussed functional trait research, the findings made from green roofs could be applied to other systems. Studies on green walls, rain gardens and treatment wetlands should examine how systems with high phylogenetic diversity impact the desired ecosystem services. Since biodiversity can enhance desired ecosystem services, the use of phylogenetics could be an efficient approach to inform plant selection (Lundholm 2015; MacIvor et al. 2016).

Increased biodiversity has been linked to increased benefits for each of the ecosystems examined in this chapter. This trend can be linked to the different functional traits among species in biodiverse mixtures. For example, in green roofs the combination of species with different canopy morphologies improved species survival when compared to corresponding monocultures (Nagase and Dunnett 2010); in green walls, species diversity may increase the type and quantity of air pollutants captured (Weerakkody et al. 2017); in rain gardens, positive correlations between functional diversity and plant cover were found (Winfrey et al. 2018), and in treatment wetlands, biodiversity can provide the secondary benefit of habitat provisioning for local fauna. Although some benefits of plant biodiversity have been documented in all four systems, guidelines specifically recommending the use of biodiverse plant mixtures are not common. When recommendations for biodiversity do exist, they tend to emphasize how biodiversity can improve aesthetics rather than other ecosystem services or long-term system stability. Regional exceptions do exist, with functional diversity specifically appearing in Australian rain garden guidelines (Payne et al. 2015). It should be pointed out that some empirical studies in all these systems show no advantage of plant species or functional diversity for particular ecosystem services, so there is certainly a need for more research to determine if and in which contexts taxonomic, phylogenetic or functional diversity in the vegetation can make a difference to the services derived from constructed green infrastructure. As each of these constructed ecosystems produces multiple ecosystem services, some work has shown that increased functional or phylogenetic diversity can result in higher levels of multifunctionality, even if a single service is not improved.

Functional trait diversity and/or phylogenetic approaches have been applied to green roofs, green walls, rain gardens and treatment wetlands, resulting in improved ecosystem service provisioning in some cases. However, work is still needed in each of these constructed ecosystems to determine which trait combinations are most efficient at providing the desired ecosystem services and the overall performance of multiple services. Additionally, as phylogenetics represent a relatively recent approach, their application to green walls, rain gardens and treatment wetlands should be examined.

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Chapter 5
Green Infrastructure Within Urban and Rural Landscapes Following Landscape Bionomics

Vittorio Ingegnoli

Abstract Territorial planning and ecology are the two disciplines more involved in the transformation of the landscapes. Thus, to understand what a landscape is, its behaviour and how it coevolves with man become key passages to realise what kind of benefits green infrastructure could provide to the environment. Is traditional ecology able to respond adequately? In light of the new scientific paradigm, which indicates the necessity to avoid the dominance of reductionism, traditional ecology must be upgraded. The new discipline of bionomics and consequent landscape bionomics propose the integration of the viewpoints of space configuration, biotic structure, functional processes and cultural-economic governance, studying the real environmental system as complex systems. We will show only a brief synthesis of the main structures and state functions in landscape bionomics. Its new directions were given to territorial planning to complete this summary. The necessity to show the main contents of landscape bionomics allows to expose two studies concerning green infrastructures: (a) urban parks and ecological networks, centred to the new quarter of city life in Milan, and (b) alteration of agricultural landscapes, for example, Albairate, in the Regional Agricultural Park of South Milan. Following bionomic principles and methods, the crucial importance of the *ecoiatra* and the planetary health emerges and, therefore, the importance of the studies on landscape syndromes and on human health.

Keywords Scientific paradigm shift · Landscape bionomics · Territorial planning · Urban park · City life quarter · Agricultural landscape

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_5

5.1 The Responsibility of Territorial Planning and Ecology

5.1.1 Territorial Planning and the Paradigm Shift

The building of big infrastructures and power plants, the sharp increase of urbanisation and the obsolete technologies and methodologies applied for territorial planning without real respect of natural laws may be sufficient to evaluate the enormous responsibility of territorial planning itself.

Traditional planning methods, entirely dominated by an urban-centred perspective even outside the inhabited centres, are still based on separate sectors, marked land-use zoning, uncritical hierarchical relationship among plans at a higher scale, technological privileges and road priorities, binding and bureaucratic choices and trivial urban greenery, following an *anti-ecological economy*. Planning takes into account separately some factors, such as pollution control, rare species and some biotopes. Historical investigations are usually limited to the state of the previous plan (ex ante > ex post), whilst further information is often focused only on the monuments and the historical urban centres to be protected. Great significance is attributed to the so-called popular participation but mostly in the sense of resource use and *economic growth* objectives. Rather conventional procedures are frequently adopted to support current plan choices. The most used model is the so-called *status/pressure/responses* (or SPR). By contrast, as these procedures are incorrect, we will argue and stress here the need to make an epistemological shift in order to leave the dominant scientific paradigms. In fact, many epistemological studies clearly pointed out that the Galilean scientific method, i.e. deductive and experiment-based, although not yet been abandoned, has severe limitations (Agazzi 2019; Urbani-Ulivi 2019). Such method is mainly reductionist, i.e. based on the assumption that the behaviour of a system may be studied starting from the properties of its components per se. Moreover, this methodology does not consider the time arrow, so it admits the reversibility of the processes involved.

Almost the opposite is the *new* paradigm, which is mainly holistic and more systemic, i.e. based on the emergent properties principle and nonequilibrium thermodynamics, admits the irreversibility of many processes and gives more importance to symbiosis and cooperation, Einsteinian relativity, information theory, transdisciplinarity, systemic quantifications, etc. Von Bertalanffy pointed out that the systemic approach enters in different domains. This idea was strongly reinforced, noted Agazzi (2019), when the notion of an *open* system was extended not only to the existence of exchanges of matter and energy with the environment but also of *information*. Concepts like feedback, regulation and self-regulation, together with models elaborated in cybernetics, could be used for a significant improvement of the interactions within systems and between systems and environment. This fact means that the concept of the system is *transdisciplinary*: that is, it can be profitably used in different disciplines.

In the light of the new scientific paradigm, the disciplines that are tightly linked with our environment are strongly implied in – and responsible for – the degradation processes which negatively affect our health. These disciplines:

- Remain mainly reductionist, because they still consider separately the components of air, water, soil, geology and natural factors separately, at most overlapping them.
- Use a synthetic *multidimensional environmental value* index, drawn up on sector analysis, in contradiction with the principle of emergent properties.
- Do not consider the natural dynamics of systemic processes and do not compare planning options with current trends in the state of health of the system as a whole, nor do they adequately take into account the regional context.

Let us underline that, in the general systems theory, the emergent properties principle affirms that the properties of its elements determine some of the characters of a whole (i.e. a system). However, other characters of the system are the consequence of *how the elements organise themselves*. The whole is greater than its components, as Gestalt's epistemology school (perception of the form) proclaimed in the first half of the twentieth century (Lorenz 1978).

5.1.2 Traditional Ecology and the New Scientific Paradigm

Physics started changing the scientific paradigm since the first half of the past century, after the discoveries and publications of Pauli and Einstein about quantum mechanics and general relativity. Biology, on the contrary, remained mainly reductionist up to present day, due to the *dogma of molecular biology* (Crick 1970) imposed after the discovery of DNA (1953) and to the dominion of neo-Darwinism. Indeed, in the light of the new systemic paradigm, this kind of biology appears obsolete and presents many limits. Consequently, new disciplines have been proposed, trying to follow the systemic paradigm, such as epigenetics, systemic medicine, environmental medicine, psycho-neuro-endocrine-immunology, and landscape bionomics. Particularly impressive are the limits concerning *traditional* ecology. Some examples are as follows:

Ecosystem The scientific concept of the *ecosystem* is ambiguous, as demonstrated by O'Neil et al. (1986), recognising the impossibility to compare the biotic and the functional perspectives: moreover, the concept of ecosystem (Tansley 1935) implies a definition based on structures and functions that are not able to vary along with the scale considered, e.g. from a small ecotope to a vast landscape (*system of ecosystems*), in contrast with the *emergent properties principle* (Ingegnoli 2002, 2015). We should always keep in mind that the scientific concept of ecosystem is not a mere synonym of ecological system.

Transformation Law Succession process occurs through distinct *seral stages* (Odum 1971, 1983), whilst the transformation of complex systems is not linear. A good model for a complex system transformation should be based on the nonequilibrium thermodynamics, i.e. taking into account irreversibility and metastability. A process of *macro-fluctuation* leads to a bifurcation point, leading to two possible paths with different dynamic steady states. Additionally, complex mutual relations occur among the system components (Prigogine 1996). Figure 5.1 shows a scheme on the possible results of vegetation dynamics according to the nonequilibrium thermodynamics principles. Note that the ecological succession through seral steps is not compatible with the new systemic paradigm, because the transformations of complex systems are not linear.

Biodiversity The interpretation of the concepts of *biodiversity* and *resilience* is incorrect. The most complex natural systems follow *resistance* stability, not *resilience* stability; in fact, *only resilience needs redundant biodiversity*. Lovelock (2006) observed that rich biodiversity is not necessarily highly desirable and preserved at all costs. For instance, some of the most mature Mediterranean communities, such as *Quercus ilex* L.-dominated evergreen forests, show low species diversity (35–50 species/survey plot), whilst the less evolved garrigues host five to six times more species (220–270 species/survey plot). This fact shows that the increase of

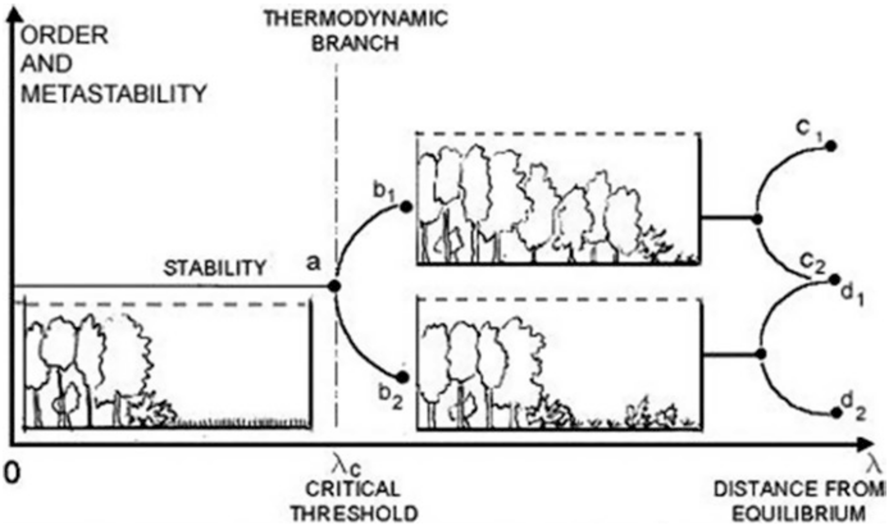

Fig. 5.1 A process of land abandonment leads to a bifurcation point with two possible ecological transformations, b_1 and b_2, which have different metastabilities. Note that after another macro-fluctuation the transformation d1 may coincide with c_2 or not (c_1 or d_2). Examples like these show the need to revise the concept of succession, leading to significative changes in vegetation science (from Ingegnoli 2015)

biodiversity stabilises species-poor ecosystems, but destabilises the ecosystems which have already reached steady levels of species richness (Massa and Ingegnoli 1999; Pennekamp et al. 2018; Pignatti 1995). Moreover, we have to consider species richness also at the landscape scale, due to ecocoenotopes (i.e. the ecobiota including the community, the ecosystem and the microcore sensu Zonneveld (1995)) and ecotopes occurring in the examined ecotissue.

5.2 Bionomics and Landscape Bionomics

5.2.1 The Landscape as the Territorial Level of Biological Organisation

The system theory states that the scale capable of maximising the importance and the quantity of relations among the components of a system is the scale that allows to discriminate the different forms, especially the relational ones. That is why Ingegnoli and Giglio (2005) and Ingegnoli (2015) highlighted, the crucial importance of the landscape, because the territorial scale is the best one to point out the relationship among both natural and human components. The need to develop a new ecological discipline, issuing from the integration of biology and landscape ecology, was first proposed by Ingegnoli (2002). This discipline is *landscape bionomics*.

The new principles of landscape bionomics focus on the Earth's surface and its spatial subdivision to distinguish what exists, i.e. life on Earth hierarchically organised in living entities, and the different approaches that can be adopted to study the environment (viewpoints), as exposed in Table 5.1 (Ingegnoli 2015). These new principles represent a sharp change with respect to those of traditional ecology because they keep in mind that hierarchical levels are types of complex biological systems, each related to a *proper space-time-information* scale.

Thus, six main scale levels constitute the real environment:

1. The organism.
2. The population.
3. The *ecocoenotope.*
4. The *landscape*, formed by a system of interacting ecocoenotopes (the green row in Table 5.1). According to Ingegnoli (2015, pp. 3–7): 'the biological organisation of a territory as complex living system formed by natural and human interacting and coevolving components' must be named *landscape*.
5. The ecoregion.
6. The Eco-bio-geo-noo-sphere.

Note that the definition of landscape proposed by European Landscape Convention (ELC) (Council of Europe 2000) is no more sustainable! It speaks about

Table 5.1 Hierarchic levels of biological organisation on the Earth: real systems and the partial different viewpoints

Scales	Viewpoints				Real systems[5]
	Space[1] configuration	Biotic[2]	Functional[3]	Cultural-economic[4]	
Global $S = 10^{13}–10^{14}$ m^2 $T = 10^7–10^9$ years B = ecoregions E = world	Geosphere	Biosphere	Ecosphere	Noosphere	**Eco-bio-geo-noo-sphere**
Regional $S = 10^{10}–10^{12}$ m^2 $T = 10^3–10^6$ years B = landscapes E = region	Macro-chore	Biome	Biogeographic system	Regional human systems	**Ecoregion**
Territorial $S = 10^6–10^{10}$ m^2 $T = 10^2–10^5$ years B = ecocoenotopes E = land	Chore	Set of communities	Set of ecosystems	District human systems	**Landscape**
Local $S = 10^2–10^8$ m^2 $T = 10^0–10^4$ years B = species/ environment E = site	Micro-chore	Community	Ecosystems	Local human systems	**Ecocoenotope**
Stationary $S = 10^0–10^9$ m^2 $T = 10^1–10^3$ years B = organisms E = minimal habitat	Habitat	Population	Population niche	Cultural/economic	**Meta-population**
Singular $S = 10^2–10^6$ m^2 $T = 10^3–10^3$ years B = cells E = vital space	Living space	Organism	Organism niche	Cultural agent	**Meta-organism**

1, not only a topographic criterion but also a systemic one; 2, biological and general ecological criterion; 3, traditional ecological criterion; 4, cultural intended as a synthesis of anthropic signs and elements; 5, types of living entities really existing on the Earth as spatiotemporal-information proper levels
Main dimensions: *S* space, *T* time, *B* biotic components, *E* environmental components

landscape in a perceptive sense and states that the character of the landscape is the result of natural and anthropogenic factors (Table 5.2). If the first part of the definition denies an intrinsic and objective existence to the landscape, the second part of this definition highlights the most significant: for the *principle of emergent properties* (Von Bertalanffy 1968), it is impossible to understand the behaviour of a complex system as a mere result of the relationships of different thematic factors. As Konrad Lorenz (1978) wrote very clearly:

> an organic whole is always greater than the sum of its parts.

Processes allowing the definition of life bear *ontological* characters, but each specific biological level expresses a process in a *personal* way, depending on its scale, structure, functions, amount of information and semiology; moreover, *each biological level* bears personal *emergent* characters too, being a complex system. In cases like these, clearly separated and distinct functioning levels depend strictly on each other to be properly operational (e.g. at the same time, independent and local).

5.2.2 *Main Structures in Landscape Bionomics*

(i) The *landscape structure* in conventional ecology is usually based on the concept of *eco-mosaic*, made of different ecosystems forming a patchwork over a given geographic territory. Conversely, in a complex system, we have to consider the concept of *ecotissue* (Fig. 5.2), i.e. the biological tissue of the landscape, the weft and the warp in weaving or the cells in a histologic tissue. The ecotissue represents a multidimensional conceptual structure: the hierarchical intertwining over the past, the present and the future, of the ecological upper and lower biological levels and their relationships (Giglio 2011; Ingegnoli 2001, 2002, 2011, 2015). In other words, the ecotissue forms a complex system and a hierarchic succession of correlated structural and functional patchworks and attributes.

(ii) The *landscape unit (LU)* is intended as a sub-landscape; it is a part of a landscape, the peculiar structural or functional aspect characterising it with respect to the entire landscape. It is not a simple arrangement of ecotopes, even if it forms a connected patch of them, and as its structure is not always immediately recognisable, it needs *ad hoc* studies. We define a (simple) LU as an interacting

Table 5.2 Contrasting definitions of landscape

European Union: European Landscape Convention (2004)	Ingegnoli V, in: Baltimore D, Dulbecco R, Jacob F, Levi-Montalcini R (eds.), Frontiers of Life (2001)
The landscape means an area, As perceived by people, Whose character is the result of the action and interaction of natural and/or human factors	The landscape means a complex system, Existing as a biological entity, Whose character and behaviour are more than the result of the action and interaction of natural and human components

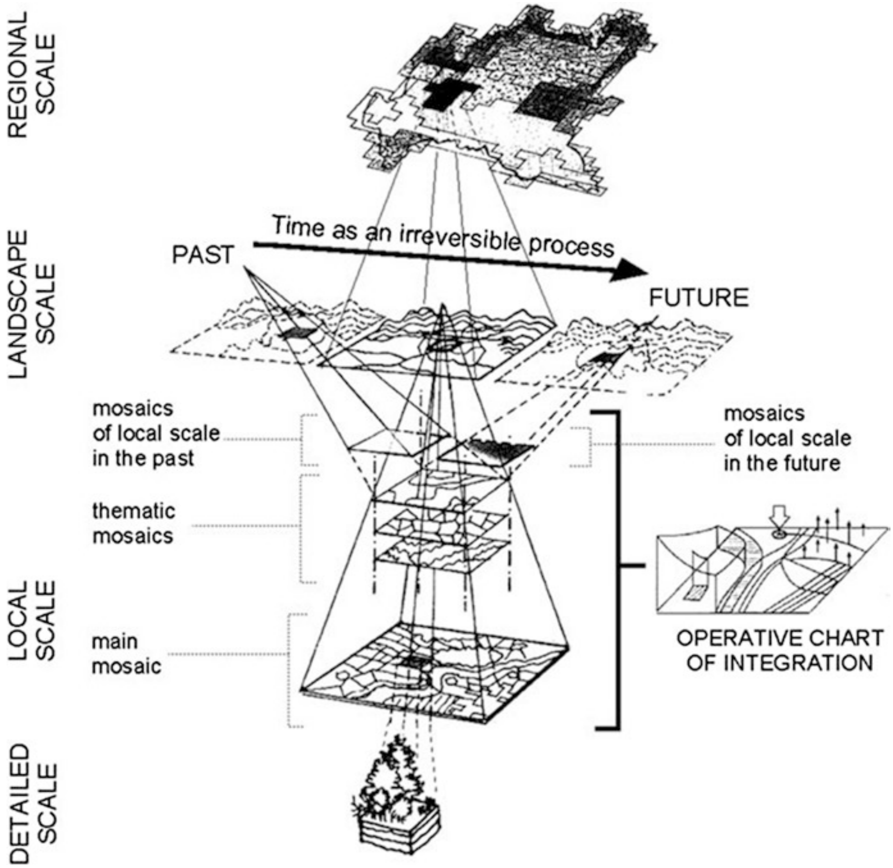

Fig. 5.2 The ecotissue model gives the right importance to the landscape and integrates the fundamental dimensions of the landscape: (1) a range of spatial scales, from regional to local configuration of elements, (2) a set of thematic mosaics on species (biomass) and resources (energy) components, (3) a range of temporal scales on developing processes, which permits the evolutionary dynamic of the landscape to be forecasted and reconstructed, (4) a set of information contents, which permits to evaluate the level of the systemic organization (from Ingegnoli 2002)

combination of recurrent and *genetic* (i.e. sharing the same physiographic and geo-pedological traits) ecotopes, which has a specific significance (function) in its landscape. Please bear in mind that in montane areas a municipality may include two or three LU (Ingegnoli 2002, 2015). The same may occur in the plain too! For instance, the municipality of Robecco sul Naviglio, within the Ticino River International Park, includes two LU, i.e. (a) the Ticino river flood bed, hosting many remnant forests and all *tesserae* (= patches) with curved natural boundaries, and (b) the plain terrace, crossed by the Naviglio (canal), with the urban centre, characterised by smaller geometric agricultural fields without trees hedgerows.

(iii) The *landscape apparatuses (L-Ap)* are the most important of these ecocoenotopes (even not connected) patchworks, forming specific configurations within the ecotissue, each apparatus performing specific functions. Many landscape apparatuses can be distinguished, such as the hydrogeological (HGL), the protective (PRT), the connective (CON), the residential (RSD), the disturbance (DIS) (elements with a range of non-incorporating disturbances), the excretory (EXR) (the local watershed processing the catabolites produced at landscape scale), the subsidiary (SBS) (components related to industries, commerce, energy production), the productive (PRD) (components linked with high biomass production), the resistant (RNT) (elements showing high metastability like forests) and the resilient (RSL) (elements with showing high recover capacity, like grasslands or shrublands). Rarely the previous functions have been linked to some basic concept of landscape ecology, such as to its structure and dynamic!

5.2.3 Main State Functions in Landscape Bionomics

The state and the time (*x, t*) are of great importance because the set *X, T* is the set of events and the *history* of the system. If we fix an instant *t*, an initial state $x\ (t_0)$ and an input function *a(.)*, then the transition function *F[., t, x(t), a(.)]* is univocally determined and named *movement*. The transition function *F* may be composed of a set of sub-functions capable of leading the system's movement; hence, these *state functions* result to be particularly important:

(iv) The *minimum theoretical standard habitat pro capite (SH*)* is the state function strictly related to the previous concepts of the vital space per capita (m^2/ab) (Ingegnoli 2011, 2015) intended as the minimum theoretical set of portions of the landscape apparatuses (within the examined LU) required for an organism to survive. It is available for an organism (man or animal), divisible in all its components, biological and relational. The *standard habitat (SH)* is the concrete, measurable one (Table 5.3).

(v) The *carrying capacity***.** The ratio SH/SH* is the state function that evaluates the self-sufficiency of the human habitat (HH), a basic factor to take into account for sustainability and ecological territorial planning. This ratio also measures the level of heterotrophy of a LU.

(vi) The *human habitat (HH)*. Based on surface area (% of LU), it allows to assess the human ability to affect and limit the self-regulation capability of natural systems. Ecologically speaking, the HH cannot cover the entire surface of a territory: they include the human ecotopes and transformed landscape subunits (e.g. urban, industrial, rural areas) and the seminatural ones (e.g. semiagricultural, plantations, ponds, managed woods). The NH are the natural ecotopes and landscape units, with the dominance of natural components and biological processes, capable of healthy self-regulation.

Table 5.3 Theoretical minimum standard habitat per capita related to the main climatic belts of the biosphere (from Ingegnoli 2015)

Climatic belts	[Kcal/inhab][a]	SH* [m^2]	Min. [t°C][b]	PRD [m^2]
Arctic	3500	2500	−45.6 to −34.4	1650
Boreal	3100	1850	−34.4 to −23.3	1230
Cold temperate	2850	1475	−23.3 to −12.2	1050
Warm temperate	2750	1360	−12.2 to −1.1	1000
Subtropical	2550	1250	−1.1 to +10	900
Tropical	2350	1020	+10 to +21.2	730

[a]Minimum edible Kcal/day per capita (very different from the 3500 Kcal/day of USA population)
[b]Following USDA Plant Hardiness Zone Map for Cultivations (Average Annual Extreme Minimum Temperature 1976–2005)
PRD = minimum field available to satisfy the edible energy per capita needed in 1 year, SH* = vital space

The sharp difference between the reductionist concept of natural and human components vs. the systemic one, in which the landscape apparatus and the human (HH) and natural (NH) habitats are integrated, has to be expressed by two nonlinear state functions. The absence of NH or HH can be possible only as an exception, for instance, in a wide industrial-urbanised area or in a totally uninhabited area.

(vii) The *biological territorial capacity of vegetation (BTC)*. The *physiology of plant communities* is tightly linked with their *latent capacity of homeostasis*. BTC can be studied on the basis of (a) the concept of resistance stability, (b) the vegetation type, (c) the data concerning the metabolism (i.e. biomass B, net or gross primary production NP and GP and respiration R) of these communities, (d) the R/GP rate (respiration/gross production), (e) the R/B rate (respiration/biomass) and (f) the dS/S rate (anti-thermal maintenance). Based on these parameters, two coefficients can be elaborated:

$$a_i = (R/GP)_I / (R/GP)_{max}$$

$$b_i = (dS/S)_{min} / (dS/S)_i .$$

a_i measures the relative metabolic capacity of the main plant communities.
b_i measures the degree of the anti-thermal (i.e. order) maintenance concerning the same plant communities.

The degree of the homeostatic capacity of a plant community is proportional to its respiration. It can be expressed as the flux of energy that the plant community must dissipate to maintain its condition of order and metastability (Mcal/m^2/year):

$$BTC_i = (a_i + b_i)\ R_i w_i\ \left[\text{Mcal}/\text{m}^2/\text{year}\right]$$

where w = 1.5–1.8 (security coefficient). Therefore, the BTC function is essential because it is systemic and can evaluate the flux of energy available to maintain the order reached by a complex system.

Note that a high level of energy flux expresses the complexity of a highly ordered system: for instance, a subtropical rainforest (high resistance) may reach values of BTC = 17–18 Mcal/m^2/year and a mature mixed broad-leaved temperate forest (e.g. *Querco-Carpinetum*) BTC = 9.0–10.0, whilst in a cultivated crop field (low resistance) BTC = 0.45–0.50 Mcal/m^2/year and a regularly mown meadow (e.g. *Arrhenatheretum*) BTC = 0.65–0.90. For instance, the comparison between two agrarian landscape units, (a) Albairate-organic farming ecotope and (b) Chiaravalle-conventional (intensive) farming ecotope, presents a very sharp difference in terms of both HH and BTC, with HH = 0.55 and BTC = 1.75 Mcal/m^2/year in Albairate vs. HH = 0.85, BTC = 0.73 Mcal/m^2/year in Chiaravalle. This example illustrates that a systemic diagnostic evaluation of a complex system like a LU is feasible.

(viii) LaBiSV. We proposed to value the BTC on the field using a new methodology called LaBiSV (Landscape Bionomics Survey of Vegetation) (Ingegnoli 2002, 2005, 2015; Ingegnoli and Giglio 2005; Ingegnoli and Pignatti 2007). The basic principles and potentialities of this methodology are summarised as follows:

(a) Reference to the concepts of ecocoenotope and ecotissue as structural entities of the landscape; (b) use of bionomic territorial capacity of vegetation (BTC) as the primary integrative function; (c) drawing up of development (succession) models of different types of vegetation (time-BTC) based on a logarithmic and exponential functions; (d) ability to determine the normal state of the ecological parameters concerning different vegetation types; (e) ability to measure biodiversity at the landscape level (diversity of biological organisation of the context); (f) possibility of comparison between the ecological statuses of each natural and human-made vegetated patch.

(ix) The *concise bionomic state of vegetation (CBSt)*. It is the measure of the efficiency of a vegetated ecocoenotope (Ingegnoli 2013). The CBSt of a given vegetation patch can be assessed by considering (i) the significance of the BTC of the surveyed patch in relation with the *maturity level* (MtL) of its vegetation coenosis and (ii) its bionomic quality (bQ) always resulted from the parametric survey (see: LaBiSV in Ingegnoli 2015). Therefore, we can express this function as:

$$\mathrm{CBSt} = \left(\mathrm{MtL} \times \mathrm{bQ}\right) / 100.$$

5.2.4 Bionomic Diagnostic Evaluation

The landscape is a specific level of life organisation on Earth; therefore, it is a *living entity* and may present many *syndromes*, as synthesised in Table 5.4, the *majority* of which are *not* due to pollution. If the hypothesis that *also these* non-toxicological landscape pathologies can influence human health were proven, the importance of landscape bio-structural rehabilitation would become imperative.

The difficulty to understand the concept of *pathology* lies in its inextricable link with *physiology*, within which, to understand a function, we need to know its alteration and vice versa, with continuous feedback. Furthermore, like in medicine, environmental evaluation needs comparisons with *standard* patterns of behaviour of a system of ecocoenotopes: how to know this normal state? After more than 25 years of studies and field surveys, the normal range of values for 8–15 complex parameters for each landscape type was defined (Table 5.5). Hence, the levels of alteration of the system can be determined, basically through the BTC function.

Table 5.4 Main categories and subcategories of landscape syndromes

Main landscape syndrome categories	Subcategories of syndromes
A – structural alterations	A1 – landscape element anomalies
	A2 – spatial configuration problems
	A3 – functional configuration problems
	A4 – multiple structural degradation
B – functional alterations	B1 – Geobiological alterations
	B2 – structurally dependent dysfunctions
	B3 – delimitation problems
	B4 – movement and flux dysfunctions
	B5 – information anomalies
	B6 – reproduction problems
	B7 – multiple dysfunctions
C – transformation syndromes	C1 – stability problems
	C2 – changing process dysfunctions
	C3 – anomalies in transformation modalities
	C4 – complex transformation syndrome
D – catastrophic perturbations	D1 – natural disasters
	D2 – human-made destruction
E – pollution degradations	E1 – direct pollution
	E2 – indirect pollution
F – complex multiple syndromes	F1 – acute
	F2 – chronic

Table 5.5 Normal range of values for some parameters of the main landscape types of temperate region

Landscapes	LTpE	(α + γ)	For-CBSt	SH/SH*	URB	AGR	FOR	RFI	pCA
Dense urban	0.3–3.0	0.45–0.55	16–19	0.1–0.3	55–70	4.5–10	3.5–5	120–140	5.0–8
Rare urban	2.7–6.3	0.5–0,65	19–23	0.3–0,6	30–55	10.0–20	5.0–8	140–180	8.0–15
Suburban rural	5.7–11	0.6–0.75	22–30	0.6–3.0	15–30	20–50	8.0–25	180–200	15–35
Agricultural	10.2–24.2	0.65–0.85	23–32	1.5–9.0	8.0–16	50–75	10.0–30	180–220	35–50
Agricultural-protective	22–40	0.7–0.9	28–38	3.0–12	4.0–10	35–60	20–55	200–250	50–65
Agro-forest-touristic	34–55	0.65–0.95	28–38	1.2–12	3.5–10	15–40	25–65	200–270	45–70
Agro-forest	45–88	0.75–1	30–40	3.5–15	2.0–5	20–50	40–75	250–270	60–75
Forest-touristic	65–140	0.75–1	30–40	1.5–15	1.0–3	10.0–25	45–80	250–300	65–80
Forest seminatural	100–245	0.8–1.1	34–45	4.0–18	0.5–2	5.0–20	60–85	260–300	75–85
Forest natural	170–500	0.8–1.1	36–50	6.0–25	0–1.0	3.0–6	65–95	260–300	80–95

LTpE, landscape-type evaluation; (α + γ), circuitation + connectivity; For-CBSt, forest bionomic efficiency; SH/SH*, carrying capacity;
URB urbanised land cover, *AGR* agrarian land cover, *FOR* forested land cover, *RFI* river functionality index, *pCA* potential core areas

5.2.4.1 HH/BTC Diagnostic Function

Local Scale A strikingly strong correlation between the *flux of energy needed* by a living system to reach and maintain *a proper level of organisation and structure* (BTC) and the measure of the human control and limitation (HH) of the self-regulation capability of natural systems was found, with an $R^2 = 0.95$ and a Pearson's correlation coefficient of 0.910. As we can see in Fig. 5.3, it was possible to build the simplest mathematical diagnostic model (HH/BTC) for the first framing of landscape units' dysfunctions to control the effects of territorial planning design and study the landscape transformations:

$$BTC_{HHnormal} = 0.0007HH^2 - 0.1518HH + 8.85\left[\text{Mcal}/\text{m}^2/\text{year}\right].$$

$$BF = BTC_{HH\,normal} / BTC_{HH\,surveyed}\left[\%\right].$$

The green curve (local scales) represents the *normal* BTC_{HH} and the *normal* BF = 1, whilst dashed curves underline the three thresholds of alteration of BF (bionomic functionality). Below typical values of *bionomic functionality* BF = 1, beyond a

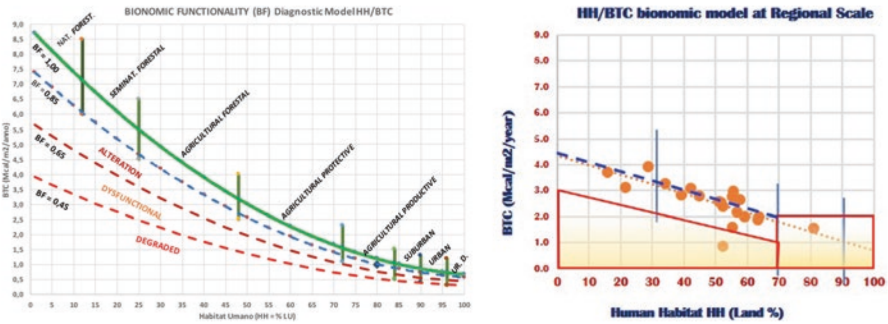

Fig. 5.3 The HH/BTC bionomic model. Correlation HH/BTC at Local (left) and Regional-National scale (right). The green curve (Local scales) represents the normality, while dashed curves mark the thresholds of worsening Bionomic dysfunctionality, measured by BF. At wider scales (right) the normality is the blue dashed line, dysfunctional fields are marked in yellow. Note that when HH > 70% a region is out of normality! Orange dots represent the medium BF of some European Countries

tolerance band BF = 1.15–0.85 with (± 0.15) from the curve of normality, three bands of alteration of BF can be found: altered (BF = 0.85–0.65), dysfunctional (BF = 0.65–0.45) and highly degraded (BF < 0.45). The vertical bars divide the main types of landscapes, from natural forest (high BTC natural) to densely urbanised: each of them may present a syndrome. Note that it is a complex model because both HH and BTC are sophisticated attributes, and their behaviour is scale-dependent and not linear.

Regional-National Scale Changing scale from local to regional-national one, the diagnostic model HH/BTC changes (because we pass from surfaces of 101–104 Km^2 to areas of 104–106 km^2), so the curve of normality is different (Fig. 5.3, right):

$$\mathrm{BTC}_{\mathrm{HHnormal}} = -0.0362\mathrm{HH} + 4.50\left[\mathrm{Mcal}/\mathrm{m}^2/\mathrm{year}\right].$$

Note that at a regional scale, HH has severe limits, because when HH values >70%, they become typical of local scale. Consequently, to better evaluate functional-systemic parameters at a regional scale, not only BF but BTC+ BF must be considered together.

5.3 Landscape Bionomics and Territorial Planning

5.3.1 A Systemic Planning Methodology

A brief synthesis of the bionomic planning criteria will be exposed in the following part of this contribution. Disciplinary and theoretical elaborations and practices derive from (1) urban and territorial planning and (2) landscape bionomics (LB).

Consequently, at least two professional figures have to cooperate: the *ecoiatra* (sensu Ingegnoli 2011, 2015) and the urban planner. Note that the formation of the *ecoiatra* cannot be the same as the planner (architect or engineer), but it must be based on bionomics. The main phases of the process, guided by LB, are supposed to be dynamic, widening the field of application of historical methodologies to the entire landscape system. Analysis and diagnosis are conceptually separated, but in fact they need iterative processes. More than one LU in the same municipality has to be remarked and delimited, strictly following bionomic criteria. To better understand the planning processes, we need to focalise a more detailed list of arguments concerning (I) landscape analysis, (II) landscape diagnosis, (III) landscape planning and (IV) Strategic Environmental Assessment (SEA).

In Table 5.6, the main conventional fields (orange) needed to study a landscape unit are shown. Note that the conventional components are essential but insufficient. Moreover, many ecologists study a given portion of the territory following a common qualitative approach: when a *quantitative* approach is adopted too, the integration of the components follows some cluster calculations, mainly variational. This fact is not correct because of the principle of the emergent properties, which asserts that we cannot infer the behaviour of a complex system from the traits of its elements. So, we must analyse the laws inherent to the structure, the functions and the transformation of a complex ecological system, its bionomic state, etc. (see Ingegnoli 2011, 2015; Ingegnoli and Giglio 2005).

Similarly, in Table 5.7, the comparison between conventional (on the left) and bionomic criteria (on the right) on Strategic Environmental Assessment (SEA) highlights a sharp difference: on the left, we can notice that the neoclassical economy approach dominates the main strategic aims in conventional planning, followed by *urban reporting* whose thematic areas consist of a qualitative impact evaluation. In this case, the environmental balance is inferred from classical thermodynamic laws, with reversible processes (e.g. degradation and recovery). On the right bionomic criteria are based on the relationships between landscape and human health, followed by the bionomic evaluation and diagnosis, controlled by non-equilibrium thermodynamics, with irreversible processes (e.g. metastability levels).

5.3.2 Green Infrastructures

The EEA defines the green infrastructure (GI) on the principle that 'protecting and enhancing nature and natural processes […] are consciously integrated into spatial planning and territorial development' (EC 2013: 2). Accordingly, the GI strategy defines GI as a 'strategically planned network of natural and seminatural areas with other environmental features designed and managed to deliver a wide range of ecosystems services' (EC 2013: 3) in rural and urban settings.

In a landscape unit (LU), the green infrastructures (GI) have been studied in urbanised or suburban landscapes and agricultural ones but not strictly related to natural components to form complex systems. Furthermore, apart from some few

Table 5.6 Field of studies for a territorial ecological planning

Main environmental elements	
A – Geological	Geology, geomorphology, stratigraphy, pedology, etc.
B – Botanical	Flora, vegetation, geo-sigmeta, geobotany, phytosociology, etc.
C – Zoological	Fauna, faunistic sensibility, rarity and vulnerability, faunistic populations, etc.
D – Hydrobiological	Water biological quality, hydrologic network, etc.
E – Urbanised	Urbanisation, industry, infrastructures, mobility, etc.
F – Economical (NC)	Neoclassical economy (labour provides the value of the land)
F – Agricultural	Agriculture, farms, irrigation, hedgerows, crops, vineyards, etc.
Bionomic analysis and evaluation	
G – Structure	Landscape units, ecotissue, ecotopes, ecocoenotopes, configurations, etc.
H – Functions	Human habitat, natural habitat, landscape apparatuses, BTC functions, SH functions, historical colonisation, photosynthetic areas, carrying capacity, landscape-type evaluation, etc.
I – Transformations	Historical dynamics, change modality, land cover, land use, change interferences, etc.
J – Bionomic state	Strategic evaluation, main state function normality, bionomic alterations, pollutions, etc.
K – Human habitat main systems	Agrarian and urban landscapes, agroecology, urban ecology, green infrastructures, landscape rehabilitation, etc.
L – Geo-health/ human-health alterations	Mortality rate vs. bionomic functionality, premature death risk, environmental stress, etc.
M – Therapy and design	Therapeutic criteria, bionomic control, ecological design, etc.
N – Economy (EE)	Ecological economy (capable to evaluate ecological services)

exceptions, the GI is mostly aimed at imprinting the landscape with human design and technologies, guided by architectural criteria. Most of the environmentalists and ecologists did not contrast this trend, because they were mostly focused in reducing pollution, saving species biodiversity and preserving biotopes. However, they have no idea how to lead a complex system like a landscape unit or an ecotope or address *ecological planning*.

Today, relativism threatens even science, reducing it to scientism. This distortion can be removed as long as we do not ignore the real essence of phenomena. On this purpose, to design an urban park, it should be taken in mind that landscape is a living entity representing a specific level of the organisation of life on Earth. So, it is essential to understand the bio-ecological laws and follow a clinical diagnostic method to act on it.

The criteria to be adopted to design a park must necessarily follow such a theorem. Even a park in a city or its suburban LU is a portion of a living entity. So, it has a direct impact on health and well-being. If a park design remains anchored to the principle of pure *formalism* and research of the maximum *originality*, it actually underestimates the crucial importance of the quality of human life itself and the need to fit local environment.

Table 5.7 Comparison between Trentino province (on the left) and bionomic principles for SEA (on the right)

Strategic Environmental Assessment	
A – Main strategic aims of SEA	
Identity, enhancing the eco-tourism Sustainability, sustainable development of resources Integration, in the European context of infrastructure Competitiveness, productive development	Health of landscape systems and of man Memory, natural history and cultural heritage Rehabilitation, sustainability of the system and therapeutic indications Control of resources, systemic, by landscape systems
B – SEA methodological criteria	
Urban reporting Assessment of consistency with the higher-level planning instruments	Bionomic evaluation Assessment of the state of health of the landscape units (LU)
Analysis: Indicators, economic and environmental planning and decision-making models simple (e.g. SWOT)	Analysis: Indicators of landscape and ecological + bionomical models for complex subsystems
Rating: Actions to achieve the strategies are evaluated through impacts by thematic area. The assessment is qualitative, for compliance and indeterminacy	Rating: Structure and functions of each LU are valued through a clinical-diagnostic methodology, in relation to dynamic states of normality. The assessment is qualitative and quantitative
Control: Planning, with simple methods of description and effectiveness with urban-economic indicators. Following measures of mitigation, compensation and monitoring	Control: Trends with and without plan, by the means of models of landscape bionomics and ecological indicators of landscape or ecological-economic factors. It follows measures of specific and systemic therapy

5.4 Examples of Bionomic Application on Green Infrastructures

5.4.1 Urban Parks and Ecological Networks

In broad metropolitan areas, the presence of a consistent ecological network is indispensable. The bionomic efficiency of these networks depends on the presence of some *green corridors* linking the city centre with rural landscapes, better with a natural park area. In the case of Milan, the only corridor available to give this linking function is a rural belt (about 25 km) from the West side of the city towards the vast Ticino River Regional Park.

Creating an ecological network between the central Park of Milan (Simplon Park) and the Regional Park of Ticino should have been very important. Figure 5.4 (left) clearly shows the *urban heat island* (UHI) and the insufficient ecological role currently played by extant urban parks, whose BTC <1.98–2.03 Mcal/m^2/year (the average regional value) consequently unable to balance the urban desert. The comparison with the forest of Cusago (BTC ≈ 8.0 Mcal/m^2/year) is symptomatic.

These data results were profoundly meaningful compared with the ecological state of Milan, which was (2004–2005) – and still currently is (2017–2018) – very degraded: the mean BTC = 0.46–0.54 Mcal/m^2/year vs. an optimum of BTC = 0.65–0.75. Only parks with the right level of bionomic efficiency can upgrade such a degraded state. Note that if a park presents a BTC < 2.0, it remains below the regional BTC, and consequently it cannot contribute to balance environmental degradation: it does not work as a park!

To activate the mentioned green network, we should have better restored the vegetation of the urban parks and insert a new element (Ingegnoli 2011, 2015), with a good BTC value. This (lost!) opportunity might have been seized in 2004, when a competition took place for the building of a new quarter in the area of the old *Fiera di Milano* (35 ha, then enlarged to 41). This competition was won by the international team coordinated by Daniel Libeskind (New York) for the company CityLife where the author was asked to develop the guidelines following ecological principles (Consigliere 2004; Bollettino dell'Ordine degli Architetti e Paesaggisti di Milano 2009) for the new urban park (Fig. 5.4, right). Some years later, the Municipality of Milan enlarged the quarter, and the park reached 15 ha, but only a few of the suggestions given in the guidelines were adopted in the executive project. As a result, considering the mean BTC of this park, it failed to become a useful hub in the ecological network. The original (and unattended) park master plan followed the bionomic criteria, especially as for the goals related to (a) the breaking of UHI and (b) the assessment of a congruent ecological range (ER). To fulfil both objectives, local vegetation should have had (a) an evapotranspiration surface of at least 85–90% (Sukopp 1998) and (b) a BTC = 4.40–4.50 Mcal/m^2/year (according to modelling, such performance could have been met within 50–60 years), i.e. at least 40–45% of the park's surface should have been covered by urban forestry.

In Fig. 5.5, a park core area of 350 m width, BTC = 4.50, is capable of reaching the regional BTC up to an ecological range ER = 292 m on both sides. A conventional urban park (e.g. 15 ha, BTC = 1.8–1.9), expressing a balancing area of 14 ha,

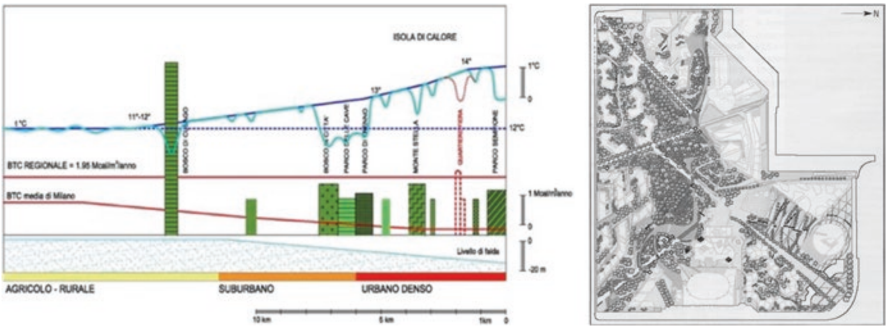

Fig. 5.4 (Left) A transect shows the UHI, amplifying the annual temperature from 12 to 14 °C and the insufficient BTC of the urban Parks (green), below the red line of regional BTC. CityLife Park (red in this transect) should have played an important role in the activation of the green network. (Right) The masterplan by Libeskind, which won the international competition in 2004, with the park designed by Ingegnoli (from Ingegnoli 2015)

should have brought to a balance area of 112 ha (+800%) if its BTC had been 4.40–4.50!

The making of an urban park with high BTC should have been remarkable effects and allow to abandon the Green Plan of Milan, based on the circular *Green Belt* model. This model is wrong (Fig. 5.6); in fact, as already pointed out by Sukopp (1998), the increase of circular green parks around the city amplifies the thermal difference (ΔT °C) between the centre and outskirts and increases the fine dust transport and deposition into the city centre. The UHI effect enlarges the process that becomes very dangerous to human health.

Remember that in 2008 a study, entitled *Exposure to Particulate Air Pollution and Risk of Deep Vein Thrombosis* mainly based on the hinterland of Milan, was published (Baccarelli et al. 2008), underlining a clear relationship between the risk of deep vein thrombosis and the level of particulate matter of <10 mm (PM10) in the year preceding the diagnosis. Note that this process begins at a level of PM10 = 12 mm/m^3/year, whilst the EU legal limit is PM10 = 40 mm/m3/year. This dangerous process seems to issue from macrophage reaction releasing many pro-inflammatory cytokines, especially IL-6, which may favour blood coagulation.

Other essential aspects of the urban park design depend on:

1. *Emergent properties principle*: even maintaining the same surface per component, if the parts of a system are assembled in a different configuration, they present diverse functionalities that are frequently not predictable.
2. *Form-function principle*: the interaction among elements is proportional to their contact margin and the interception of the energy flux or transport.

The results of the research carried out by CityLife and Comune di Milano (2010) following the mentioned principles are synthesised in Fig. 5.7 (master plan models). We add a variant of the model M10 as M15 (Fig. 5.7, right). The selection of the best form, from an integrated ecological point of view, needed the application of bionomic diagnosis, principles and methods.

So, the master plan M15, with oblong park and various offshoots, was analysed following bionomic principles (Table 5.8). This version considers one more parameter (the orientation of the park) because a *pivot* area (about 6 ha) was added at the northwestern edge of the old area. The orientation assessment has been carried out

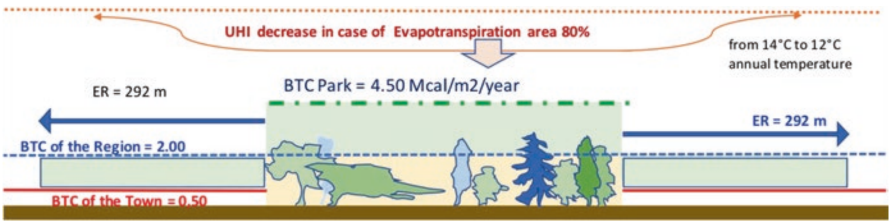

Fig. 5.5 The effects of an urban park on the Ecological Range of balancing influence (ER) and on the UHI (Urban heath island). Note that the width of this example is 350 m (park core area) and leads to ER = 292 m x 2

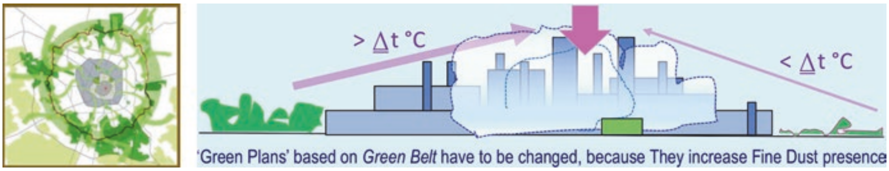

Fig. 5.6 Note that the increase of green parks around the city increases ΔT°C and so the fine dust transport and deposition in central town. The UHI effect enlarges this process, that becomes very dangerous to human health

concerning the axis of the ecological network that goes from Simplon Park to the Ticino River passing through the ex-Fiera quarter. The result of the ecological evaluation was 0.786, a decent value, yet still suboptimal.

Note, finally, that the current planning fails to recognise the importance and the need to activate the Midwest's ecological network or understand that, just to improve air quality, initiatives like *Eco-pass* or similar would be more effective if accompanied by parks with an appropriate form, placed in the proper locations of the city, and with a vegetation that is not only aesthetically remarkable but also ecologically efficient, i.e. parks built by applying environmentally friendly design criteria. Hopefully, the scientific-technical upgrade for the ecological design at the landscape scale, proposed by Ingegnoli (2015, Chapter 13), will be quickly adopted also by big cities.

5.4.2 Green Infrastructure Role in Altered Agricultural Landscapes

To investigate the use of GI within agricultural landscapes, the case study of Albairate, located about 20 km West of Milan within the Regional Agricultural Park of Milano Sud and adjacent to the Natural Regional Park of Ticino River, was considered by verifying its bionomic state. This landscape unit (LU) is subject to a protection regimen and mainly agrarian, has a surface of 1538.2 ha and hosts 4700 inhabitants.

Regional data of land use and land cover and the historical data dating back to years 1954 and 1989 were obtained from Dusaf-Ersaf (2015), but the vegetation analysis was made directly in the field and also based on the 1:25,000 scale maps of IGMI (Istituto Geografico Militare, 1900). The components of the LU present seven landscape apparatuses, from 1900 to 2016.

The most significant changes appear in the urbanisation process, with the residential apparatus shifting from 2.06% (1900) to 7.05% (2016) and the subsidiary one from 0.6% to 6.65%.

Conversely, the protective apparatus decreased from 8.11% in 1900 to 3.94% in 2016. As for the productive apparatus, cropland with trees disappeared, whilst grasslands and rice fields had an exceptional increase: from 0.32% to 6.76%

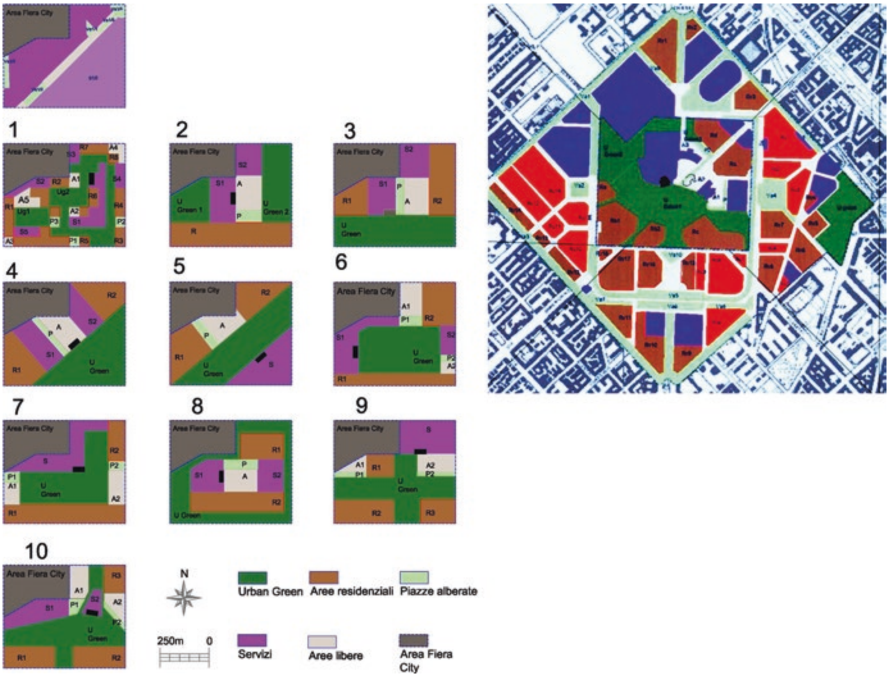

Fig. 5.7 (Right) Synthetic diagram of the better ten models considered in the research; (Left) M15, the model more similar to that approved in the PII (Program of intervention). Evaluation is equal to 0.80 for the parameters of neighborhood and 0.77 for those of LU, with a mean value of 0.786. Dark green = Urban Green; light green = tree-lined square; brown = residential with gardens; red = residential without gardens; violet = services and sheds; grey = free areas (from Ingegnoli 2015)

(grasslands) and from 0.97% to 9.94% (rice). The total productive apparatus decreased from 83.11% to 72.67% (−12.56% of the agrarian surface).

The surface covered by resilient apparatus is currently small but larger than before. The resistant apparatus appears unchanged (4.9%), but it suffered from a fast reduction after the war (1954). Even rivers and canals remained the same.

The main bionomic parameters HH and BTC present different changes: the human habitat is nearly constant, from 78.8% in 1900 to 79.4% in 2016, after experiencing a small growth phase in the medium period; the vegetation capacity (BTC) shows an evident decrease, from 1.24 to 1.02 Mcal/m^2/year (−17.7%): this is not a good sign.

About one-fifth of this territory is cultivated following organic farming, more than the regional average. Two organic farms (62.5 ha) were compared with two conventional ones. Focusing the two bionomic functions BTC and CBSt, the results (Vaglia and Samprogno 2017) indicate a better ecological performance of organic farming, particularly evident when comparing the CBSt values (organic farming:

Table 5.8 Ecological evaluation of the CityLife model M15

Ecological parameters of the quarter	Normal	M 15	Δ15	Score
Dimensione frattale verde (D)	1.5–1.8	1.69	0	2
Connessione verde (α + γ)	0.75–1.15	0.91	0	2
Core area verde (%V)	45–75	35.2	21.8	0.65
Rapporto A/P verde	30–60	26.9	10.3	1.31
Contatti del V con esterno (%pV)	20–60	31	0	2
Area costruita/perimetro V (m^2/m)	45–90	34.1	24.2	0.63
Diversità strutturale (ψ)	3.6–9.1	9.5	4.3	1.72
Bilancio climatico (ΔT °C)	0–0.75	0.67	0	2
Biopotenzialità V quartiere (Mcal/m^2/a)	0.75–0.9	0.75	0	2
Biopotenzialità V parco (30 a)	1.6–1.9	1.53	4.4	1.75
Somma scores				*16.06*
Diagnostic index Q	0.85–1			0.803
Ecological parameters of the landscape unit	Normal	M15	Δ15	Score
Dimensione frattale verde (D) UdP	1.45–1.75	1.57	0	2
Connessione verde (α + γ) UdP	0.5–0.9	0.46	8	1.47
Biopotenzialità UdP	0.6–0.8	0.49	18.3	0.78
Raggio di influenza ecologica (min)	310–500	194	37.4	0.52
Source/sink (% transetti)	25–75	29	0	2
Grana giardini/grana gegerale	4.0–6.0	5.6	0	2
Orientamento parco (% core area)	45–60	55	0	2
Somma scores				*10.77*
Diagnostic index LU	0.75–0.90			0.769
General diagnostic index	0.80–1.0			0.786

crop fields = 16.5, pastures = 13.4; conventional farming: crop fields = 8.3, pastures = 10.7).

Moreover, even if forest has partially recovered, local organic farming is not sufficient to maintain the examined LU in a healthy state, mainly because of the disruption of the tree corridor network and the scarce bionomic efficiency of the local forests (Table 5.9). Note that, even if the soil humus efficiency (RxN) is the same, the mean BTC of Albairate forests is 5.27 vs. 6.33 Mcal/m^2/year of the Milan hinterland, i.e. lower than the standard value recorded for the native temperate forests (BTC = 7.38).

Applying the diagnostic model HH/BTC to the case study of Albairate, the results confirm the alterations. However, they especially indicate the recent drastic change of direction of the movement of this complex system (Fig. 5.8): from at least 90 years strictly near the curve of normality (green) to an abrupt change of direction after 1990, going out the tolerance threshold (dotted), with BF = 0.83, i.e. altered. This drastic change was not related to an extraordinary event: it corresponds to the exceeding of a cultural limits after a period of small but continuous changes (Fig. 5.1), whose interaction and redundancy triggered a severe change (emergent property principle).

The disruption of the tree corridor network needs an explanation. In Fig. 5.9, we compare the maps of this network in 1954 (left) and 2016 (right). The differences are striking:

- In 1954, the network was formed by 440 nodes and 669 links. It covered 114.99 ha, and the BTC was higher than today, due to the frequency of autochthonous species such as *Quercus robur* L. and *Alnus glutinosa* (L.) Gaertn. So, BTC = 3.20 Mcal/m^2/year, and the energy flux of maintenance was 3.3.68 × 10^6 Mcal/year;
- In 2016, the same network presented 133 nodes and 405 links. It covered 50.68 ha, and the BTC was reduced to BTC = 2.90 Mcal/m^2/year. Consequently, the energy flux resulted in 1.47 × 10^6 Mcal/year.

The surface occupied by tree corridors experienced a loss of 55.7% (115 vs. 51 ha), but the decrease of the bionomic flux of maintenance of the network was 60% (3.68 vs. 1.47 × 10^6 Mcal/m^2/year)! This fact is due to the reduction of the traditional seminatural tree corridors dominated by *Quercus robur*, *Alnus glutinosa* and *Ulmus minor* Mill. The corridor has a width > 12 m, a threshold size value to host plant and animal species in the inner area, as underlined by Forman and Godron (1986). Today, these corridors have been frequently replaced by monotonous *Populus* × *canadensis* Moench (an alien hybrid tree) rows, and their width reduced to less than 12 m. The destruction of the tree corridor network leads to out-of-scale dimensions of the crop fields, one of the basic features of intensive industrial agriculture, thus overcoming a threshold value, to a new lower metastability level and system reorganisation.

Today, we cannot adequately define too many agrarian landscapes as landscapes, due to their absurd homogeneity. These environmental changes follow neoclassical economic paradigms, which reduce the economic value of these fields to the amount of labour required. Therefore, (a) the *ecological services* are only perceived from the perspective of human society and are very limited; consequently, (b) the market value of the lots subject to intensive agriculture are low (one order of magnitude), and their conversion in urbanised lots sounds acceptable (Ingegnoli et al. 2018).

One of the most urgent and effective therapeutic actions to be applied to rehabilitate the agricultural landscapes appears the restoration of crop field connectivity through the implementation of a crucial green infrastructure: the tree corridor network.

Tree corridors positively affect adjacent crop fields, mainly on two aspects: (1) the protection from extreme climatic events and (2) the achievement of a sufficient bionomic balance of BTC. In the first case, a dense windbreak may protect crop

Table 5.9 Comparison between the forests of Albairate and the hinterland of Milan

Forests of Milan hinterland	HC	PB/10	BTC	CBSt	RxN
Albairate mean forest	19.38	26.80	5.27	14.36	34.44
Milan hinterland forests	23.50	43.37	6.33	24.70	34.14

HC canopy height, *PB* plant biomass volume, *RxN* soil humus condition

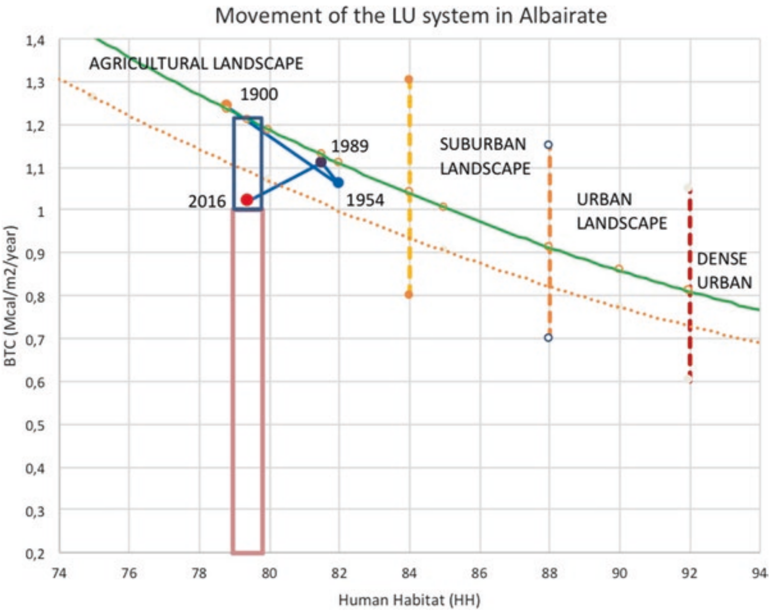

Fig. 5.8 The transformation of the LU of Albairate since 1900. Note the movements of the complex system for at least 90 years strictly near the curve of normality (green). Only recently the direction went out of the tolerance (yellow dotted)

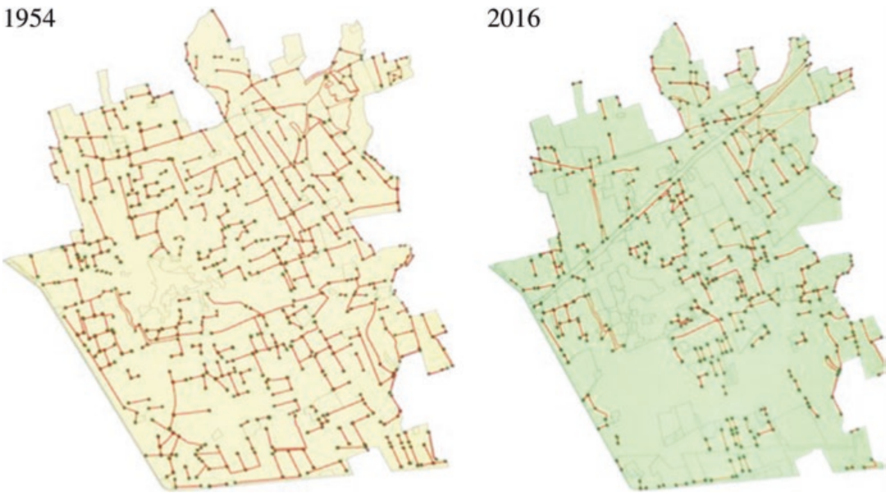

Fig. 5.9 Evident big changes in ecological network of the tree corridors in Abairate from 1954 to 2016. Note that to the disruption of connectivity and circuitation of the network, we must add the increased occurrence of allocthonous tree species, e.g. *Robinia pseudoacacia* and *Populus hybrida* in substitution of *Quercus robur* and *Ulmus campestris*

fields up to a distance of approximately five to six times the height of the trees (Forman and Godron 1986), i.e. 75–120 m according to European standards. In the second case, a 18-m-wide and 20-m-high tree corridor having a BTC = 3.60 Mcal/m^2/year brings to an ecological range of balancing influence ER = 54 m, becoming ER = 67.5 m if BTC = 4.20. This second process is about one-third more restrictive, but if the corridor becomes a forest strip (e.g. width = 25 m, BTC = 6.50), the ER = 165 m. A tree corridor influence going currently from 54 to 165 m, the crop fields limited by hedgerows may reach dimensions doubling these values; considering a 10% of tolerance, we may reach field width of about 120–360 m, one order of magnitude less than the current imposition of industrial agriculture.

These results confirm and enhance what is already underlined in Fig. 5.8: the examined LU of Albairate, despite its belonging to the Regional Agricultural Park of South Milan, reveals a particular disease.

If we plot the relationships between the LU bionomic dysfunction (BF = 0.83) and the mortality rate (MR = 9.8/1000 inhabitant/year) and compare this situation with BF/MR correlation (Ingegnoli and Giglio 2017), the result is alarming (Fig. 5.10): ΔMR = 9.80–7.41 = 2.39/1000.

Let us evaluate the risk factor from the BTC/HH Model, ruling out the 24% of risk related to population age:

$$\Delta MR_{\mathrm{BF}} = \Delta MR \times 76\% = 2.39 \times 0.76 = 1.8164 \times 10^{-3}$$

The population of Albairate is 4708 inhabitants, so it is possible to estimate the premature yearly death risk:

$$4.71 \times 1.8164 / 1000 = 8.53 \text{ premature deaths / yr}$$

Note that an MR = 9.80 in a municipality counting 4700 inhabitants brings 46 deaths/year, and the ratio 8.53/46 = 0.191 is very high. In the Hinterland of Milan, this ratio is generally half of those values. So, probably the premature death risk is due to two components: (a) the environmental stress, dependent from the bionomic alteration of the LU, and (b) the pollution due to the synthetic chemical compound use for intensive crop cultivation (herbicides, pesticides, fertilisers, etc.).

Once assessed the bionomic diagnosis of alteration of the LU of Albairate, considering that a therapy should follow the diagnosis, a short mention of the main criteria of landscape rehabilitation must be suggested. Landscape bionomics plays a crucial role because their principles and methods can address the goals and the monitoring tools of any projected territorial master plan.

As exposed before, this LU presents the following main syndromes:

1. Alteration of the ratio ‘normal BTC/surveyed BTC’ beyond the tolerance threshold, i.e. BF = 0.83.
2. Presence of transformation deficit TD = 12.14% (2.636×10^{11} Kcal).
3. Disruption of the local ecological network, both in terms of linear extension and efficiency.

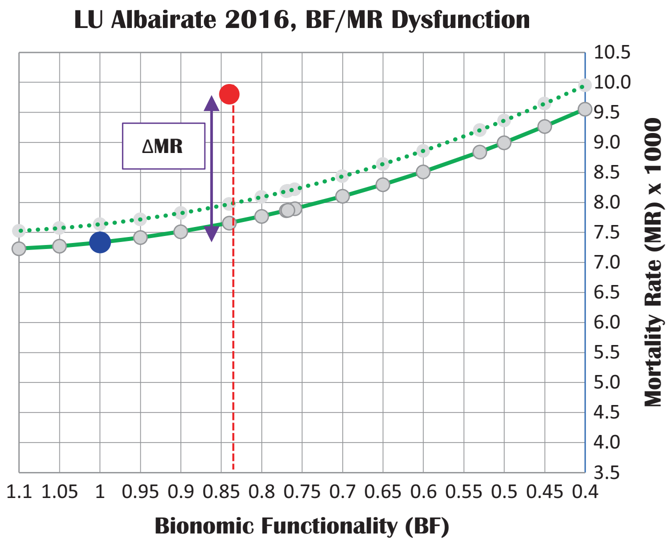

Fig. 5.10 Alteration of an agricultural landscape. A clear dysfunction shown in BF/MR model through the distance ΔMR from present mortality rate 9,8 (red dot) to the normal condition (blue dot)

4. Weak BTC and low CBSt of remnant forest fragments which also show an inappropriate distribution patterns.
5. Loss of extensive crop fields and exceeding homogeneity of cultures.

The diagnostic index DI of Albairate presents an altered condition, more dangerous than the one shown by the BTC/HH control, because of the number of parameters. This index, conceptually similar to BF but measured on a group of bionomic parameters (Ingegnoli 2015), experiences further degradation after 2010, going from low alteration state (Fig. 5.8) to a full dysfunctional state (e.g. the construction of a new provincial road is planned).

The effectiveness of bionomic control procedures is significant and allows to evaluate the direction and the level of the therapeutic actions. Therefore, the main goal of territorial planning is to invert the ongoing negative trend. To reach the needed blue goal, the following processes should be implemented:

1. To improve the local forest fragments both in terms of CBSt (Ingegnoli 2013) and cover through new forest plantations in the southern border of the LU, so that CBSt passes from 14.40% to 36.00% and the forest cover from 4.85% to 9.00.
2. To restore the tree corridors, both in terms of species used for forest plantation and network connectivity, first between the old and the new forest plantation, so that ER became 50 m and the length of the corridor reached the values of 50 years ago.

3. To promote organic farming, both in terms of surface and of ecological quality, first of all applying the EBP cultivation methodologies (i.e. crop fields based on number of inhabitants).
4. To carry out a SEA control of the development of local territory, following the bionomic suggestions exposed in Table 5.5.
5. To apply the emergent properties and form-function principles (see paragraph *Urban Parks and Ecological Networks*) to the control of landscape elements and apparatus configuration, particularly considering the design of an ecological territorial plan.

Summarising, we must underline the capability of landscape bionomics to help and control, step by step, the elaboration of a therapeutic ecological planning of the territory.

5.5 Conclusions

The case studies presented in this contribution show that environmental degradation, perceived mainly in urban and suburban areas, should be recognised even in agricultural landscapes, where green infrastructures must be carefully evaluated, planned and controlled. Applying this process, the crucial importance of the professional figure of the *ecoiatra* stands out. In fact, we need specific diagnostic skills to evaluate the bionomic and ecological state of a landscape unit following a medical approach: the environmental disease brings to human disease.

The recent signing of planetary health (Horton and Lo 2015) is impressive, especially after the foundation of Planetary Health Alliance (PHA), a research consortium of universities, NGOs and other partners working to support the growth of planetary health, a transdisciplinary field focused on human health and the impact of human activities causing disruptions of Earth's natural systems.

In this context, green infrastructure (GI) and vegetation science (VS) may play a key role in evaluating and restoring our altered landscapes but only following the advanced theories and methods proposed by bionomics. This purpose is particularly useful in upgrading VS, without which GI risks to be reduced to a landscape architecture tool, mostly following mere visual concepts.

We hope that this contribution should be beneficial to all people who fight to improve man/nature relationships.

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Chapter 6
Roof Greening with Native Plant Species of Dry Sandy Grasslands in Northwestern Germany

Kathrin Kiehl, Daniel Jeschke, and Roland Schröder

Abstract Green roofs can mitigate negative environmental effects of urban densification to some extent, but they are often covered by species-poor *Sedum* mixtures with a low value for biodiversity. By combining a habitat template and a seed-provenance approach, we review the suitability of plant species from regionally occurring dry sandy grasslands (*Koelerio-Corynophoretea*) for extensive roof greening in northwestern Germany. Since 2015, we have studied the effects of species introduction on vegetation dynamics on experimental mini-roofs. Treatments included sowing seeds of regional native origin in two densities (1 g and 2 g/m^2) and the transfer of raked material from an ancient dry grassland area classified as Natura 2000 site. The applied raked material contained diaspores of 27 vascular plant species (including seven threatened species) and vegetative fragments of grassland-specific mosses and lichens. Since 2018, we have tested more species-rich seed mixtures in a large-scale experiment on a roof of 500 m^2 with different engineered green-roof substrates and layering. In 2019, a green roof of 10,200 m^2 was established in cooperation with a local enterprise to support regional native biodiversity. In this chapter, we summarise the most important results of our studies and discuss how to support regional native biodiversity on green roofs.

Keywords Extensive green roof · Dry grassland · *Koelerio-Corynephoretea* · Plant species transfer · Seed · Raked material

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_6

6.1 Introduction

Urban green infrastructure with multifunctional ecosystem services includes not only parks, gardens, alleys, brownfields, agricultural areas and urban forests but also buildings with green facades and/or green roofs (Francis and Lorimer 2011; Dennis et al. 2018). Because of ongoing urbanisation and densification due to building activities, however, the spatial extent of urban green infrastructure is declining in many cities even though there is an increasing need for ecosystem services related to climate change adaptation (Zölch et al. 2016). Green roofs can mitigate negative environmental effects of urban densification to some extent, for example, through stormwater retention, regulation of temperature extremes for buildings and reduction of fine dust pollution and noise (Oberndorfer et al. 2007; Rowe 2011; Berardi et al. 2014). Green roofs offer more diverse habitats for urban biodiversity than non-vegetated roofs (Brenneisen 2006; Williams et al. 2014), but conventional extensive green roofs (EGRs) are often covered by species-poor mixtures of non-native *Sedum* or *Phedimus* cultivars with a low value for native biodiversity. Some of these non-native plant species can even become problematic in natural and seminatural vegetation because of their invasive behaviour (Rusterholz et al. 2013; Kinlock et al. 2016). In addition, more diverse plant species mixtures can improve green-roof ecosystem multifunctionality compared to species-poor vegetation dominated by succulents (Lundholm 2015).

If green roofs become elements of the urban ecological network, they should provide habitats not only for common generalist species, like honeybees, but also for native insects occurring in urban grasslands and other remnants of ecosystems typical for the respective landscape (Schröder and Kiehl 2020a). Green roofs with higher plant diversity and diverse substrates can provide more valuable habitats for flower-visiting invertebrates than simple *Sedum* roofs (Williams et al. 2014; Witt 2016; Kratschmer et al. 2018). In summary, this means that it is better to use species-rich mixtures of regionally typical native plant species to support native biodiversity (see also Kiehl et al. 2014).

During the last decades, seminatural dry grasslands have become rare in Europe, and many dry grassland species are endangered throughout Europe due to land-use intensification, aerial nitrogen deposition, afforestation or direct destruction (Dupré et al. 2010). Therefore, ecological restoration of species-rich grasslands for habitat-specific native plants and insects is increasingly needed (Kiehl et al. 2010). In Germany, the formerly widespread dry sandy grasslands of the class *Koelerio-Corynephoretea* and associated heathlands with their specialised stress-tolerant species have become very rare (Finck et al. 2017). With their extreme environmental conditions, green roofs may provide appropriate secondary habitats for dry grassland species (Bates et al. 2013; Catalano et al. 2016) as well as urban brownfields do (Schadek et al. 2009; Schröder and Kiehl 2020b).

This paper reviews different techniques for the design of extensive green roofs (EGRs) in northwestern Europe by using native plant species of regional provenance. In our studies, we combine Lundholm's (2006) habitat template approach and the seed-provenance approach used in Germany for native seed production of herbaceous plants and ecological restoration (Bucharova et al. 2019). We focus on the establishment of plant species of dry sandy grasslands referred to the phytosociological class *Koelerio-Corynephoretea* and related dry grassland types on EGRs. First, we describe which types of green roofs and which substrates are suitable for roof greening with native grassland species. Second, we give an overview of different measures for the establishment of native grassland species on EGRs. Finally, we present examples for roof greening with dry sandy grassland species in northwestern Germany and summarise conclusions and perspectives for future urban development.

6.2 Extensive Green-Roof Layering and Substrates for Native Grassland Species

Finding the ideal green-roof layering, including substrate composition and depth, is challenging for extensive roof greening. EGR design generally has to deal with the requirement of low weight, taking into account building statics whilst simultaneously offering sufficient water storage for plant growth (Catalano et al. 2018; FLL 2018). Additionally, the physical structure and substrates of green roofs should allow not only water storage for drought periods but also appropriate drainage to prevent waterlogging over longer periods. Drainage layers, which also fulfil water storage functions, often consist of engineered plastic mats but can also be realised by coarse draining substrates. Typically, EGRs are designed with substrates of 4–20 cm depth that contain low-weight mineral aggregates mixed with small amounts of organic material. Depending on the specific characteristics of the substrate (different mineral components, amount of organic matter) and the type of the water storage/drainage layer, this design results in additional weight on the roof of about 100 to 200 kg/m^2 (at the maximum water-holding capacity).

Although they are adapted to dry soil conditions, many plant species from native dry grassland vegetation of northwestern Europe are more susceptible to drought than species of the Crassulaceae family (Ellenberg et al. 2001). In our experiments, a substrate depth of 8–9 cm combined with an underlying drainage and storage mat (Aquatec® AT45, ZinCo GmbH, Germany) filled with the same substrate led to a good establishment of sown regionally typical dry grassland species (see the examples shown in the following paragraph). The substrates included mineral components like lava, pumice, expanded clay, recycled bricks and organic matter (compost) as a plant nutrient source. A low organic matter content and therefore low nutrient supply are favourable for drought tolerance of plants (Molineux 2010; Nagase and Dunnett 2011). Depending on the specific quality, an organic matter content of about 10% (related to volume) seems appropriate for sustainable plant growth (Nagase and Dunnett 2011; Schröder and Kiehl 2020a). Our EGR design exhibited a maximal water-holding capacity of 28–42% (volume) and a maximal weight (water saturated) of 98 kg/m^2 (8 cm substrate depth) to 146 kg/m^2 (9 cm substrate). Slight irrigation during vegetation establishment can be necessary during extreme drought periods even in the temperate Atlantic climate because spring and summer droughts have become more frequent recently due to climate change.

To promote biodiversity on green roofs, it is suitable to increase habitat diversity by using different substrate depths and materials (e.g. gravel, sand mounds, dead wood) on the same roof (e.g. Baumann and Kasten 2010; Bates et al. 2013; Thuring and Grant 2016; Catalano 2017). In Switzerland, even natural soils of varying depth are used for green roofs larger than 500 m^2 (Brenneisen 2006). Varying substrate types and depths can be combined then with plant species adapted to more or less xerophytic conditions (see also example 3).

Standard EGR substrates often lack potentially mutualistic soil microorganisms. In a pot experiment, we tested whether inoculation with arbuscular mycorrhizal fungi (AMF) might increase plant performance and drought resistance of native dry grassland species (Schröder et al. 2019). Over 88 days of moderate drought conditions, inoculated plants produced more aboveground biomass and more flowers compared to controls. After the complete stop of watering, however, the larger plants wilted earlier than the control plants. These results indicate that further research on the effects of environmental stress, mycorrhiza and other soil amendments is necessary before practical recommendations can be derived (see also Molineux et al. 2017; Xie et al. 2018).

6.3 Selection of Native Plant Species and Techniques for Their Introduction

Most plant species that are able to reach green roofs on their own are common wind-dispersed ruderal species (Vanstokkem et al. 2019). This means that as in ecological restoration of seminatural grasslands (Kiehl et al. 2010; Török et al. 2018), active introduction of habitat-specific target species is necessary to overcome the dispersal limitation of grassland species on green roofs.

To enhance the value of extensive green roofs for native biodiversity, we combined a habitat template approach (Lundholm 2006; Lundholm and Walker 2018) with the German concept of regionalised native seed production for ecological restoration (Bucharova et al. 2019). We aim to create diverse mixtures of regionally typical plant species with high value for insects. We identified vascular plant species typical for this habitat type based on the phytosociological literature about dry grasslands in northwestern Germany (e.g. Jeckel 1984; Schröder 1989; Preising et al. 1997) and on our own field surveys on vegetation species composition and soil conditions carried out in remnant areas of ancient dry grassland. Because of the sandy and acidic to neutral soils in the northwestern German lowlands, most of the species belong to the phytosociological class *Koelerio-Corynephoretea* and to allied vegetation types of the class *Nardo-Callunetea* (syntaxonomy according to

Dierschke 2017). Some species of mesophytic vegetation units of the class *Molinio-Arrhenatherea* and dry ruderal communities (species of the alliance *Dauco-Melilotion* and few species of the class *Stellarietea*) were also found. We used Ellenberg indicator values on moisture and nitrogen (Ellenberg et al. 2001) for the further selection of species that are potentially suitable for EGR. We included not only stress-tolerant perennials but also annual species in our seed mixtures to promote a quick establishment, early flowering aspects and the ability to recolonise gaps after disturbance (cf. van Mechelen et al. 2014). For the selected species, we checked whether seeds from regional seed production were available. For some species not available on the market, a cooperating seed producer started the propagation of seeds within the seed-provenance zone 1 (northwestern German Lowland). For a few other species, hand collections were necessary for our experiments.

On conventional EGRs, plant species are usually introduced by seeding, spreading vegetative plant parts (especially *Sedum/Phedimus* shoots), laying turfs or vegetation mats and sometimes also planting (Catalano et al. 2018; FLL 2018). In ecological restoration, target species can be introduced not only by sowing native seeds but also by direct transfer of diaspore-containing plant material that is harvested on species-rich donor sites with environmental conditions similar to the receptor site (Kiehl et al. 2010; Scotton et al. 2012). Freshly cut green hay or seeds harvested by threshing the vegetation of ancient grasslands on site have already been used in the 1990s on a few roofs in southern Germany, e.g. at the Bavarian Environment Agency in Augsburg (LFU 2019). Roof greening by hay transfer has also been tested in Switzerland and was included in the Swiss roof greening norm (SIA 2013; Catalano et al. 2018).

In dry sandy grasslands, where mowing with large machines is often not possible because of low biomass production and protected landscape elements, like inland dunes, the use of seed-containing raked material collected manually by rakes is a suitable method to introduce high numbers of target species from species-rich donor sites to receptor sites with dry and nutrient-poor soil conditions (Řehounková and Řehounek 2011; Storm et al. 2016). With this method, not only seed-containing litter but also vegetative parts from low-growing vascular plants (e.g. native *Sedum* species), mosses and lichens can be transferred successfully to restoration sites (see also Jeschke 2008, for calcareous grasslands). To the best of our knowledge, the transfer of raked material had not been used in roof greening before we started our first experiment in 2015 (Schröder and Kiehl 2020a). We collected raked material containing seeds, litter, mosses, lichens and vegetative parts of some grass and forb species in autumn, when seeds had been shed by most dry grassland species. The material was harvested in ancient grasslands and heathlands (NATURA 2000 areas and other protected areas) in Lower Saxony, Germany.

6.4 Examples: Dry Sandy Grasslands as a Habitat Template in Northwestern Germany: From Experimental Mini-Roofs to Large-Scale Roof Greening

Example 1: Effects of Different Seed Densities and Species Introduction by Using Raked Material on Vegetation Dynamics on Experimental Mini-Roofs In spring 2015, we started an experiment at the campus of Osnabrück University of Applied Sciences (Lower Saxony, Germany) with regionally typical native plant species (see above) on 15 experimental mini-roofs of 2 m^2 each. Our study aimed to test the effects of a seed mixture of 25 vascular plant species that was applied on experimental plots (EP) in two different sowing densities (EP1: 1 g/m^2, EP2: 2 g/m^2) and in combination with diaspore-containing raked material (EP3) from an ancient dry sandy grassland near Osnabrück (NATURA 2000 site ʻAchmer Sand'). Each of the three treatments had five replicates. The substrate composed for this experiment contained lava, sand, pumice and xylit and was very nutrient-poor (for details, see Schröder and Kiehl 2020a). Vegetation analyses were carried out yearly from 2015 to 2018.

At the beginning of the experiment, a germination test for seeds present in a sieved fraction of the raked material was carried out during five weeks in a greenhouse (18 °C). Vascular plants emerged on sterile standard potting soil. Mosses and lichens were identified after they had established within the experimental plots as well as additional vascular plant species which had not germinated in the greenhouse due to lack of stratification. The germination test and vegetation relevés in all experimental plots indicated that the raked material contained seeds of 27 vascular plant species, out of which 23 species established within the experimental plots (Table 6.1). In addition, several vascular plant species that had not been detected in the germination test in the greenhouse established only in plots that had received raked material and are hence included in Table 6.1. Six moss and seven lichen species from the donor site in the ancient grassland were found in plots that had received raked material (EP3, Table 6.2). Nine species (seven vascular plant and two lichen species) are relevant for nature conservation because of their Red List status (Tables 6.1 and 6.2, Garve 2004; Hauck and de Bruyn 2010).

Until early summer 2016, 80–88% of the sown species established, and vegetation cover increased up to 60–70%; seeding density had no significant effect (Schröder and Kiehl 2020a). After stopping initial watering, several weeks of severe drought in late summer 2016 led to a strong decrease in the cover of vascular plants in 2017. Total establishment rates of the sown species hence decreased to 40–48% in the two seeding treatments compared to 60% in the plots with raked material. Interestingly, the decrease of vascular plants' cover was less pronounced in the plots with additional raked material, where grassland-specific cryptogams showed 33.8% (mosses) and 20% (lichens) cover in 2017 (Schröder and Kiehl 2020a). In 2017, vascular plants covered 22.3% in plots with raked material, which was significantly higher than in the seeding treatments, where their cover reached only 9.3% or 8.0%,

Table 6.1 Vascular plant species in the raked material collected in an ancient dry grassland detected by germination test (last column) and in the experimental plots (EP). Treatment EP3 received seeds + raked material and EP1 and EP2 seeds only. Threatened species listed in the Red List (RL) of Lower Saxony or the Lower Saxonian hill region are marked by * (Garve 2004), whilst nomenclature follows Jäger (2011)

Taxon	EP3: seeds + raked material	EP1, EP2: seeds only	Germination test
Vascular plant species typical for dry grassland			
Agrostis capillaris	x	x	x
*Aira praecox**			x
Arabidopsis thaliana	x		
Cerastium arvense	x		x
Cerastium semidecandrum	x	x	x
Corynephorus canescens	x	x	x
Crepis capillaris			x
*Dianthus deltoides**	x	x	x
Festuca brevipila	x		
Festuca filiformis	x	x	
*Filago minima**	x		x
Geranium molle			x
Hypericum perforatum	x	x	x
Hypochaeris radicata	x	x	x
*Jasione montana**	x	x	x
Leontodon saxatilis	x		x
*Ornithopus perpusillus**	x		x
*Petrorhagia prolifera**	x		
Pilosella officinarum	x		x
Plantago lanceolata	x	x	x
Rumex acetosella	x	x	x
Sedum acre	x	x	x
Trifolium arvense	x	x	x
Vicia angustifolia	x		
*Vicia lathyroides**	x		
Other vascular plant species			
Betula sp.			x
Chenopodium album			x
Conyza canadensis			x
Epilobium ciliatum			x
Epilobium hirsutum			x
Oenothera sp.			x
Salix sp.			x
Taraxacum sect. *Ruderalia*			x
Trifolium repens	x		

For methodological details, see Schröder and Kiehl (2020b)

Table 6.2 Mosses and lichens detected in the experimental plots (EP) that had received raked material collected in an ancient dry grassland. Threatened species listed in the Red List (RL) of Lower Saxony are marked by * (Hauck and de Bruyn 2010). None of the species was found in the plots with seeds only. Nomenclature follows Frahm and Frey (2004) for mosses and Hauck and de Bruyn (2010) for lichens

Taxon	EP3: seeds + raked material
Mosses	
Brachythecium albicans	x
Cephaloziella sp.	x
Hypnum cupressiforme	x
Polytrichum juniperinum	x
Polytrichum piliferum	x
Scleropodium purum	x
Lichens	
*Cetraria aculeata**	x
Cladonia rei	x
Cladonia furcata	x
Cladonia scabriuscula	x
Cladonia humilis	x
Cladonia subulata	x
*Peltigera rufescens**	x

For methodological details, see Schröder and Kiehl (2020b)

respectively ($p < 0.01$, ANOVA and post hoc Tukey's HSD). Because some of the vascular plants regenerated from the seed and bud bank, their cover increased further in 2018 (18.2–21% in seeding plots, 26.1% in plots with raked material). Our results indicate that the mostly pleurocarpous moss species and the lichen species introduced by raked material (Table 6.2) provided safe sites and facilitated the survival and growth of vascular plants (see also Heim and Lundholm 2014; Heim et al. 2014). In contrast, only ruderal acrocarpous mosses (e.g. several *Bryum* species) and no lichens were present in the two seeding treatments (Schröder and Kiehl 2020a).

Due to the very low organic matter and nutrient content of the substrate, vascular plant species from our seed mixture with 25 species did not establish optimally under severe drought in the first experiment. Hence, we started a second mini-roof experiment in 2016 with a modified seed mixture containing 28 dry grassland species to test for the effects of different substrate types. Here, survival rates of the sown species were higher, and more pronounced blooming events could be observed even during the very dry year of 2018 (Fig. 6.1).

Example 2: Effects of Different Restoration Measures on the Establishment of Dry Grassland Species on Different EGR Types In 2018, we started roof-greening experiments on 500 m² roof area of the library building of the Faculty of Agricultural Sciences and Landscape Architecture of Osnabrück University of Applied Sciences. We tested the establishment success of a more species-rich seed mixture with 43 native plant species of regional provenance on three differently designed EGRs concerning substrate, layering and water-holding capacity (Table 6.3). On each of the three roof types, we compared three different greening measures (each with five replicates), i.e. (i) seeding only, (ii) seeding plus mycorrhiza

Fig. 6.1 Flowering of *Silene vulgaris*, *Thymus pulegioides* and *Hypericum perforatum* in the second mini-roof experiment at the end of June 2018 (in the background: *Festuca filiformis*). (Photo credit: Daniel Jeschke)

Table 6.3 Characteristics of the three differently designed EGR types and procedures adopted for species introduction. Substrates and layering were prepared in cooperation with ZinCo GmbH, Germany. The seed mixture was the same on each roof and included 43 vascular plant species. WHC: water-holding capacity

	Type I (moderate weight, high WHC)	Type II (low weight, high WHC)	Type III (low weight, low WHC)
Substrate depth (above drainage layer)	9 cm	8 cm	8 cm
Drainage/water storage layer	Aquatec® AT 45	Aquafleece AF 300 Floraset® FS 50	Aquatec® AT 45
Weight (water saturated)	146 kg/m^2	98 kg/m^2	100 kg/m^2
Maximum water storage capacity	40 l/m^2	42 l/m^2	28 l/m^2
Introduction of native plant species	Treatments: Seeding, seeding + mycorrhiza inoculation, transfer of raked material (each treatment n = 5 per roof type)		

inoculation and (iii) introduction of raked material from the NATURA 2000 site 'Achmer Sand' (without seeding). Seeding and application of raked material were carried out in September 2018. In May/June 2019, the total establishment rates of the 43 sown species reached 88.4–90.7%. In germination tests on sterile potting soil running for 1 year (including stratification of the five cloth-covered germination boxes in winter outside), seedlings of 44 vascular plants were detected. In all 15 experimental plots that had received raked material, 64 vascular plant species from the donor sites were found. The total species richness of plots with raked material

Fig. 6.2 Green-roof experiments started in late summer 2018 testing the establishment of native dry grassland species on EGR types I (left) and III (right) at the library and lecture building of Osnabrück University of Applied Sciences (for details, see Table 6.3). Flowering aspect of annual species (e.g. *Viola tricolor*, *Papaver argemone*) in May 2019, eight months after sowing. (Photo credit: Daniel Jeschke)

reached 41 on roof type I, 45 on roof type II and 53 on roof type III. In plots of all treatments (incl. seeding), 85 species were found altogether. Many species flowered already in the first vegetation period with a flower aspect dominated by annuals in May (Fig. 6.2), followed by perennial species like *Dianthus deltoides*, *Jasione montana* or *Pilosella officinarum* in summer 2019.

Mean cover of vascular plants reached 44.6–45.0% on seeding plots and 36.5–42.7% on plots with raked material on roof types I and II with higher water-holding capacity. In contrast, vascular plant cover was lower (seeding: 30.4%, raked material: 22.5%) on roof type III with low water-holding capacity. The cover of cryptogams was below 0.5% on all seeding plots in the first vegetation period, whereas living mosses covered on average 19.1–28.0% and lichens 10.7–17.0% on plots that had received raked material.

Example 3: Large-Scale Roof Greening in Practice: A Local Enterprise Supports Regional Biodiversity In autumn 2019, we started a large-scale roof-greening project in Wagenfeld, Lower Saxony, on a large roof of 10,200 m^2 subdivided in two outer parts of 4500 m^2 each with different substrate depths (see below) and a middle part of 1200 m^2 with 15 cm substrate (Fig. 6.3). The green roof was built on a large production and storage building of a local enterprise interested in ecological restoration and nature conservation. Funding was provided by the enterprise itself (Friedrich Lütvogt GmbH & Co. KG), the European Regional Development Fund and the federal state of Lower Saxony (grant No. ZW 6-85039365).

Fig. 6.3 Construction of a 1 ha-wide green roof with different substrate depths (8–15 cm) and biodiversity elements in Wagenfeld, north-western Germany, in autumn 2019. Dry grassland species were sown on shallow substrates and mesophytic species on areas with higher substrate depth. (Photo credit: Hermann Tegeler, provided by Friedrich Lütvogt GmbH & Co. KG)

To increase habitat diversity (see above), the different roof parts were designed with substrate depths from 8 to 15 cm to simulate different habitat types of dry sandy grasslands, which occur on inland dunes in the region. The two large roof parts with shallow substrates of 8 to 10.5 cm (53% of the area) were mainly sown with two seed mixtures. Most of this area was sown with a mixture of 35 drought-tolerant vascular plant species typical for dry sandy grasslands (for species selection, see above). On 500 m^2 (i.e. 5.9% of the area), additional species (e.g. *Aira caryophyllea*, *Filago minima*, *Spergularia rubra* and *Teesdalia nudicaulis*) were sown, for which hand-collected seeds were available only in a limited amount. The seed mixture for the roof part with 15 cm substrate depth (in the middle, see Fig. 6.3), and for small 'mounds' on the two other roof parts with up to 15 cm substrate, contained 43 vascular plant species, including also some mesophytic species characteristic of the class *Molinio-Arrhenatheretea*, like *Leucanthemum vulgare*, *Knautia arvensis* and *Silene latifolia*. In addition, we used raked plant material from regionally occurring ancient dry sandy grasslands on 5% of the whole roof area, which contained seeds of vascular plants as well as vegetative fragments of mosses and lichens. The habitat function of the green roof was further improved by including habitat structures such as small unvegetated sand/loess mounds and dead wood to offer nesting sites for insects and small shallow water bodies. Irrigation tubes were installed within the substrate on approximately 60% of the area (for emergency watering only during periods of extreme drought). The benefit of this newly constructed green roof for native plant and animal species will be evaluated in a future assessment.

6.5 Conclusions and Perspectives

Our results indicate that several native plant species of northwestern European dry sandy grasslands are well suited for EGRs with moderate substrate depth of at least 8–9 cm with slight irrigation in periods of extreme drought. This means that it is possible to create more diverse green roofs that could also represent valuable steppingstones of habitats suitable for native insect species (Thuring and Grant 2016). Habitat diversity of green roofs can probably be improved by different substrate depths and material for nesting sites (see example 3, Baumann and Kasten 2010; Kratschmer et al. 2018).

Nevertheless, the results from our ongoing studies are still preliminary, especially when considering the challenge of climate change. Therefore, it is necessary to evaluate the effects of different measures of species introduction, substrate types, roof heights, vegetation management and spatial localisation of green roofs on plant and animal diversity in the long run.

In our studies, roof sizes ranged from experimental mini-roofs of 2 m^2 over 500 m^2 up to 10,200 m^2 including different substrate depth and materials, which can affect plant population size and the recolonisation potential after extreme drought. As long-distance dispersal of many grassland species is limited (Török et al. 2018), the probability to build up viable populations and to recolonise areas where introduced species died may increase with roof size, substrate and local microclimate variability (Thuring and Barth 2016; Catalano 2017).

Despite the first establishment success of introduced plant species, we have to underline that our studies do not aim at making identical copies of seminatural dry sandy grasslands on EGRs. Although we used a habitat template approach to identify suitable plant species in the cultural landscape of northwestern Europe, environmental conditions of original dry sandy grasslands will often differ from those on EGRs, as Lundholm and Walker (2018) also stated in their general evaluation of this approach. For example, the mostly coarse technogenic substrate with restricted rooting depth, water and nutrient availability may be less suitable for more mesophytic species of later successional vegetation stages and for soil-digging animals, at least during the first decades. Long-term studies showed, however, that soil conditions on green roofs can improve on the long run (e.g. Bornkamm 1961) and that many different animal taxa can be found on older green roofs (Brenneisen 2006; Thuring and Grant 2016). As green roofs develop under succession over time, the future vegetation of EGRs established by seeding native plant species may contain a mix of native dry grassland species and some ruderal species invading from the urban matrix (see also Catalano et al. 2016). Nature conservation values of such EGRs have to be studied in detail and subsequently implemented in urban planning and compensation schemes. If green roofs with regionally specific plant species are constructed close to existing ancient grassland remnants, they may even contribute to the connectivity of grassland habitat networks (e.g. Braaker et al. 2014). For isolated green roofs within large areas of grey infrastructure, in contrast, the probability of colonisation by grassland-specific arthropod species may be lower. Nevertheless, such green roofs can still contribute to climate change mitigation

(Oberndorfer et al. 2007) and may provide diverse aesthetic aspects for people living and working in urban areas (Butler et al. 2012).

Acknowledgements We thank V. Straub, C. Jung, A. Krampe and L. Dannenberg for data collection and R. Walker (ZinCo GmbH) for his advice concerning green-roof substrates. We are grateful to H. Bültmann for the identification of lichens and to C. Schmidt for moss and liverwort species determination. Funding for the different green-roof experiments was provided by the Ministry of Science and Culture of Lower Saxony, Germany (grant no. ZN 2950), the European Regional Development Fund (grant no. ZW 6-85003114) and the company Friedrich Lütvogt GmbH & Co. KG.

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Chapter 7
Nature-Based Solutions as Tools for Monitoring the Abiotic and Biotic Factors in Urban Ecosystems

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Abstract Nature-based solutions (NBS) include a wide spectrum of situations: natural and seminatural green spaces, urban forests, designed gardens and parks, green road lines and roundabouts, bio-swales, productive gardens, green roofs and walls. In each site, the challenge is to provide the best solution according to the environmental and cultural context and the citizens' demand. The urban horticulture in synergy with NBS provides to design, realise and manage green solutions for specific problems in the urban context. NBS supplies actions able to improve urban resilience and many opportunities for improving urban quality, optimising the delivering of a mixed range of ecosystem services (ES). This chapter highlights that NBS can be used for monitoring, soil, air and water quality, water matrices and pollinator diversity. We therefore describe methods for monitoring the quality of soil, air, water matrices and pollinator diversity and abundance. In conclusion, we point out

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_7

some key aspects, under an interdisciplinary perspective, in order to promote further and deeper knowledge in the application of NBS in the urban environments.

Keywords Air quality · Water quality · Soil fertility · Pollinators · Urban horticulture

7.1 Introduction

The International Union for the Conservation of Nature (IUCN 2020) considers nature-based solutions (NBS) as an umbrella concept for ecosystem-related approaches. NBS can be adopted especially in urban ecosystems that are altered and complex systems designed to mainly provide citizens with a range of economic and social services, rather than ecosystem services (Melles 2005). NBS address several societal challenges, contributing to green growth, improving human well-being and economic opportunities and creating ecologically, economically and socially resilient cities (van den Bosch and Sang 2017; Keesstra et al. 2018). Specifically, NBS can be a tool for combining biological information with planning methodologies (Pickett et al. 2004) in order to provide a pleasant environment for local residents and to protect the downstream environment.

With regard to the benefits for wildlife and living organisms, NBS can maintain or increase the level of genetic, biological, habitat and landscape diversity in cities, often higher than in several seminatural or rural areas out of the urban context (Savard et al. 2000; Niemelä 1999). This colonisation, which involves pollinators as well, is also related to the presence of different green areas with a rich variety of flowers and trees in the urbanised environment.

Regarding human well-being, NBS are strictly linked to the concept of ecosystem services (ES). ES have been framed into four different categories: provisioning (food, timber, fresh water), regulating (air quality regulation, pollination, pest control and climate control), cultural (psychological and cognitive benefits, sense of place, aesthetic value, tourism) and supporting (biogeochemistry, nutrient cycling) (MEA 2005; TEEB 2011). The ES concept, strongly anthropocentric (Hunter et al. 2014), was mainly based on economic and ecological disciplines (Chaudhary et al. 2015), but research in this area has considerably evolved. The supply/demand balance of ES was previously poorly considered (Baró et al. 2015). In addition, citizens do not always directly benefit from urban nature, but sometimes there is a disservice, considered as damages, costs and negative effects of nature on human well-being (e.g. allergies, human and plant pathogens, greenhouse gasses emission) derived from processes and functions of urban ecosystems (Shapiro and Báldi 2014; Shackleton et al. 2016). Specific applications of NBS could reduce such disservices supporting synergies among ES.

The extreme selective pressures exerted by human environmental changes suggest that the evolution of urban ecosystems is likely to be the evolution under unbalanced conditions in rapidly changing environments (Collins et al. 2000). The NBS concept supplies actions able to improve urban resilience, intended as the ability of a system to return to a previous or improved set of dynamics following a shock, strengthening the ability of a city to mitigate, adapt and recover from internal and external stresses (United Nations Conferences on Housing and Sustainable Urban Development 2017). The way in which an urban ecosystem recovers from a disturbing event can be drastically or positively influenced by human intervention. NBS have an integrative and systemic approach and include the experience of several stakeholders, so that positive actions contribute to achieving all dimensions of sustainability (Nesshöver et al. 2017). Urban greening represents a specific kind of NBS, facing the challenge of climate change adaptation and improving human well-being through the supply of ES (Panno et al. 2017).

In the next paragraphs, some specific characteristics of NBS in urban areas are analysed. In particular, the topics of environmental and ecological monitoring are investigated.

7.1.1 Urban Horticulture

The cultivation of vegetables and ornamental plants in cities is called urban horticulture (UH). Commonly, it is easy to identify UH practice in urban gardens and parks, thus influencing and modifying their structure and use. Therefore, like the UH concept, the concept of urban gardens and urban parks has evolved over time, conceiving the new green areas as spaces that must provide ES, thus focusing on ecological aspects and ensuring human well-being. As stated in the introduction section, currently there seems to be a tendency to conceive the green areas as spaces that must provide ES, focused to ecological aspects and to guarantee human well-being. The tendency to construct new buildings is decreasing in favour of re-using the existing ones; similarly, many industrial areas around the world are being transformed into urban parks (e.g. Dora Park in Turin, Landschaftspark Duisburg in northwestern Germany or Freshkills Park in New York).

Therefore, in order to achieve these objectives, NBS is necessary and a new and attentive UH is the key for proper management. In Turin (Italy), a good example is the birth in 2019 of a new public-private area of community gardens called *Orti generali*, located in the neighbourhood of Mirafiori, the former headquarters of the ex-FIAT car company (now STELLANTIS Group) (Fig. 7.1), managed with an innovative economic, ecological and social approach (www.ortigenerali.it).

In such contexts, UH plays an important role in providing or maintaining multiple ES. In the last years, therefore, UH is applied to design, realise and manage green solutions for specific problems in the urban context (NBS) so authors introduced the concept of environmental horticulture as the application of environmentally sustainable practices in urban greening (Cameron and Hitchmough 2016). In this context, many opportunities to promote NBS as tools for improving urban quality – optimising the delivering of a mixed range of ES – can be developed.

Fig. 7.1 Example of NBS Community gardens *Orti generali* at Mirafiori neighbourhood in Turin

Box 1: NBS for the urban environment

Since 2016, the European Union, with the Horizon Research and Innovation Programme, funded several large-scale demonstrative projects in cities as living labs for NBS for driving urban sustainable development. As preliminary results issuing from some of these projects, catalogues and applied examples of NBS have been proposed (URBANGREENUP, URBiNAT, CLEVER, ThinkNature, proGIreg, EdiCitNET). Some important and common solutions aim at supporting biodiversity in cities and enhancing the quality of the urban environment. In this chapter, we outline some aspects describing NBS as tools for monitoring, in particular, soil, air, water matrices and pollinator diversity.

The NBS realisation starts with a particular attention to preserve the soil capital and improve soil ES (Morel et al. 2015). Experimental research with new regenerated soils are going to be performed in Turin (Italy), while some interesting examples in France are already available as ‘Le Jardin des Joyeux est’ in Aubervilliers, by the Wagon landscaping studio (www.wagon-landscaping.fr).

Moreover, the issue of air quality in urban areas is more and more perceived by citizens. As the effectiveness of air purification service mostly depends on the complexity of the structure of the vegetation found in green areas, wooded areas play a major role. Otherwise managed and other vegetation types, like lawns and single trees, appear to be less effective in mitigating climate changes and improving air purification (Vieira et al. 2018).

(continued)

Another important component of urban spaces is water: its quality and availability and its regulation are the main issues. Ponds and other small water bodies frequently occur in parks and gardens, and they turn out to be important ecological features. Furthermore, water bodies are useful for water purification, temperature regulation, flood control, biodiversity and aesthetic enjoyment (Blicharska et al. 2016). These ecological characteristics must be considered by the various forms of urban horticulture practised in urban green areas, so as to preserve high biodiversity levels.

Moving to the plant species selection, it is possible to plan, design and manage green spaces aimed at increasing the environmental quality and biodiversity. The realisation of areas with meadow-like vegetation contributes to increase plant and animal diversity and aesthetic, with low cost involved in maintenance (Bretzel et al. 2016). In this way, the presence of pollinators due to a high level of biodiversity is beneficial to the community gardens, both to ensure the production of vegetables and to strengthen the food web. These aspects are explained more in detail in the following paragraphs.

7.2 NBS as Environmental Monitoring Tools

The evaluation of the benefits related to the NBS implementation in urban areas is a crucial aspect for assessing their efficiency, for increasing the measurability of their effects and the comparability between different nature-based approaches (Sparks et al. 2011). However, the assessment of these benefits still represents a challenge, since existing systems are rarely able to address the cross-sectoral benefits provided simultaneously by NBS (Ordóñez et al. 2019). To this aim, several key indicators, monitoring parameters and recommended methods have been developed and applied. Furthermore, the definition of standardised protocols for the monitoring of NBS environmental benefits would also bring, and in few cases have already brought, to the use of NBS themselves as suitably designed monitoring stations in urban context.

7.2.1 Monitoring and Indicators of Local Climate and Air Quality Regulation Provided by NBS

Climate change is expected to worsen climate conditions of cities, due to the so-called urban heat islands effect (UHI) (IPCC 2014). NBS can ameliorate urban microclimatic conditions, mainly by shading and/or regulating evapotranspiration (Vieira et al. 2018).), thus reducing air temperature, mitigating extreme heat-wave events and, as a consequence, reducing urban energy use (McDonald et al. 2016). The cooling effect of several NBS can be evaluated through direct measurements, meteorological modelling of air temperature or key indicators, such as mean and maximum daily temperatures (NCAR & UCAR n.d.). Cameron et al. (2014) investigated the performances of different green wall types for air temperature reduction, proving the efficiency of green walls by measuring ambient air temperature, irradiance and humidity through weather stations and temperature sensors. Largest temperature differentials were recorded at mid-late afternoon, when air close to green walls was 3 °C cooler than the one near to non-vegetated walls. Interestingly, the relevance of the species selection for increasing the cooling efficiency of NBS was also reported.

Green infrastructure also plays an important role in urban air pollution abatement (Abhijith et al. 2017). The interaction between vegetation and air pollutants is mainly driven by the leaf stomata uptake of gaseous pollutants and by the leaf deposition of particulate matter (PM) (Tong et al. 2015; Jayasooriya et al. 2017). The NBS impact on air quality can be evaluated by monitoring the concentrations of atmospheric pollutants such as PM_{10}, $PM_{2.5}$, O_3, NO_2, CO and SO_2 and toxic metals (As, Cd, Ni, Pb and Hg), as retrieved from monitoring stations or during experimental campaigns (ISO 2018). Net fluxes of air pollutants can be either measured by eddy covariance (Guidolotti et al. 2017) or estimated through the application of air quality models (such as the i-Tree Eco model, USDA Forest Service, 2019). However, these approaches have been proven to be effective more at the city scale, rather than at the NBS scale (Selmi et al. 2016). Air quality mitigation at the NBS level should be assessed through experimental techniques able to determine the pollutant uptake at the single tree scale (or lower). To this aim, several approaches have been already proposed to assess PM removal at the single leaf scale and applied to green roofs, green walls and urban parks. The vacuum filtration procedure, described in Dzierżanowski et al. (2011), is a widely used gravimetric technique able to assess leaf-deposited PM amount, into different size fractions (e.g. PM_{10}, $PM_{2.5}$). Saturation isothermal remanent magnetisation (SIRM) signals allow to assess the amount of magnetic PM on leaves (Power et al. 2009), and SIRM has been successfully used to evaluate the removal of traffic-related PM from a street tree canyon in Gent (Belgium) (Kardel et al. 2012). Finally, the analysis of leaf surfaces by scanning electron microscopy combined with energy dispersed X-ray (SEM/EDX) can provide a detailed characterisation of leaf-deposited PM in terms of particle size distribution and elemental composition (Baldacchini et al. 2017) and also a reliable quantification of leaf-deposited PM (Baldacchini et al. 2019). Weerakkody et al. (2018) analysed by SEM/EDX microanalysis the leaves of a green wall situated in a busy road of Stoke-on-Trent, UK, thus estimating an average number of $122.08 \pm 6.9 \times 10^7$ PM_1, $8.24 \pm 0.72 \times 10^7$ $PM_{2.5}$ and $4.45 \pm 0.33 \times 10^7$ PM_{10} captured on 100 cm^2 of the living wall. The use of SEM allowed also to highlight differences between the PM capturing efficiencies of the living wall species, likely due to specific leaf surface characteristics, as further confirmed also on tree species (Sgrigna et al. 2020).

7.2.2 Indicators of the NBS Impact on Soil Fertility and Stability

Soil sealing, connected to the urbanisation process, can increase the risk of floods following intense rain events, which are becoming increasingly frequent in the climate change scenario (Marafuz et al. 2015). This process is also responsible for a significant reduction of soil-atmosphere gas exchanges (Weltecke and Gaertig 2012), soil organic carbon, basal respiration and microbial activity, thus limiting soil fertility and the overall provision of ecosystem services (Fini et al. 2017). NBS can counteract these negative effects, providing several benefits on soil stability, fertility and resilience towards the impacts of climate change.

Carbon storage can be used as an indicator of the increased resilience and mitigation potential against climate change impacts provided by specific NBS such as green roofs (Getter et al. 2009). Whittinghill et al. (2014) evaluated the differences in carbon storage and sequestration potential of various in-ground or green roof systems. Green areas composed by woody plants (shrubs), or herbaceous perennials and grasses, resulted to have higher content of carbon stored (up to 78.75 kg m^{-2}), while green roof systems were less efficient in this sense.

The NBS-induced soil physical resilience can be evaluated by measuring its organic matter content, texture, structure and permeability. Oldfield et al. (2014) investigated the potential of afforestation procedures in increasing soil quality in an urban park in Queens, NYC. Data analysis underlined positive effects on soil quality provided by trees in combination with specific procedure of soil preparation (weeding, rototilling and the use of compost). These practices determined significant changes on soil properties and resulted effective in improving soil traits that are critical for ecosystem services such as water infiltration and nutrient retention.

7.2.3 Monitoring and Indicators of the Impact of NBS on Water Quality and Management

Urbanisation leads to changes of surface cover that are able to affect negatively also the hydrological cycle, reducing the interception, storage and infiltration of rainwater and increasing the volume of storm water runoff and the risks of local flooding (Zölch et al. 2017). Runoff waters are often characterised by the presence of several pollutants (US EPA 2009) that are able to cause the degradation of downstream ecosystems (Pennino et al. 2016). In this context, NBS represent an efficient alternative to grey infrastructures for the mitigation of runoff water and for the improvement of water quality, being also able to control the circulation of pollutants (Tiwary and Kumar 2014). As a result, specific NBS defined also as storm water control measures (SCMs), such as rain gardens, detention ponds and green roofs, have been implemented in order to help mitigate flooding and water quality problems in urban areas (Jayasooriya and Ng 2014).

Zölch et al. (2017) reported quantitative evidences of NBS efficiency, using an integrated hydrological simulation tool (MIKE SHE) for the modelling of future scenarios based on different variations of green cover in a high-density population area of Munich (Germany). Results obtained revealed the high efficiency of NBS (trees and green roofs) for the regulation and the management of storm waters.

In order to quantify the effects of NBS implementation on water quality, the concentrations of nutrients and metal pollutants are monitored (Reedyk and Forsyth 2006). To this aim, test kits or ion selective electrodes (ISEs) can be used, thus providing rapid but usually less accurate results. Other known chemical pollution indicators are the biogeochemical oxygen demand (BOD) and the chemical oxygen demand (COD). Total suspended solids (TSS) or turbidity (% or total) measurements can be used to assess the reduction of sediment runoff, before and after the NBS implementation. TSS is typically calculated through a gravimetric approach based on the filtration of water samples and subsequent drying and weighting of the sediments removed. Leroy et al. (2016) reported the evaluation of the efficiency of vegetated swales for the improvement of water quality, taking into account 12 different storm events and carrying out measurements of parameters such as TSS, COD, BOD, total phosphorus (TP), trace elements and polycyclic aromatic hydrocarbons (PAHs). Results underlined the efficiency of swales planted with macrophytes in reducing trace metals and PAH concentrations from 17% up to 45%.

7.2.4 NBS as Living Monitoring Stations for Environmental Quality Parameters

The efficiency and the high spatial resolution of some of the techniques developed to monitor and assess the NBS benefits have suggested that NBS could be used as monitoring stations within the urban context (Baldacchini et al. 2019; Cherqui et al. 2019). This results in the potential of having high-spatial resolution networks useful for environmental monitoring and in the decreasing need of on-site stations. To date, very few research studies have focused on this aspect. In Baldacchini et al. (2019), leaves are proposed as passive samplers, proving their efficiency for low-cost and in situ urban PM biomonitoring. The chemical and physical characterisation obtained through SEM/EDX microanalysis of leaf surfaces allowed to obtain information useful to identify the impact of PM emission sources. As shown in Fig. 7.2, the proposed approach efficiently discriminated the different impacts of sources on leaves of seven different *Quercus ilex* L. trees located within an urban park of Naples (about 6 ha): PM collected on the trees close to the street was characterised by high levels of traffic pollutants (such as Fe, site 2 and 4); PM deposited on leaves from trees exposed to the marine breeze (sites 1, 5 and 7), with high levels of ions linked to salt-spray exposure (Na and Cl), was observed; elements from the crustal component (namely, Si and Al) were mostly abundant in the leaf-deposited PM recorded in the remaining sites.

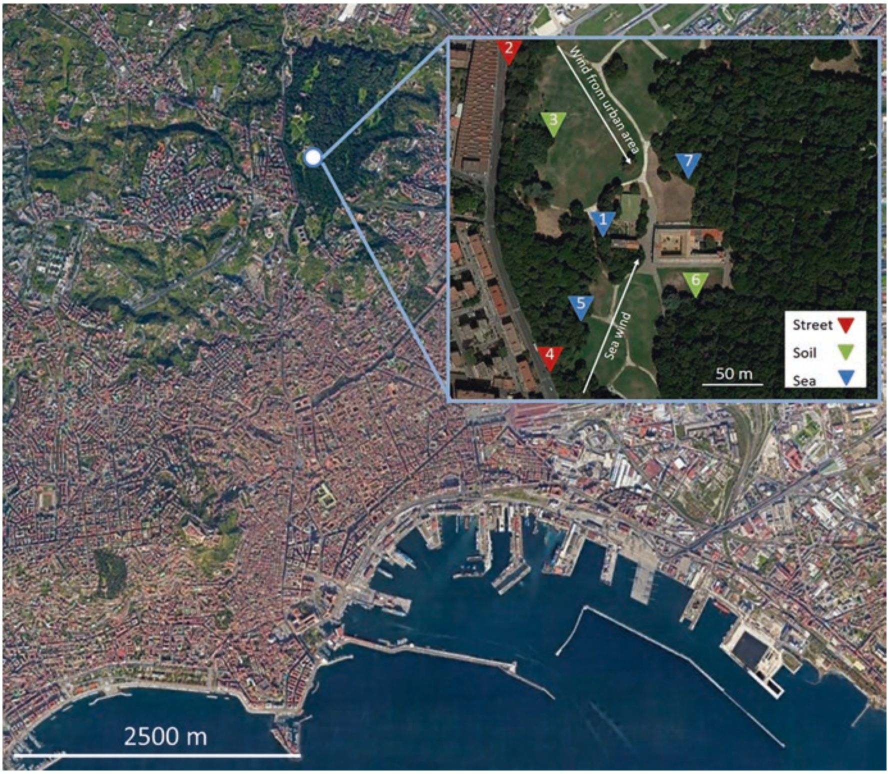

Fig. 7.2 Air pollution source apportionment issued from the SEM/EDX analysis of the PM deposited on the leaves of *Quercus ilex* L. trees in an urban park in Naples, southern Italy. (Adapted from Baldacchini et al. 2019)

A similar approach has been proposed by Cherqui et al. (2019) for water management: the use of a micro-controller (e.g. based on easy-to-use hardware and software) applied to specific SCMs, in combination with open-access monitoring data, with the purpose of designing a monitoring system. This innovative approach results to be useful for the achievement of information with high spatial resolution that can be used for the management of storms and flood events in urban areas.

7.3 NBS as Arthropod Diversity Monitoring Tool

A wide range of insect taxa can potentially play a crucial role as pollinators in ecosystem services, even if the most effective ones are bees (Hymenoptera: Apoidea) (Potts et al. 2016). Among non-bee flower-visitor insects, hoverflies (Diptera: Syrphidae), tachinids (Diptera: Tachinidae), butterflies (Lepidoptera), beetles (Coleoptera), sphecids (Hymenoptera: Ampulicidae, Sphecidae and Crabronidae) and wasps (Hymenoptera: Chalcidoidea) may provide key ecosystem services, such as pollination and biological control (Ferracini and Alma 2007; Corcos et al. 2019). Pollination is an important ecosystem service, providing food production and enabling plants to reproduce. Over 80% of wild and cultivated plants grown in Europe strictly depend on insect pollinators, mainly bees. In 2005, this pollination service represented over 153 billion € throughout the world and over 14.2 billion euros in Europe, with about 84% of all crops that have been studied depending on, or benefiting from, insect pollination (Gallai et al. 2009; Ferrazzi et al. 2017). Moreover, other beneficial arthropods (e.g. predators and parasitoids) may sustain easily their populations when they have access to non-prey foods as pollen and nectar (Picciau et al. 2019).

In urban green areas, pollination and biological control represent very impressive examples for NBS supported by and using nature to provide environmental benefits. Unfortunately, the impact of urbanisation on pollinators is poorly studied. Although landscape changes, due to increasing urbanisation, have been identified as drivers of pollinator decline, there is evidence of the biological value and ecological importance of cities providing nutritional resources and suitable habitats for pollinators, thus helping in conserving biodiversity (Hicks et al. 2016; Hall et al. 2017).

Bees, and in particular honey bees, are good indicators of biodiversity in cities, and any type of biomonitoring aiming to census and quantify them is an effective method to evaluate the ecosystem supply of urban environments.

Urban green spaces include a range of habitat types. Habitats with greater vegetation complexity often benefit natural enemies by providing resources, such as alternative preys and hosts, nectar and pollen for omnivores, suitable microclimates and habitat for multiple life stages (Parsons and Frank 2019). A positive correlation between flower numbers and pollinator abundance has been demonstrated (Pardee et al. 2014). Awareness of the role of wild pollinators has significantly grown in recent years. According to Underwood et al. (2017), training initiatives for local authorities and procurement policies for green space management to adopt pollinator-friendly management strategies are needed.

Besides floral abundance and richness, beneficial arthropods are positively affected by increased mulch and leaf litter cover, larger garden size, perennials and increased structural diversity (Arnold et al. 2019). Several research comparing pollinator communities in urban and non-urban landscapes demonstrated that cities can support higher bee species richness compared to agricultural and natural ecosystems (Matteson et al. 2008; Kennedy et al. 2013; Goulson et al. 2015; Baldock et al. 2019; Wenzel et al. 2020). Bees include both solitary and eusocial species, especially cavity nesters and pollen generalist species (Hernandez et al. 2009; Cariveau and Winfree 2015), and specialised species indicative of high-quality habitats, even though specialist bees are rare in cities (Tonietto et al. 2011). In particular, urban areas can host greater species richness of bumblebees than rural or natural landscapes, and green roofs can be also used by pollinators as foraging and nesting habitat (Ksiazek et al. 2012; MacIvor et al. 2015).

Diverse urban bee communities also may provide a benefit by pollinating urban crops and garden plants (Larcher et al. 2017). Numerous lists of 'pollinator-friendly' plants are available, even if most of them are not well grounded in empirical data, nor they do specify the taxonomic composition of pollinator assemblages attracted by particular plant species (Mach and Potter 2018). Studies on floral resources and pollinators have traditionally focused on flower strips, urban gardens, parks and allotments (Somme et al. 2016). Besides, the urban foraging sources provided by urban areas may be consistent as investigated in the city of Turin (NW Italy) (Vercelli and Ferrazzi 2014). Several broadleaved trees, shrubs and herbs give an opportunity to urban beekeeping, also allowing to produce local monofloral and multifloral honey (Fig. 7.3) (MV, personal investigations). Regarding the pollination process, the correlation between high visitation rates and increased fruit and seed set in urban areas was demonstrated by several authors (Lowenstein et al. 2015). Concern for bees' survival among the general public has led to an increase in the numbers of beekeepers and pollinator-friendly gardens in cities. The introduction of bee-friendly gardening (artificial nests and bee flora) to enhance and support wild pollinators is quite a widespread practice in conservation programmes (MacIvor and Packer 2015; Bortolotti et al. 2016). Bee hotels are specialised nesting devices that can be installed in urban areas (Fig. 7.4). Using a variety of untreated materials and varying tunnel diameters will bring a diversity of bee species, even if mason bees (*Osmia* spp.) and leafcutter bees (*Megachile* spp.) are considered the most common ones.

Regarding urban beekeeping, it has recently become almost a fashion, with hives on the roofs of historic or prestigious buildings, as in Paris, London, Turin and many other European cities (Moore and Kosut 2013; Vercelli and Ferrazzi 2014) (Fig. 7.5). The blooming scalarity allows to maintain a high number of hives in the cities. This environment proves to be favourable for bees together with the heat islands effect, which ensures survival and reproduction during winter. Furthermore, a feasible management without chemical treatments may positively affect pollinators' life.

A growing body of research, national and international initiatives and citizen science activities have been carried out to monitor the support provided by cities to conserve and restore biodiversity (Quaranta et al. 2004, 2018; Van Swaay et al.

Fig. 7.3 Typical pollinator-friendly species of the urban environment

Fig. 7.4 An urban nesting device, also called “bee hotel”

Fig. 7.5 Urban beekeeping in Turin

2010; Nieto et al. 2014; Potts et al. 2016; Roy et al. 2016; Underwood et al. 2017; Bonelli et al. 2018; Maes et al. 2019).

A variety of sampling methods is available for arthropod census, even if some methods can be biased, and their performance varies widely (Rega et al. 2018). Direct counts of individuals, sweep-netting and trapping methods (pan traps, malaise traps and sticky traps) are commonly used (McCravy 2018).

Bee presence is measured in terms of diversity and abundance in several habitats using the estimate methods proposed by several authors (Westphal et al. 2008; O'Connor et al. 2019; Bartholomée and Lavorel 2019). The most common sampling methods for bees and beneficial insects are resumed in Table 7.1. To assess the total bee species richness and abundance, a combination of transect walks conducted by trained bee collectors and pan trap sampling is suggested.

The indirect indicators of biodiversity, represented by food source availability in urban environments and the consequent bee foraging activity, can be measured through field surveys and melissopalynological analyses of the bee products. Nectar

Table 7.1 Typology and description of the most common estimated methods to monitoring bees and beneficial insect diversity and abundance [methods proposed by Westphal et al. (2008) and subsequently modified in terms of length, width and time of transect walk, and placing time of pan traps (Dennis et al. 2012; O'Connor et al. 2019)]

Typology	Description
Observation plots	Ten equally sized rectangular (1m long × 2 m wide) plots were located according to a random design. During a 6-min observational period, every bee visiting a flower is recorded and then identified checking wings or collected for further identification. The observations are conducted throughout the main flowering period
Standardised transect walk	Permanently marked (250 m long × 4 m wide) corridor divided into ten 25-m-long subunits is used for the standardised transect walks. Each subunit is surveyed for 5 min during which all bees visiting flowers are registered or collected (i.e. 50-min recording time for the whole standardised transect)
Variable transect walk	1-ha plot adjacent to the area where the other sampling methods are undertaken is identified. In the variable transect plot surveyors are allowed to search actively for bees throughout the plot by slowly walking around for 30 minutes
Pan traps	15 pan traps set up in five clusters separated by 15 m are established in the study area. Each cluster contains three UV-bright pan traps, coloured in white, yellow and blue taking account for different colour preferences of bee species. The pan traps are mounted on a wooden pole at vegetation height, filled with 400 mL of water and a drop of liquid dishwashing detergent and left active for 48 hours
Trap nests	Ten poles are mounted in the study area containing five trap nests each. Two types of trap nests are used: (1) traps made of ca. 150 stems of common reed *Phragmites australis* internodes each, with 2–10 mm in diameter and 15–20 cm in length, and (2) trap nests filled with paper tubes of distinct diameters, 6.5, 8 and 10 mm, respectively. Each pole carries two trap nests with common reed internodes and three paper tube nests

and pollen forage activity may be defined in relation to flower visitation rate, pollen loads and honeys. Furthermore, pollen transfer, pollination success and harvest for human consumption are used to measure the pollination capacity (Bartholomée and Lavorel 2019).

The abundance and diversity of native bee species in urban landscapes underline the biological value and ecological importance of cities. In this context, conserving pollinator assemblages may be essential for ecosystem restoration, and the urban environment with its variety of forage and nesting sites can act as a refuge for insect pollinators. In the last decades, research on bees and beneficial arthropods in cities showed that diverse populations live in urban landscapes (Somme et al. 2016; Wenzel et al. 2020). Bees, and in particular honey bees, are good indicators of biodiversity in cities, and any type of biomonitoring to census and quantify them is an effective method to evaluate the ecosystem supply of urban environments. Further evidence comes from the analysis of honey bees and wild bees and related products. Specific ecological green space management plans are needed, encouraging the use of native flowering plants and the combination of annuals and perennials, in field margins and flowerbeds. Weed species provide many important resources for beneficial insects such as pollen or nectar as well as microhabitats. The possibility to combine beekeeping and the use of flowers highlights the importance of adopting melliferous plants when designing urban areas, and also properly managing the practices for the urban green spaces (e.g. reduced lawn mowing practices) can significantly affect insect biodiversity.

7.4 Concluding Remarks

In conclusion, we point out some key aspects, under an interdisciplinary perspective, in order to promote further and deeper knowledge in the application of NBS in the urban environments.

NBS can be used as low-cost tools for the environmental monitoring in urban areas. New strategies are needed in order to upscale the information achieved through the measurements of parameters and key indicators described in the previous paragraphs.

In order to enhance the functioning and health of urban ecosystems, a larger engagement and a stronger connection of citizens and stakeholders to nature are desirable, for example, regarding the raising awareness on the decline of pollinators and biodiversity.

The more citizens comprehend the value of nature and participate reasonably in the codesign and co-management processes, the more NBS will achieve self-standing and long-term results. In this contest, the various forms of collective use of green spaces are essential for creating a nature-based educated population, promoting a more ecologically responsible behaviour (Colding and Barthel 2013; Battisti et al. 2017; Larcher et al. 2017).

Finally, since decisions concerning management can affect conservation of threatened and endangered species, we argue that a multifunctional approach to conserve and restore cities using NBS should be adopted.

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Chapter 8
Anthosart Green Tool: Selecting Species for Green Infrastructure Design

Patrizia Menegoni, Riccardo Guarino, Sandro Pignatti, Claudia Trotta, Francesca Lecce, Federica Colucci, Maria Sighicelli, and Loris Pietrelli

Abstract The environmental and economic costs of greenery depend on the planning criteria adopted and on the plants used. These costs can become more sustainable and can also be significantly lowered by using native flora and getting inspired by local plant communities. Nature-based solutions entail the use of species that co-occur naturally, thus replicating a model of coexistence consolidated by the evolutionary coherence of the biosphere. Planning, using and (re-)producing – getting inspired by natural ecosystems – may foster the dissemination of ecological awareness, with gardens, avenues, rooftops, walls and balconies seen as spaces available for the urban reconciliation with nature. The Anthosart Green Tool may support these actions, as a freely accessible online tool dedicated to the species belonging to the Italian flora, by recognizing their value as environmental and cultural assets. This tool is designed for those who want to engage in greenery design work using wild species, discover their potentials in terms of ethnobotanical knowledge and seek out information on the species of the flora of Italy.

Keywords Urban green infrastructure · Nature-based solutions · Urban greenery · Italian vascular flora

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_8

8.1 Introduction

At present times, the percentage of people living in urban settlements worldwide exceed that of people living in rural areas, as a result of rapid urbanization and demographic growth started around the middle of last century. According to the United Nations, over 55% of the world's population lived in urban areas, and it is estimated that this number will reach 68% by 2050 (United Nations 2019). Demand for land in and around cities is becoming progressively more critical. As a consequence of urbanization, along with the demographic, cultural and socio-economic implications, the urban area expands at the expense of the suburbs, and formerly rural areas are therefore currently incorporated or converted into larger metropolitan areas. Thus, agricultural areas, pasturelands and forests are likely to change their destination into urban settlements. Therefore, rapid and drastic alterations in land use and cover are changing landscapes in cities and the countryside nearby (EEA 2006).

Environmental degradation, habitat fragmentation, biodiversity loss, poor air quality, soil sealing and water pollution are part of the price to pay to city expansion and unsustainable development. Besides, urban population growth is increasing demand for public services, housing and other infrastructure, as well as for natural resources not directly present locally, inducing even more pressure on urban environments. Cities are therefore hubs of alteration of the environment where human well-being and health are endangered (Verderber 2012). Urbanization and the other global challenges that the humanity and other life forms on the planet are facing call for urgent measures and policies to accommodate urbanization while ensuring good quality of life and health and minimize environmental damage.

Integrated policies taking into consideration the connections between urban and rural areas and their existing economic, social and environmental relationships are needed to enhance the well-being of both urban and rural dwellers (United Nations 2019). According to the Sustainable Development Goals for the 2030 Agenda for Sustainable Development (United Nations 2015), cities must be inclusive, safe, resilient and sustainable and assume a leading role in nature conservation and environmental sustainability. Creating healthier urban environments, fulfilling the above-mentioned goals depends increasingly on the successful management and planning of urban growth. In the effort to achieve some of these goals, nature-based solutions (NBS) are gaining traction among scientists and experts.

NBS imply actions inspired by natural ecosystems to tackle societal challenges such as climate change while providing human well-being and biodiversity benefits (Eggermont et al. 2015). In comparison to grey infrastructure, NBSs are often low cost and long-lasting and protect the ecosystems on which we depend. For example, NBSs relying on green infrastructures (GI) can contribute to preserve urban biodiversity and ecosystem services at the local level and can contribute to the mitigation of climate change effects. According to the European GI Strategy, green infrastructure is a (European Commission 2013):

> strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings

Urban green infrastructure (UGI) mainly consists of open spaces or seminatural areas partially or completely covered by vegetation (Wentworth 2017) and designed to produce valuable services (Lundholm 2015). The ecosystem services provided by UGI range from recreation to the mitigation of heat, runoff, noise and fine dust pollution, being this last one of the most serious drawbacks on human health in urban areas (von Schneidemesser et al. 2019). Numerous projects have been proposed, planned and implemented in European cities after the adoption of the GI Strategy by the European Commission in 2013 (European Commission 2016; Slätmo et al. 2019). The strategy also has set the ground for policy that aims to provide ecological, economic and social benefits through NBSs and to boost investments that sustain and surge those benefits and the research around them. For instance, green roofs and walls, hedgerows, parks, gardens and flowerbeds have become progressively common in large cities for their diverse benefits, supported by specific economic policies such as climate change adaptation and mitigation policies (Catalano et al. 2016).

Green infrastructures in urban areas may also counteract the loss of plant and animal species caused by urbanization. Additionally, for urban citizens, UGI may be their unique experience of natural spaces. The public greenery of our cities and the private greenery of gardens and balconies represent the *proximal* space where we can act personally and collectively by applying innovative solutions consistent with the European policies. One way to do this is to adopt a nature-based solutions framework, rigorous and based on the evidence that the adaptability and resilience of biodiversity stem from millions of years of experimentation by natural evolution. However, as already pointed out by other authors (Lundholm 2015), the design of green infrastructures from scratch often results in a lack of continuity with natural ecosystems. Factors such as natural soils, isolation from other ecosystems and species composition can influence the success and efficiency of green infrastructure. In particular, the design of species assemblages can become a critical outlet involving not only the ecological aspect but causing also economic and human health issues.

In Europe, many of the plants used by human activities (agriculture, horticulture and forestry) are not native to the continent. A small percentage of these plants introduced on purpose or accidentally became naturalised and able to invade natural ecosystems (Brunel and Heywood 2011). Among urban green managers and private citizens, there is not much awareness that exotic plants introduced for ornamental purposes can become invasive and pose a serious threat to biodiversity, ecosystems and public health as well (Simberloff et al. 2012). Therefore, it is necessary to foster greater knowledge and raise awareness of the problem (Brunel and Heywood 2011) to ensure that invasive or potentially invasive species are not used on a large scale, especially in the choice of plants for public green areas.

The Regulations nr. 1143/2014 and nr. 1141/2016 of the European Parliament aim at preventing and managing the introduction and spread of invasive alien species by forbidding the cultivation and commercialisation of plants and seed mixtures including any of the invasive alien plant species of union concern. However, little attention is paid to these regulations by common people.

Solutions replicating what happens in nature involve the use of species that co-occur in nature, thus replicating a model of coexistence consolidated by the evolutionary coherence of the biosphere. In response to environmental filtering and dispersal limitations, different plant species pools tend to co-occur in different habitats, forming assemblages that represent the primary producers of any biotic communities. Within each community, the relative abundance of species is regulated by mutual, neutral or competitive relationships, synergic facilitation mechanisms and, very often, by genuine symbioses. Nature-based green infrastructure should entail the use of species that frequently co-occur in natural habitats.

Knowing and using local plant species while promoting the adoption of NBS, protecting biodiversity and reducing management costs is one of the categorical imperatives of our time. These principles are acknowledged by the guidelines for the management of public green spaces and by the national strategy for the urban green, both issued by the Italian Ministry for the Environment (MATTM 2017, 2018):

> The spatial organization of the new green infrastructure should avoid fragmentation, guarantee aesthetic and functional quality, optimize present and future costs through, for example, the correct choice of plant species (native species, rustic, etc.) and the adoption of low input technical solutions (energy, water, etc.).

In support of a design sustaining the principles and regulations mentioned above, a decision supporting tool named Anthosart was implemented, addressing a broad and diverse spectrum of stakeholders: the horticultural sector, designers, research institutions and private citizens. Shortly after the release of Anthosart, a survey has been carried out, in order to obtain a feedback from designers and citizen about the acceptance of Anthosart and about the adoption of nature-based solutions for the urban greening. The results are presented in this chapter.

8.2 The Anthosart Green Tool

The Anthosart Green Tool (AGT) is a free online facility offering a multi-faceted look over the 'green world' that surrounds us. It stems from the experience acquired during the editing of the second edition of the Flora of Italy (Pignatti et al. 2017–2019), i.e. the most comprehensive commented inventory concerning the Italian vascular plant species (over 7000 species), but it is also a virtual space for debating and sharing knowledge on garden design and the cultural value of single plant species. Acknowledging the environmental ethics developed by Hundertwasser

(Barak 2017), the *Anthosart philosophy* traces the reference lines of the initiative (Anthosart Project 2019):

> Urban greenery and green infrastructures are a means whereby humans can restore to nature some of the resources that they removed by building their town and cities. The environmental and economic costs of greenery depend on the planning criteria adopted and plants used. These costs can become more sustainable and can also be significantly lowered by using native flora and getting inspired by local plant communities.
>
> Planning, using and (re-)producing – according to nature – may foster the dissemination of ecological awareness, with gardens, avenues, rooftops, walls and balconies seen as spaces available for the urban reconciliation with nature; islands of nature in a sea of cement.

Thanks to a report plugin based on *ad hoc* database, the AGT allows dynamically created queries, based on the needs of the data user. The *ad hoc* database consists of a collection of unrelated, nonhierarchical tables, including a large amount of information on plant species resulting from an original blend of taxonomy, plant traits, ethnobotany and various humanistic disciplines. The AGT allows the user to target, select and relate pools of woody or herbaceous plant species native to Italy. These can be used for creating green spaces inspired by environmentally and economically sustainable criteria. AGT also provides a series of additional information to promote the ecological and cultural value of the Italian floristic heritage, in order to equip green projects with diverse and heterogeneous contents. AGT is particularly suited for those who want to engage in design work using wild species, discover potential uses (ethnobotanical, food, etc.) and seek out any of the species of the Italian vascular flora.

The tool deploys several separate resources: "DESIGN", "DISCOVER", "FIND", "GROWS WELL WITH…" and "CONTACT THE PRODUCERS".

DESIGN This resource is designed for all users who want to adhere to the *Anthosart philosophy* by designing green infrastructure such as flowerbeds, avenues, hedges, roadside greenery, rock gardens, ponds and temporary wells and green roofs. This tool enables users to select from a pool of 1400 plant species (annuals or perennials) native to Italy. These plant species were selected basing on some of the descriptive traits mentioned in the *Flora d'Italia* (Pignatti et al. 2017–2019). In particular, the species pool leaves out all the alien species and the native ones reported as rare or endangered at regional or national level. Among the remaining species, an additional selection was carried out by expert knowledge, in order to exclude species having low germination performance or little tolerance to environmental disturbance.

This resource allows users to readily select groups of species basing on their regional distribution and the environmental features of a given site, without disregarding the look or the aesthetic outcome. The thumbnails of the species of the native flora of Italy which are suggested to be used for designing green infrastructure are flagged with a small green leaf (, for more detail, see https://anthosart.florintesa.it/).

DISCOVER This resource enables users to discover the ethnobotanical and cultural value of approximately 2100 plant species of the Italian vascular flora. The species are catalogued according to their ethnobotanical uses (as food, raw material, cultural and religious rituals, traditional medicine and so on) but also based on the part of the plant used (stalk, stem, trunk, fruit, flower, root). A fact sheet and bibliographic references are provided for users who wish to know more.

FIND This resource may be used when the common or scientific name of the plant to learn more about is already known. The related database contains all the nominal species included in the Flora of Italy edited by Pignatti et al. (2017–2019) and allows to retrieve up to six photographs for each species (extracted from the Flora of Italy) and links to additional on-line resources, such as the forum Acta Plantarum (https://www.actaplantarum.org/).

In order to engage in planning activities following the natural species assembly rules, AGT provides the following two functions:

GROWS WELL WITH… For each of the species selected via the *DESIGN* resource of the AGT, it is possible to obtain a related species pool that share the same habitat in nature. The groups of species selected in this way ensure resilience to the green infrastructure and should create ideal conditions for the spontaneous colonisation by other species from the given habitat template (Catalano et al. 2016). These indications should facilitate the *continuum* between built greenery and natural habitats.

CONTACT THE PRODUCERS AGT also aims to create a network of nursery garden operators who want to adhere to the *Anthosart philosophy* and cultivate the species included in the *DESIGN* resource of the AGT and include them in their catalogues. This section provides also contact data for such operators.

8.3 Feedback from Green Designers and Citizens

Following the release on the web of AGT on February 2019 (Anthosart Project 2019), a questionnaire addressed to green designers and citizens was drawn up, in order to collect data, opinions and information about the use of AGT and about the potential utility of the species of the Italian vascular flora to design and implement nature-based solutions for the urban greening. The questionnaire was both published on the homepage of the AGT and sent to all members of the AIAPP (Italian Association of Designers and Landscape Architects). It has also been distributed via e-mail to the over 1500 persons registered to the Anthosart website (Fig. 8.1).

The following questions are presented and analysed hereafter:

Fig. 8.1 Conceptual map of the Anthosart Green Tool with its three related functions: to design, to find, to discover. Each of them is linked to its constituent elements and contents related. For further explanation, see the main text

1. Do you use the native species of Italian flora in your projects?
2. If so, in what percentage?
3. Do you feel it is important to use the native species of the Italian flora in your projects?
4. Why? (motivate the previous answer).
5. Do you have trouble in finding native species of the Italian flora in Italian nurseries?
6. Is it of interest to you to design by using solutions based on habitat templates, i.e. trying to reproduce the species assemblage of plant communities occurring in natural ecosystems?

As of January 2020, 214 questionnaires were collected, 64% of which from private citizens and 36% from AIAPP members. Some answers revealed a strong interest in using the native species of the Flora of Italy for the making of greenery, both in public and private infrastructure.

According to the answers received, 45% of the sample uses the native species usually, 42% sometimes. 11% rarely and only 2% of the sample never use native species (Fig. 8.2). Among the people who usually use the native species of the Flora of Italy, 53% declared that they use them with a percentage greater than 60%, 36% with a percentage between 31% and 60% and 11% with a percentage lower than 30% (Fig. 8.3). Among the people who sometimes use the native species of the Flora of Italy, 69% declared that they use them in their green projects with a percentage of less than 30% (Fig. 8.4), and 97% declared that it is important to use native species in green projects. Interestingly, even if nearly all the interviewed recognise the importance of using native species in their works, only 45% of them declared to use them regularly. Therefore, there is a gap between the perceived need and what people can really do in their green infrastructure projects. The motivations expressed on why it is important to use native species can be referred to six categories:

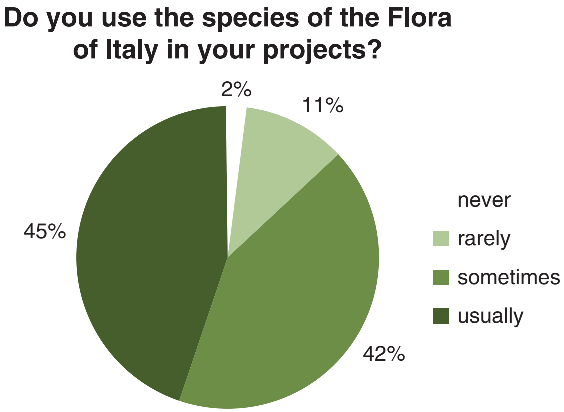

Fig. 8.2 Percentage of answers on the use of native species in the making of green infrastructure

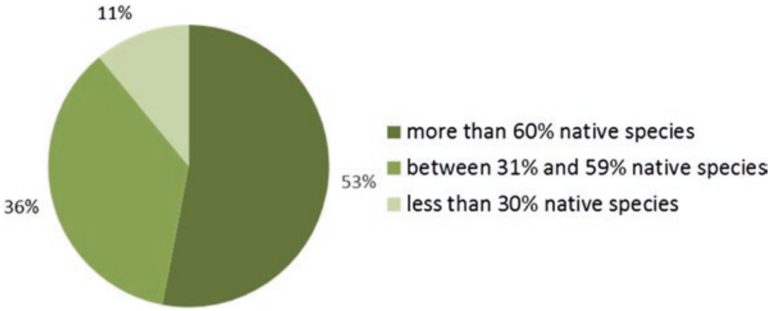

Fig. 8.3 Percentage of native species used in the making of green infrastructure by designers who regularly used them

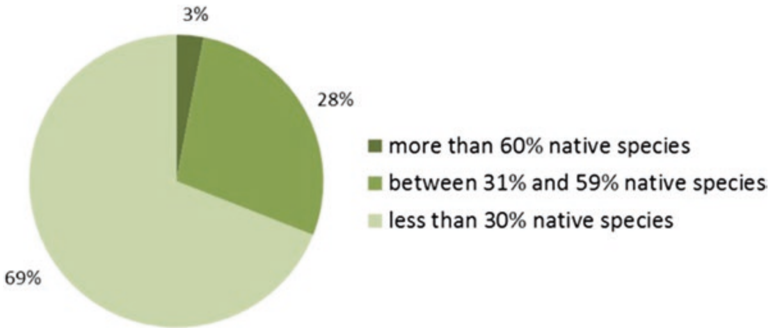

Fig. 8.4 Percentage of native species used in the making of green infrastructure by designers who sometimes used them

1. The need to respect the identity of places and nature, traditions and coherence with the surrounding environment (19% of the sample).
2. The need to implement green works with sustainable species (less water consumption, resistance to diseases and climate change) (33% of the sample).
3. The need to implement green works to preserve biodiversity (8% of the sample).
4. The need for beauty. The species of the vascular flora of Italy are beautiful (1% of the sample).
5. Personal motivations (3% of the sample).
6. Educational purposes. To raise people's awareness on the importance of enhancing the species native to Italy (1% of the sample).

However, 66% of the sample declared that it is difficult to buy native species on the national market. The totality of the sample (98%) considered AGT useful because it allows to retrieve a lot of information, to identify and target the native species, to choose among the species that best fit for the environmental design and to select those that live well together. A support in the species selection and, especially, in the species assemblages is important not only to diversify the species usually included in projects but also to take inspiration from in-depth studies. The will expressed by designers to adopt solutions that mimic the natural patterns of organisation of plant communities present in nature is also relevant.

The set of answers provided can be resumed in the following two quotes:

1. Because natural plant communities are by their very nature balanced, I always aim at the creation of plant assemblages which are, as far as possible, natural-like, above all in the perspective of an ecological and ecosystem value of the new project.
2. Because maintenance and related costs are greatly reduced and therefore the survival of green spaces is guaranteed even in the absence of economic resources and/or competent maintenance workers.

8.4 How Anthosart Can Contribute to the Enhancement of Sustainable Green Infrastructure

The Anthosart initiative has multiple-level objectives: it intends to participate in the collective reflection on cultural models about the sustainability of our living on the planet, to share the wealth of knowledge and experience coming from different disciplines and to create and disseminate contents that can be used in citizen science initiatives on ecological design.

Green infrastructure offers ecological, economic and social benefits by resorting to *natural* solutions. AGT is aimed at providing the necessary support for their realisation (Fig. 8.5).

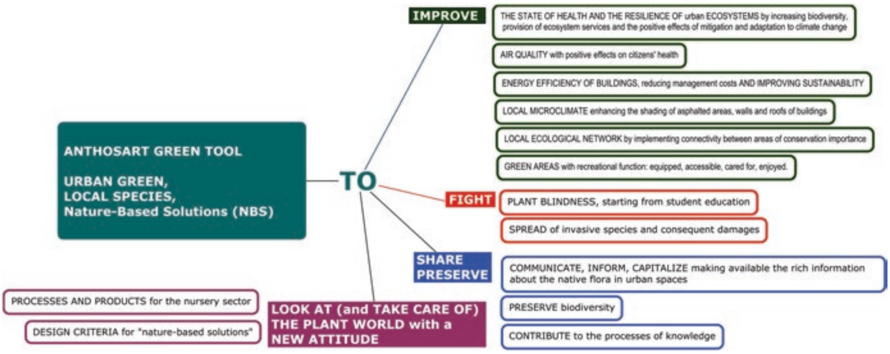

Fig. 8.5 The possible contributions of the Anthosart Green Tool to the enhancement of green infrastructure functions

Biodiversity, air and water quality, public health and well-being now seem to have a direct connection with the application of approaches based on the features of site-specific ecosystems (Raymond et al. 2017). Places and their communities seem to be the laboratories par excellence of change, transformation, conceptual and factual re-compositions (Earth Charter 1987):

> Strengthen local communities, enabling them to care for their environments, and assign environmental responsibilities to the levels of government where they can be carried out most effectively

It is in places and their communities that the wealth of knowledge and experiences can become a practice of sustainability. The anthropocentric vision underlying the model of *ecosystem services* tells a vision still oriented towards a utilitarian image of nature: a weak change in this direction emerges from the IPBES 2019 report (Díaz et al. 2019) with the concept of *Nature Contribution to People* (NCP). The conceptual substitution does not solve the semantics that still characterizes the relationship between nature and people as one-way and the value of nature as instrumental to the provision of benefits to man. At the basis of this operation would be the search for a pluralistic approach to knowledge and values, incorporating a wide range of ontologies and epistemologies on human-nature relationships (Rounsevell et al. 2018). Although there is a risk of reducing the IPBES approach to a simple policy-driven rebranding, the discussion is symptomatic of a need for change with respect to anthropocentrism. (Kenter 2018)

8.5 Conclusions

Scientific awareness on how green infrastructures benefit people has increased in recent years to include social, environmental and economic aspects. Nonetheless, the scientific community, citizens and institutions need to enhance their ability to rethink behaviours and choices starting with the strengthening, sharing and capitalising of knowledge and raising awareness of plants in the life of the planet. A correct use of native species in urban greenery can support the protection of landscapes, the best functional yield of the plants, the energy reduction in the management phases, the limitation of damages induced by the introduction of alien species, the safeguard and enhancement of biodiversity and the boost of companies oriented to rediscover, enhance and preserve the Italian floristic heritage.

Reflecting on the greenery of our cities is also a valuable opportunity to think about our way of being in the world by observing the most proximal relationship we can have with the plant world in our daily lives, not the wide satin landscape of the tourist magazines but a landscape of interstices, lines and small spots in the middle of the grey concrete. It is also necessary to overcome the total blindness (plant blindness) typical of the urban condition and allow to bring out the growing need for contact with the natural world to which we evolutionarily belong. Therefore, not a generical love for nature in an anthropocentric perspective, considering plants (and animals) only as resources for health, wealth, human well-being, but an intimate reconsideration of the *non-human,* starting from the recognition that the green colour of green infrastructure comes from several different species, worth to be recognized and given space of different nature.

The starting point is to learn how to recognise the *voices* of nonhumans, their language, their names, their diversity and their way of being in the world. What do we love when we love a plant? To what extent are we able to get out of the logic of *utility*? How light, respectful, attentive and discreet can it be to take care of them? Urban greenery with all the questions still open is then a fertile field where it is possible to confront each other, expand our knowledge and our feelings and, perhaps, become better people.

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Chapter 9
Stewardship Innovation: The Forgotten Component in Maximising the Value of Urban Nature-Based Solutions

Caroline Nash, Heather Rumble, and Stuart Connop

Abstract Nature-based solutions (NBS) enable the ecosystem service benefits associated with natural landscapes to be embedded into the built environment, simultaneously providing environmental, social, and economic benefits. This represents a mechanism for renaturing cities that can address many of the interrelated challenges associated with urbanisation and climate change. If NBS can be delivered effectively on citywide scales, it presents an opportunity for the development of sustainable, resilient, and liveable cities. Examples of innovation in relation to planning and delivering NBS are emerging globally. However, the stewardship plan, an essential element of NBS that typically underpins the long-term success of these high-profile initiatives, is often overlooked or under-planned. Careful consideration of the technical, financing, and governance aspects of NBS stewardship can be critical to determining whether an NBS is able to deliver the multifunctional benefits for which it was designed, adapt to changing needs and environmental conditions, and avoid becoming a liability to those communities it was designed to benefit. Here we present a series of case studies demonstrating how innovation in NBS stewardship can secure and maximise the long-term success of NBS and avoid the legacy of neglected or poorly managed *green wash*.

Keywords Urban planning legacy · Management · Maintenance · Biodiversity

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_9

9.1 Introduction

9.1.1 Valuing Nature: Ecosystem Services

Nature is a hugely beneficial asset to human society, providing us with a vital earth support system that creates the oxygen we breathe, cleans the water we drink, and provides the food we eat. In the last few decades, we have termed these benefits *ecosystem services* (ES). ES are defined as the benefits provided by ecosystems that contribute to making human life both possible and worth living (UK NEA 2011). These services can be at the global, landscape, or local scale. Whilst most proponents of the ES approach tend to think of whole organisms or ecosystems as providing ecosystem services or ES as direct products, for example, food and wood, the definition is extremely broad. At the global scale, Costanza et al. (2014) estimated that in 2011 we received $125 trillion of benefits from nature, compared to a global GDP of $75 trillion per year. Worryingly, they also estimated that between 1997 and 2011, $4–20 trillion per year of these benefits were being lost through land use change.

At the landscape scale, there are numerous examples of ecosystem service provision being enhanced to benefit cities. For example, for the last decade, the Forest Research, UK, has been engaging in a project to restore upland forests to decrease upland water flow, promoting woody debris build-up in streams and thus reducing the amount of water flowing down to the lower catchments, where urban areas typically lay (Nisbet et al. 2015). In Portland, Oregon, USA, large sections of upland riparian habitat have been purchased by the municipality in order to conserve wildlife and prevent development, reducing downstream flooding (The City of Portland Environmental Services 2020).

At a local scale, trees provide an enormous range of ecosystem services within cities. The surface area of a single mature tree is very large; for example, a densely leaved tree, such as the small-leaved lime (*Tilia cordata* L.), could have something like 100 m^2 of leaf surface area, whilst occupying only a fraction of this in realised crown space (Trowbridge and Bassuk 2004). This surface area traps particulates from the atmosphere (Nowak et al. 2006) and stores water droplets in rain events (the so-called interception, see Wang et al. 2008). In the London i-Tree Eco project (Rogers et al. 2015), it was estimated that London's urban forest, with it's 1140 km^2 of leaf area, removes 1700 tonnes of air pollutants, equivalent to £70 million in value.

9.1.2 Ecosystem Services Approach: Benefits and Trade-Offs

The popularity of the ecosystem services concept has been driven by the fact that a large range of ecosystem services are able to be quantified, monetised, and therefore compared to services offered by grey infrastructure. As such, this enables an architect to justify the inclusion of vegetation not only because of its aesthetic benefit but also because it is a long-term investment that will, for example, reduce the energy costs of the building (Nowak et al. 2017). Tree officers and parks managers, whose budgets are reducing over time, are now able to balance their books, demonstrating the monetary value that is being gained from ecosystems, as well as the costs involved in their installation and maintenance. Whilst proponents of ES see it as a necessary tool to ring-fence ecosystems in a strongly capitalist society, others have argued that some non-market benefits such as the social, cultural, and resilience values of ecosystems cannot be adequately evaluated using monetary metrics and continue to be missed as hidden externalities (Gomez-Baggethun and Ruiz-Pérezet 2011; Gomez-Baggethun and Barton 2013; Chan et al. 2012). This can lead to a focus on solutions that provide single or a narrow range of ecosystem services, with those that are difficult to value being overlooked. Nature-based solutions have emerged as a new framework for the delivery of ecosystem services that has the potential to address some of these pitfalls.

9.1.3 Nature-Based Solutions: An Emerging Model for Ecosystem Service Delivery

A nature-based solution approach promotes the maintenance, enhancement, and restoration of biodiversity and ecosystems as a means to address environmental, economic, and societal challenges simultaneously (Kabisch et al. 2016). Having emerged relatively recently, nature-based solutions are still evolving as a concept. The European Commission has developed and driven this priority area, defining them as (European Commission 2015: 4):

> […] actions which are inspired by, supported by or copied from nature. Many nature-based solutions result in multiple co-benefits for health, the economy, society and the environment, and thus they can represent more efficient and cost-effective solutions than more traditional approaches.

This is not, however, a universally adopted definition, and alternative descriptions have been proposed. The International Union for the Conservation of Nature has defined nature-based solutions as (Cohen-Shacham et al. 2019: 21):

> […] actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.

Whilst there is yet to be a consensus on an exact definition, the principles behind the definition are clear. The nature-based solution concept is intended to build on ecosystem services and ecological engineering approaches and offer an integrative and more holistic method for addressing ecological/environmental degradation and societal challenges, whilst delivering economic benefits and building resilience in the face of climate change (Nesshöver et al. 2017; Cohen-Shacham et al. 2019). As such, nature-based solutions represent an umbrella concept that incorporates ecosystem-based approaches (e.g. ecosystem services, green infrastructure) and goes beyond them in terms of its more explicit focus on addressing social and economic challenges and alignment with policy agendas (Cohen-Shachem et al. 2019).

9.1.4 Why Are Nature-Based Solutions Important?

With an urgent need to deliver on global sustainability challenges, and predictions that this need will be exacerbated by climate change, nature-based solutions represent potentially cost-effective sustainable solutions that work in harmony with nature rather than exploiting it (European Commission 2015). This is particularly the case in urban areas, where biodiversity has largely been excluded at the expense of grey infrastructure-engineered solutions. Research has identified the potential for nature-based solutions to address a broad range of urban challenges such as biodiversity conservation (Connop et al. 2016), stormwater management (Haase 2015), carbon capture (Davies et al. 2011), improving health and social cohesion (Kabisch et al. 2017; Rutt and Gulsrud 2016), and generating economic growth (Gore et al. 2013). Nature-based solutions have the potential to deliver more co-benefits than predominantly hard-engineered infrastructure (Raymond et al. 2017); they are generally more adaptive to changing conditions (Reguero et al. 2018) and therefore more resilient to climate change. Perhaps, most critically, their development is also more likely to involve local communities in a co-creation/co-production process. This facilitates a stronger focus on social benefits and stronger links to community ownership and stewardship of implemented nature-based solutions (Frantzeskaki 2019). Nature-based solutions can directly contribute to the delivery of Sustainable Development Goals (United Nations 2015; Cohen-Shachem et al. 2019), and there is growing evidence it is a cost-effective alternative to traditional approaches (Reguero et al. 2018).

9.1.5 Three Phases of Nature-Based Solution Implementation: Planning, Delivery, and Stewardship

To position Europe as a global leader in nature-based solution delivery, the European Commission Horizon 2020 programme has funded a series of research innovation actions to generate a more comprehensive evidence base and develop a framework for effective and more widespread implementation and upscaling of nature-based solutions (European Commission 2015). The Connecting Nature project represents one of the consortia funded through these innovation actions. The project brings together industry, local authorities, local communities, NGOs, and researchers to create a community of cities that fosters peer-to-peer learning and capacity building in the field of nature-based solutions. A key objective for the project is to facilitate cities in scaling up and scaling out innovative nature-based solution pilots, so that they can be implemented on a citywide scale and become the mainstream good practice approach to creating green, healthy, and resilient cities.

The consensus emerging from the Horizon 2020 nature-based solution projects is that there are key phases in the implementation of nature-based solutions. Whilst there is agreement over the differentiation between design and delivery phases (Somarakis et al. 2019), different approaches have been adopted when it comes to categorising the ongoing management of nature-based solutions. Some projects include this as part of the delivery phase (Somarakis et al. 2019); however the Connecting Nature project categorises three key phases associated with the implementation of nature-based solutions: planning, delivery, and stewardship (Connop et al. 2019). Here stewardship is defined as *the process of long-term management, operation, and maintenance in a way that protects and adaptively sustains the nature-based solution*. In relation to these categorisations, the *planning* stage examines (amongst other things) the challenges and policy priorities the city faces and the type/design of nature-based solution that could address these needs, and considers benefits/co-benefits/trade-offs, potential funding sources, and the range of stakeholder involvement needed for effective delivery. The *delivery* stage involves the implementation of the nature-based solution, including securing the necessary funding, ensuring that benefits and co-benefits are not lost during implementation, minimising impacts, and dealing with trade-offs if they arise. The *stewardship* phase is concerned with management, maintenance, and monitoring of the nature-based solution after delivery, to evaluate whether expected benefits are being sustained and (where necessary) to adaptively manage the project so that it has the flexibility to adjust to change over time and/or to future demands. The framework in Fig. 9.1 illustrates the role of stewardship in sustaining the delivery of nature-based solution benefits.

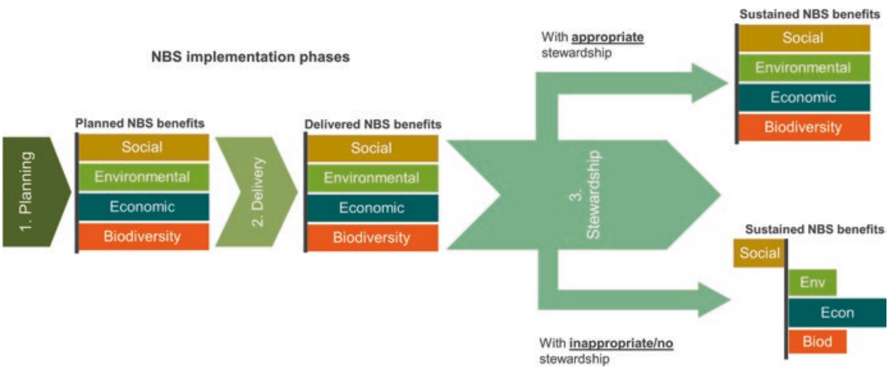

Fig. 9.1 Framework depicting an example of the role of stewardship in relation to the sustainable delivery of nature-based solution benefits. The framework comprises the three phases of nature-based solution implementation: Planning, Delivery and Stewardship

9.1.6 Stewardship: The Forgotten Component

During the process of exploring the barriers and drivers for nature-based solutions with Connecting Nature cities, it was evident that the majority of resources was typically devoted to the planning and delivery phases of nature-based solution implementation. Conversely, the stewardship phase received limited consideration and resources in comparison. Indeed, the stewardship phase was repeatedly identified as a key barrier to wider adoption of the nature-based solution approach. In particular, lack of technical experience in monitoring and evaluation and problems with governance and funding for long-term management/maintenance were identified as key challenges. For many pre-existing nature-based solution projects, the stewardship phase was almost entirely overlooked. This not only impacts the capacity of nature-based solutions to deliver benefits but also means that most cities have not generated an evidence base to demonstrate the multifunctional benefits of adopting a nature-based solution approach, thereby impeding its mainstreaming and upscaling at a policymaker/decision-maker level.

This lack of focus on the stewardship phase is also mirrored across nature-based solution case studies presented in emerging online databases. Whilst a plethora of nature-based solution good practice examples are emerging online (Nature4Cities 2019; Naturvation 2019), there is a tendency for these to focus on technical design, governance, and funding at the project planning and delivery stage, but with limited reference to technical performance, financing, and governance during the stewardship phase.

9.1.7 The Importance of Stewardship Planning

Ignoring or under-resourcing the stewardship phase of nature-based solution implementation brings with it risks, not just for the project itself but for nature-based solution implementation in general. Nature-based solutions are typically implemented to deliver a number of targeted benefits and a range of associated co-benefits. For these to be sustainable beyond the delivery phase, there is a need to ensure that the nature-based solution is appropriately evaluated, managed, and funded (Frantzeskaki et al. 2019; Somarakis et al. 2019). Without this approach, ecological, environmental, social, and/or economic benefits can be lost. Appropriate consideration of stewardship is also necessary to ensure that the nature-based solution is flexible enough to adapt to changing external conditions and future demands. Such changing demands can mean that merely attempting to retain the status quo of the original conditions at the time of delivery can be an ineffective strategy for delivering long-term benefits.

When stewardship is not effectively considered or resourced, the nature-based solution can become a white elephant (or even a liability) for the communities that it is intended to benefit (Fig. 9.2). Under such a scenario, it is often perceived to

Fig. 9.2 Example of a nature-based solution with inadequate stewardship. The stewardship of this stormwater management ditch was not considered in relation to appropriate management. As such, it is seen as a negative feature of the area and is used for dumping of trash. (Photo credit: Stuart Connop)

have *failed*. A prevalence of perceived *failed* nature-based solutions can act as a barrier to the rollout of further nature-based solutions (a drawback identified during Connecting Nature workshops with city practitioners). With nature-based solutions still an emerging concept, there remains scepticism regarding their performance compared to more established, traditional approaches. Schemes that are perceived to have failed or under-performed can therefore reinforce such scepticism and jeopardise further adoption of nature-based solutions. It is thus critical to ensure that the stewardship phase is given equal consideration and resourcing as the planning and delivery phases of nature-based solution implementation.

9.2 Case Studies

The following case studies demonstrate how innovation and forward-thinking in relation to ongoing stewardship can secure and maximise the long-term legacy of nature-based solutions, preventing pioneering projects from becoming neglected or poorly maintained *green wash*.

9.2.1 *Nature-Based Solution Stewardship: Technical, the Queen Elizabeth Olympic Park*

For many nature-based solution projects, the design focus is on technical performance, with this linked to the delivery of environmental, social, and economic benefits. However, for the technical design to sustain the desired level of performance in the long term, appropriate stewardship is crucial, otherwise ecosystem service delivery can diminish over time (Cohen-Shachem et al. 2019). The following case study illustrates that even when the technical design has resulted in pioneering and multifunctional nature-based solutions, inappropriate habitat management can potentially compromise a key ecosystem service benefit, in this case biodiversity and nature conservation, a primary target of the technical design.

London's Queen Elizabeth Olympic Park (QEOP) was built for the 2012 Olympic Games and has since been transformed into one of the largest urban parks in Western Europe. A fundamental aspiration was to break the mould of traditional park design and create a landscape that was multifunctional, inclusive, and sustainable. A key aspect of the technical design of the QEOP was that it would make a significant contribution to nature conservation and the environment, as well as promoting and delivering core objectives such as social equality, healthy lifestyles, employment opportunities, and economic growth. Biodiversity was considered to play a key role in achieving all of this, and therefore enhancing biodiversity was a top priority for the park (LLDC 2013). To achieve this, around 100 hectares (ha) of natural and semi-natural habitats have been created, including wetlands, wildflower meadows, and biodiverse brownfield habitat, as well as formal parks, recreational green spaces, and green roofs (ODA 2008). The habitat design for the QEOP was intended to set new standards and be an exemplar case in the delivery and management of wildlife-rich habitats within a high-profile urban park (Fig. 9.3).

Fig. 9.3 An area of the Queen Elizabeth Olympic Park, London UK, managed specifically to support biodiversity. (Photo credit: Stuart Connop)

As part of the exemplar approach, a biodiversity action plan (BAP) was developed for the park, and part of its function was to provide a long-term monitoring tool for evaluating whether ongoing management was delivering the biodiversity aspirations of the technical design. Ecological surveys measure and monitor biodiversity across the park, including a number of specific 'target' species and groups. These surveys have provided evidence of just how vital appropriate ongoing management practices were to sustaining the ecological legacy of this innovative urban green space. In particular, the results of invertebrate surveys of wildflower meadows and a biosolar green roof in the park identified that the meadows were being managed in a uniform way that was potentially detrimental to species and faunal groups that the technical design was intended to benefit.

Through the BAP monitoring, it became evident that standard maintenance actions for meadows were to cut and clear all vegetation at the same time towards the end of the main flowering period. Whilst some form of mowing/cutting is necessary to encourage flower diversity in meadows, such a blanket, essentially generic management approach, caused a catastrophic loss of above-ground plant resources for a whole range of biodiversity, including some of the park's target species. This is because countless species, including some pollinators, rely on resources within these meadows beyond just the pollen and nectar offered by flowers. For instance, for a broad range of fauna, winter seed-bearing flower heads provide food; thick grass tussocks are used for nesting and seed heads and stems for overwintering. Indeed, the results of the BAP monitoring surveys indicated there was a negative impact on biodiversity from this management approach, with dramatic declines in invertebrate species richness recorded in areas subjected to a blanket cut. Species quality index scores (an indicator of site quality) followed a similar trend, except in one meadow that was left uncut and on the green roof, which was never cut but *naturally* disturbed by the effects of summer drought stress.

The focus on managing wildflower meadows to provide pollen and nectar resources for bees/pollinators and the pressure to *tidy up* public pollinator havens appear to have made this approach standard practice, not just in the QEOP. In terms of the QEOP BAP, the outcomes of this practice were contradictory to the habitat requirements of several of their target species, as well as a broad array of other biodiversity. From the monitoring results, it was clear that innovative management was needed if the biodiversity aspirations for this urban green space exemplar were to be sustained.

Mosaic management represents one such innovative approach (Connop and Nash 2019). Inspired by the patchy, sporadic, and localised disturbances that occur on *open mosaic habitat on previously developed land* (OMH) – a highly biodiverse urban habitat – mosaic management is the antidote to prevalent regimented, blanket, and intensive habitat management practices. Instead, mosaic management uses a patchwork and rotational approach, where for wildflower meadows, some sections are cut whilst others are left uncut, and these are rotated on an annual or biennial basis. Uncut areas provide a continuity of resources, critical for the successful completion of the complex lifecycles of many insects. Meadow swards can be cut to different heights in different sections, increasing structural heterogeneity, and, if undertaken creatively, can create patterns and frames for uncut areas. This not only provides visual interest but ensures that areas look cared for. In terms of co-benefits, mosaic management can be more cost-effective and reduce greenhouse gas emissions as overall less cutting is needed annually than typical intensive management techniques.

After implementation of this mosaic management, the monitoring results were extremely positive. Species richness had increased by over 30%, and four times as many nationally rare species were recorded. Whilst species richness in all the mosaic-managed meadows surveyed that year had shown an increase, those that had been subjected to the standard blanket management had no change in the number of rare species. Without a replicated experimental set up, it is difficult to confidently determine causation of this increase in rare species. However, the fact that the number of rare species did not increase as dramatically in the other meadows suggests that this management approach could be an important factor and an effective driver for increasing the nature conservation value of urban wildflower meadows.

Learning outcome: This case study highlights that *locked in* habitat management practices based on custom and aesthetics must be transformed to meet the long-term technical aspirations of such innovatively designed nature-based solutions. It also illustrates the importance of evaluation of the technical aspects of stewardship to ensure that the original intended benefits and co-benefits of nature-based solutions are sustained in perpetuity.

9.2.2 Nature-Based Solution Stewardship: Governance, the Barking Riverside Community Interest Company

Nature-based solutions affect a broad range of stakeholders, and facilitating multi-stakeholder participation in projects can ensure the generation of multiple benefits (Ershad Sarabi et al. 2019; Nesshöver et al. 2017). Engaging communities in understanding the function and delivering the management of nature-based solutions can be crucial to its long-term success (Frantzeskaki et al. 2019). Without this involvement, citizens can misunderstand and undervalue nature-based solutions, potentially resulting in misuse or neglect. Ultimately, this can compromise multifunctionality, with nature-based solutions being perceived as a liability by the very community it was intended to benefit. Moving away from traditional, top-down, public-sector-led stewardship and actively involving local people in the governance of nature-based solutions can foster knowledge sharing and greater acceptance of this approach (Ershad Sarabi et al. 2019). Through active participation in the stewardship of nature-based solutions, local communities can develop a sense of ownership and empowerment, which not only engenders feelings of belonging and place but also offers an innovative mechanism to secure the successful and sustainable long-term stewardship of nature-based solution projects. The following case study illustrates how a new housing development has developed an innovative governance model to involve the local community in the stewardship of their local nature-based solution assets.

Barking Riverside, in the London Borough of Barking and Dagenham, is a 180 hectare brownfield site that is being transformed into a new sustainable community and will be one of the largest new housing developments in London. On completion it will comprise approximately 10,800 new housing units, along with seven schools, sport facilities, and a health and community hub, and around 40% of the site will be dedicated to green space and parkland. The vision for Barking Riverside is that it will be an exemplar of sustainable and resilient urban design and provide a healthy and well-connected community. Much of the innovation of the development resides in the way its ecological, cultural, and industrial heritage have been interwoven into the design, to make a positive contribution to local ecosystem service provision and climate change mitigation. Located on the riverfront, the site was historically part of the floodplains of the River Thames, until the landscape was industrialised and, for several decades, was occupied by a coal-fired power station. When this was decommissioned, the site transformed once more into a richly biodiverse, post-industrial brownfield site.

In recognition of this heritage, and the associated ecosystems service value of the pre-development site, a green infrastructure master plan was established to ensure that biodiversity and sustainability were core to the design for the Barking Riverside development. This included state-of-the-art nature-based solution features such as biodiverse green roofs designed specifically for locally important biodiversity, as well as multifunctional sustainable drainage systems (SuDS) that not only provided flood risk mitigation but also offered important habitat resources for wildlife and attractive recreational spaces that would contribute to the health and well-being of the local community. These features were integrated into the heart of the new neighbourhoods, to bolster sustainability and resilience and provide opportunities for residents to experience nature where they live (Fig. 9.4).

To encourage residents to understand and engage with the design, management, and maintenance of the local green and social assets within the development, the Barking Riverside Community Interest Company (CIC) was set up in 2009. A CIC is a form of social enterprise that has an overriding community purpose and has a formal legal status in the UK. An essential part of a CIC governance structure is the concept of *asset lock*, whereby all assets have to be held for the benefit of the community and any surplus proceeds used for community purposes. For Barking Riverside, this innovative governance model included key stakeholders involved in the development and served to empower local residents, through self-management, to support and create a sustainable community – socially, environmentally, economically, and also institutionally. As well as responsibility for control and management of the community and nature-based solution assets of the Barking Riverside development, the CIC will also function as an interface between new and existing communities, providing information and community services for incoming residents.

The Barking Riverside CIC was formally constituted through its governing document with powers to hold and manage the community social and green assets and

Fig. 9.4 An example of nature-based solutions within the public realm of the Barking Riverside development. The stewardship of this amenity, biodiversity, and stormwater management area will be taken over by the Community Interest Company. (Photo credit: Stuart Connop)

to invest in community cohesion, social enterprise activities, and local infrastructure according to the needs and wishes of local residents and businesses. The CIC is currently funded from the proceeds of ground rents and is expected to become self-financing when sufficient residential units have been constructed. Initially the CIC was established in partnership with the local authority – the London Borough of Barking and Dagenham and the development company Barking Riverside Limited, with two directors from each organisation represented on the CIC board. This institutional representation on the CIC board enabled residents to learn how such boards were run and to become familiar with the responsibilities and range and scope of activities open to the CIC. Once the CIC has built capacity amongst residents in terms of developing the required management and business skills, it will become an entirely community-led venture that manages assets for the benefits of all and upskills local people to improve their employment opportunities and prosperity.

Involving a resident group has already provided a way for the Barking Riverside CIC to effectively connect and relate to their local environment. As such, residents are now actively suggesting activities they would like to have at Barking Riverside and identifying opportunities for new nature-based solutions to be delivered through the CIC. For instance, a new garden has been created at one of the schools where children can grow food and foster contact with nature. **Learning outcome**: The Barking Riverside CIC offers an innovative governance model for holding and managing community assets at this neighbourhood scale and represents a sustainable and resilient method for delivering the stewardship of long-term nature-based solution benefits through community-engaged management and ownership.

9.2.3 Nature-Based Solution Stewardship: Finance, Glasgow SuDS Adoption

Ensuring that a financial legacy is in place is critical to the long-term functioning of nature-based solutions. Without this, the sustainable delivery of benefits and co-benefits cannot be guaranteed (Somorakis et al. 2019). Various opportunities exist in relation to sourcing the finance required for stewardship (e.g. payments for ecosystem services, adoption into local authority management duties, entrepreneurship associated with the nature-based solution that reinvests back into management, etc.) (Vandermeulen et al. 2011; Somorakis et al. 2019), with strategies typically based on the type and scale of the nature-based solution. However, compared to finance for planning and delivery, stewardship financing is often underestimated or even completely overlooked (personal communications, Connecting Nature cities). Even under the lowest-cost scenario (for instance, a voluntary/community group taking responsibility for maintenance), long-term funding will be required for stewardship operations such as maintenance equipment purchase/servicing, repairing damage, replacing plants, irrigation, and expert input on evaluation/redesign. Without financial planning for these whole life costs, it is unlikely the implemented nature-based solution will sustain its targeted performance. Moreover, this leaves little or no financial capacity for adaptation of the nature-based solution to changing demands and/or in relation to a changing climate. Under such scenarios, not only does this risk the nature-based solution become a liability, if it is perceived to have failed, it can also represent a barrier to future rollout of nature-based solutions.

Innovative approaches to securing the economic legacy necessary to ensure the sustainability of nature-based solutions are emerging. One such example is provided by the adoption of SuDS nature-based solutions in Glasgow. Glasgow is a city situated on the River Clyde in Scotland's West Central Lowlands (UK). It has a population of approximately 615,000 people. With a strong industrial heritage, the city has a history of population and industrial expansion and contraction. Currently, in a post-industrial phase, Glasgow is focused largely around tertiary sector industries such as financial and business services, communications, biosciences, creative industries, healthcare, higher education, retail, and tourism. Whilst the city hosts booming areas of regeneration, a matrix of luscious green parks, grand buildings, and many attractions, it also contains areas of deprivation and a high proportion of vacant and derelict land.

Like many cities of its era, it faces myriad challenges associated with its ageing infrastructure and changing demographics. A key challenge currently faced is its ageing stormwater infrastructure, a problem that is being exacerbated by climate change and is expected to worsen. Consequently, dealing with flood management and urban water has become a strategic priority for the city. Glasgow has embraced a nature-based solution approach to urban design, most recently through the development of a citywide open space strategy and through embedding green infrastructure principles into the city development plan. A nature-based solution approach is also reflected in the establishment of the Metropolitan Glasgow Strategic Drainage

Partnership (MGSDP), which focuses on the delivery of the national Flood Risk Management Act locally through the delivery of sustainable drainage systems (SuDS) solutions.

SuDS represent a departure from the traditional way of managing stormwater using grey infrastructure pipes that rapidly convey water offsite to an underground sewer network. Instead, SuDS mimic a more natural catchment approach and offer an alternative to using heavily engineered grey infrastructure that is proving to be costly and unsustainable in the face of ever-increasing demands on its capacity. By storing stormwater on site, allowing it to infiltrate into the ground, and/or releasing it more gradually, it is possible to reduce the demand on the sewer network, recharge groundwater tables, and improve water quality before it enters the sewer system. By using a nature-based solution approach to SuDS, it is also possible to provide a broad array of additional benefits including supporting biodiversity, providing relief from heat stress, providing green recreational and play spaces, improving air quality, and making more attractive living and work spaces (Woods Ballard et al. 2015).

Glasgow's Local Flood Risk Management Plan requires developers and engineers to produce flood risk assessments and drainage impact assessments for any development that will impact infiltration and drainage. The MGSDP requires, where possible, a SuDS approach to deal with these predicted impacts from new development. Responsibility for the management and treatment of water is shared between the local authority and the water company (Scottish Water). Originally, there was a consensus between the two partners that the stewardship of SuDS delivered on private property was the responsibility of the individual. However, it very quickly became apparent that, under such a scenario, stewardship was not carried out and that SuDS ceased to be effective: permeable paving blocked up with silt and was no longer permeable, overgrown swales no longer had the same storage and conveyance capacity, and detention basins filled with fly-tipping and rubbish. In response to this, it was recognised that SuDS stewardship needed to be transferred to an organisation that would look after it in perpetuity. As an example of innovation in collaborative stewardship of nature-based solutions, a memorandum of understanding was developed between Scottish Water and the Local Authority Highways Department to adopt all SuDS schemes implemented in Glasgow managing stormwater draining from public roads and/or the curtilage of housing or dwellings (land immediately surrounding it, including any closely associated buildings and structures). Such adoption is dependent upon the implemented SuDS being approved by local authority assessment and following Scottish Water design principles. Once adopted, however, a financial legacy is assured that will enable the SuDS systems (including nature-based solution SuDS) to be managed effectively and appropriately, securing the legacy of the scheme (Fig. 9.5).

The memorandum of understanding determines that Scottish Water will take responsibility for below-ground aspects of the SuDS and the local authority will take responsibility for the above-ground aspects. In urban areas, this can mean that the burden of stewardship falls upon the local authority, as the majority of maintenance is litter removal and vegetation management. However, whole life cost analysis (Pittner and Allerton 2004) was used as a foundation for this memorandum, and

Fig. 9.5 An example of a well-adopted Sustainable Drainage System (SuDS). Consideration for the SuDS stewardship means that it is well-managed and considered to be a valuable asset by the local community

this includes the cost of replacement of the asset if it is no longer functioning. This replacement responsibility falls upon Scottish Water, and, as such, it was determined that the burden of cost would be split equally between the two partners. Such an approach was found to be cost-effective for both partners as, due to the division of responsibility for aspects of water treatment, conveyance, and management in relation to roads and curtilage, the alternative would be that each partner would have to look after an entire sewer pipe system in isolation. It is cheaper to look after half a system than a whole system and, as such, represents value for money for both partners and a mechanism to provide wider benefits.

Learning outcome: This approach represents an excellent example of collaborative working for a combined goal, and an innovative example of ensuring that stewardship finance is in place to secure sustainable functioning of nature-based solutions in perpetuity even when developed on private land.

9.3 Concluding Summary

These case studies detail some emerging innovative approaches for ensuring a sustainable legacy to nature-based solution implementation. Such approaches are vital if nature-based solutions are to be effective in delivering on their design aspirations and if barriers to more widespread rollout across our cities and rural landscapes are to be broken down. It has been suggested by other researchers that assessing diverse case studies is an important tool for operationalising nature-based solutions, demonstrating their value and their effectiveness and highlighting knowledge gaps and potential challenges (Kabisch et al. 2016; Cohen-Shacham et al. 2019). In order to raise awareness of the importance of the stewardship phase, it is essential that good practice is captured and shared on databases showcasing nature-based solution projects globally. Only by recognising the importance of the stewardship phase will the long-term performance of nature-based solutions be secured, a critical step if nature-based solutions are to be considered a viable and reliable approach to tackling socio-environmental and economic challenges.

Acknowledgements The authors would like to thank Mic Ralph (Transport Planning Manager, Development & Regeneration Services, Glasgow City Council) and Dr Paula Vandergert (Senior Research Fellow, University of East London) for their help gathering the case study information. We would also like to thank the Connecting Nature partners for their work gathering data on barriers and drivers for nature-based solution implementation. The Connecting Nature project is funded by the Horizon 2020 Framework Programme of the European Union Grant Agreement No 730222.

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Chapter 10
Nature as Model: Evaluating the Mature Vegetation of Early Extensive Green Roofs

Christine Thuring and Nigel Dunnett

Abstract Nature served as the model for the early designers of extensive green roofs, who drew inspiration from spontaneously vegetated gravel roofs as well as natural plant communities. This chapter evaluates the nature-based model by assessing the conditions that shaped the vegetation of a sample of old extensive green roofs (EGRs), two to three decades after installation. With a special focus on the conditions that shaped the plant communities surveyed, the ecological requirements of each species were evaluated by using the ecological indicators sensu Ellenberg, which relate environmental variables to the composition of species assemblages. Overall, the mature vegetation was characterised by species of warm, well-lit environments that are tolerant and/or indifferent to freezing and moisture extremes and with preference for neutral, nitrogen-poor soils. Cluster analyses defined three major vegetation types, including *Sedum* meadows with varying degrees of floristic diversity. These findings vindicate the ecological intuition behind the habitat template used in the early research and development of green roof technology, while also hinting at complexities of conditions and mechanisms behind species assembly. Applying nature's model may broaden the potential of green roofs as urban ecosystems. If ecological function is deemed important, then green roof guidelines must integrate relevant details into their recommendations.

Keywords Ellenberg indicator values · Old green roofs · Floristic diversity · Ecological intuition · Habitat template approach

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_10

10.1 Introduction

10.1.1 Background and History

Nature served as model for the German pioneers of extensive green roof systems in the 1970–1980s. On the one hand, the plant communities of spontaneously vegetated gravel roofs were considered templates. In particular, tar-paper gravel roofs of the nineteenth century had been studied and described by early plant sociologists, and this provided an empirical basis for the research and development of modern, low-maintenance green roof systems. On the other hand, early designers also drew reference and inspiration from natural plant communities with the understanding that the growing conditions on shallow, free-draining roof substrates would drive plant selection. Drawing inspiration from these natural models, plant trials were conducted to screen species of regional provenance, as well as cultivars bearing promising traits.

By 1971, the first extensive green roof (EGR) products appeared on the German market, alongside improved waterproofing and drainage (Adler 2005). EGRs are defined by shallow substrates (5–20 cm) and weigh between 60 and 240 kg/m^2. In the time since those first prototypes became commercialised, EGRs have become popular technologies because of the numerous benefits and services they provide (Oberndorfer et al. 2007). In 2014, Germany had a roughly 86 million m^2 of green roofs, with around eight million additional m^2 added every year (EFB 2017). Within Europe, Germany still has by far the greatest share of green roof coverage, with yearly sales amounting to around 250 million euros (EFB 2017). Green roof implementation grew markedly beyond Europe since the late 1990s, particularly in North America, in the UK and Australia, but also in tropical and Mediterranean countries.

The widespread use of EGRs is due to their relatively low cost, their simplicity and their versatility. Being shallow and relatively light, EGRs can often replace gravel ballast roof retrofits. Shallow depths also reduce maintenance, since only the hardiest plants will survive, namely, species with minimal needs and negligible biomass (Dunnett et al. 2008). Along with the technical systems, the species lists and substrate compositions originally devised in the 1970–1980s are still recognisable within the present day industry, both in Germany and abroad. This can be attributed to the technical and rigorous guidelines developed by the German Landscape Research, Development and Construction Society (FLL), which have been referred to in the establishment of green roof regulations in other countries (Catalano et al. 2018).

This chapter evaluates the nature-based model by assessing the conditions that shaped the vegetation of old green roofs over the span of two to three decades. In a sense, we evaluate the habitat template approach, a term first attributed to green roofs by Lundholm (2006) and since revaluated (Lundholm and Walker 2018). The original term proposed a framework to describe how the evolution and adaptive strategies of species were determined by the characteristics of a habitat (Southwood 1977), which serves green roof ecology studies well.

10.1.2 Nature as Model

10.1.2.1 Spontaneous Green Roof Vegetation

The *Holzcementdach* (Koch 1894), or tar-paper gravel (TPG) roof, was relatively common across Central Europe from 1860 until the mid-twentieth century. The system was developed in 1839 by Samuel Häusler in Silesia (south-western Poland) and became popularised across Europe after it proved to withstand the ravages of two city fires in that region (Koch 1894). Standards varied from city to city, but TPG constructions generally involved 3–4 layers of reel paper fixed onto a wooden deck with a bonding agent of pitch, tar and brimstone (Fig. 10.1). This "wood cement" was very durable and remained elastic over time. The tar component, being a root repellent, ensured leak protection. The waterproofing was protected from foot traffic by layers of finely sieved sand (10–15 mm), loamy sand (<30 mm) and gravel ballast (30–50 mm).

In addition to protection from fire, hail, foot traffic, etc., the sandy-gravel layers of these undisturbed roofs supported long-lasting plant communities and soil development, which piqued the curiosity of ecologists. Inspired by Kreh's (1945), *The plant world of our gravel roofs in Stuttgart*, in the 1950s, Reinhard Bornkamm (1961) expanded his work on plant ecology and community classification to include old TPG roofs in Göttingen (1961). Later, while Bornkamm's students continued these observations in Berlin (Darius and Drepper 1983) (Fig. 10.2) and Osnabrück (Bossler and Suszka 1988), EGR systems started to emerge. Apparently aware of these developments, in the introduction of their diploma thesis, Darius and Drepper (1983: 4–5) stated:

> Naturally, the vendors of particular green roof systems may object that gravel roofs do not deliver optimal results with respect to evaporation, water storage, thermal insulation, etc. […] Still, we commend the simple construction of these old gravel roofs, as it is economical and the earth fill can be installed at one's own initiative. And whoever is interested can observe for themselves whether the spontaneous colonisation by plants progresses, as hypothesised, by our research (Authors' translation).

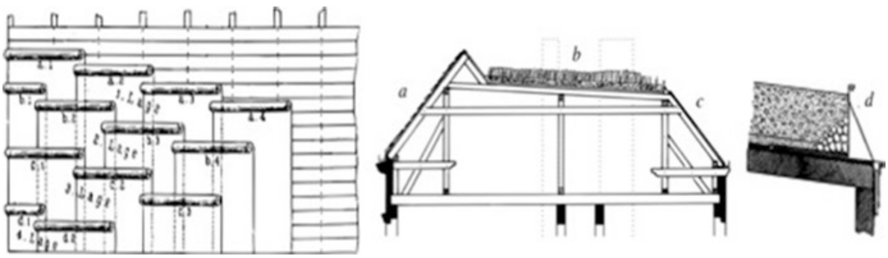

Fig. 10.1 Tar-paper gravel roofs involved glue-brushing overlapping paper using "wood cement" onto a wooden roof deck (on the left), the protecting it with layers of sand, loam and gravel (on the right). (From Koch 1894)

Fig. 10.2 Cover image from Darius and Drepper (1983) thesis, "Ecological investigations of vegetated gravel roofs in West-Berlin"

10.1.2.2 Natural Ecosystems

The naturally occurring plant communities to which all shallow green roofs in Europe are related, whether through intentional design or spontaneous formation, are framed into the phytosociological class *Sedo-Scleranthetea* (Bornkamm 1961; Bossler and Suszka 1988; Buttschardt 2001; Darius and Drepper 1983; Thommen 1988). Plant communities belonging to *Sedo-Scleranthetea* occur in well-lit environments with little to no shade, on soils less than 100 mm deep, and these species assemblages are characterised by a preponderance of evergreen species that produce flowers from May to September (Ellenberg 1986). Technically, these communities are defined as nutrient-poor grasslands consisting primarily of low-growing herbs, short-culmed and thin-leaved grasses, mosses and lichens. The herbaceous species linked to these communities are mostly succulents, in particular *Sedum* species, and winter annuals (Ellenberg 1986). Correspondingly, the Central European plant communities screened for physiologically appropriate and ecologically pre-adapted species to be used on the roofs included dry grassland, montane scree, cliffs and talus slopes (Krupka 1985), as well as steppe, heath and sandy habitats (Kolb et al. 1983).

10.1.3 Plant Communities Described with Ecological Indicators

As in natural habitats, urban flora is shaped by environmental, physical and chemical conditions and filtered by the availability and spatial arrangement of habitats, the pool of species and evolutionary selection pressures (Pickett et al. 2009; Williams et al. 2009). To explain some of these driving factors, ecological indicators can elaborate on the strategies and needs of the species identified within a vegetation type. For the Central European flora, Ellenberg indicator values (EIVs) represent one of the best-known systems of bioindication (Persson 1981; van der Maarel 2005). They are routinely used for rapidly estimating site conditions relating to species composition when values for environmental variables are not available or difficult to measure (Diekmann 2003). EIVs help plant scientists to better understand the autecology of plant species and are useful for determining the habitat conditions of a site depending on the presence or absence of anticipated species (Humbert et al. 2007).

Provided their limitations are recognised, EIVs have been found to be reliable and robust (Diekmann 2003; Ewald 2003). EIVs were not designed to define species' ecological requirements, which can only be credibly established through physiological inquiry of competition-free cultures (Ellenberg et al. 1991). The common occurrence of a species in particular circumstances does not mean that the species is at its physiological optimum but rather that it is a good competitor in those specific circumstances. In that regard, EIVs describe the *ecological existence* rather than the *ecological potential* of a given species in a particular habitat (Humbert et al. 2007). Indeed, the potential range (physiological behaviour) of all plant taxa is typically greater than their range of existence (ecological behaviour) at the larger (landscape) scale. As with any generalising method, care must be taken to avoid biased results and misinterpretations (Zeleny and Schaffers 2012).

Other studies seeking to understand the ecological processes on green roofs, and the long-term effects of rooftop growing conditions, surveyed *mature* roof vegetation and used EIVs in their analyses, too. Unsurprisingly, this work is limited to Germany, where the oldest green roofs are to be found and where EIVs are a practical tool. In Osnabrück, Bossler and Suszka (1988) attributed EIVs to the species they identified on eight spontaneously vegetated gravel roofs of different types and ages, including five TPG roofs installed at the turn of the century and three sand-gravel roofs dating to the 1960s. In Karlsruhe, Buttschardt (2001) used EIVs to describe the spontaneous vegetation of 4 EGRs 15–20 years after installation; he also surveyed 17 TPG roofs, while in Berlin, Poll (2008) surveyed 8 TPGs and 13 EGRs. Building on those results, Köhler and Poll (2008) synthesised the data from 6 other plant ecological studies of vegetated roofs, including 150 TPG roofs in Göttingen by Bornkamm (1961), the 22 TPG roofs surveyed by Bossler and Suszka (1988) in Osnabrück and, in Berlin, 55 TPG roofs surveyed by Darius and Drepper (1983), 11 TPG roofs surveyed by Baier and 8 EGRs surveyed by Jänel.

10.1.4 Research Aims

This chapter explores whether the assumptions of analogue communities line up with actual growing conditions on the roofs. How accurate or effective is the habitat template approach? How have those assumptions fared over the long term? Accordingly, by characterising the growing conditions of EGRs in a temperate continental climate using indicator values, the research aims to characterise *mature* green roof vegetation types.

10.2 Methods

Using methods of field ecology and descriptive analyses associated with plant community ecology, this chapter describes the mature vegetation of EGRs with a special focus on the growing conditions that shaped the species assemblage.

10.2.1 Description of the Roofs Sampled

Since the green roof industry began in south-west Germany, the oldest roofs are located in this region. An industry-academia partnership between the University of Sheffield and ZinCo GmbH helped grant access to a number of old roofs along with documentation of their construction, components and maintenance in some cases. Some of the roofs were prototypes at the time; some became typical products on the global market. The roofs surveyed were within 50 km from the city of Stuttgart (Germany, 48°47’ N, 9°10′ E; 252 m a.s.l.), including smaller cities like Esslingen, Köngen and Tübingen (Fig. 10.3). This region is characterised by a warm-temperate continental climate, i.e. warm summers, cold winters and no dry season (Kottek et al. 2006). Most of the annual rainfall (annual average, 689 mm) occurs during summer (highest average in June, 96 mm) (DWD Climate Data Centre 2016).

Roof selection was determined by accessibility, age and location within the region. In addition to six of the industry partner’s oldest installations, three non-ZinCo roofs were surveyed. Table 10.1 presents the roofs in order of age, with reference to their physical characteristics (area, slope, depth) and environmental conditions (aspect). The range of characteristics of the selected roofs presented opportunities for description although it also posed challenges to analysis. Notwithstanding their differences, the roofs were all typical extensive green roofs, in line with the *principles of green roofing* published by the FLL Research Society in 1982 (8 years before the first FLL guidelines). The roofs surveyed all employed multiple-layered systems and featured dominant *Sedum* coverage with varying cover by flowering herbs and grasses (Fig. 10.4).

Fig. 10.3 The study area included sites in Stuttgart, Köngen, Nürtingen, Tübingen and Esslingen

Table 10.1 Details of nine old EGRs sampled over two growing seasons (2010, 2011) in Stuttgart region

Roof name	Date installed	Area (m²)	Slope (°)	Aspect	Depth (mm) (mean ± standard error)
Killesberg	1991	450	30	N- and S-face	84.7 ± 0.7
Stuttgart Rathausgarage, lower roof	1990	1000	0	None (flat)	69.7 ± 0.7
Stuttgart Rathausgarage, PV	1990	1300	0	None (flat)	75.2 ± 2.9
FH Nürtingen	1987	258	0	None (flat)	72.3 ± 4.2
Köngen, Römermuseum	1987	350	17, 15	NW-SE-facing	78.1 ± 5.6
Tübingen, Gärtnereihof	1986	2160	15	N- and S-face	61.5 ± 0.6
Esslingen Verkehrsbetrieb 1	1986	1860	0	None (flat)	53.3 ± 0.5
Esslingen Verkehrsbetrieb 2	1986	2064	0	None (flat)	58.1 ± 0.6
Pliensaufriedhof	1977	500	0	None (flat)	61.6 ± 0.6

10.2.2 Vegetation and Substrate Sampling

Primary survey methods with ecological objectives were deemed appropriate for absorbing the diversity of roof constructions since the intent was to correlate local variation in vegetation composition with variation in environmental factors (van der Maarel 2005). The surveys took place over two growing seasons (2010 and 2011),

Fig. 10.4 The nine EGRs surveyed were all multi-layered systems with under 10 cm substrate depth

with each roof sampled for vegetation and substrate. They are considered *snapshot surveys* because the quality of the data is like that of a photograph: colourful and detailed but statically limited to that particular moment in time. In order to provide the option for future repeated sampling, the corners of all sample plots were marked with permanent labels, and detailed maps were prepared which illustrate quadrat locations.

10.2.2.1 Vegetation Sampling

Floristic sampling occurred once per roof, from early June to mid-July, over the course of several days. The methods for vegetation sampling and description followed the *National Vegetation Classification Users' Handbook* (Rodwell 2006). Taxonomic nomenclature was standardised using The Plant List (2013). Substrate was collected in autumn, after above-ground plant material had been removed.

Above-ground cover abundance was measured using a 1 m^2 quadrat to record per cent cover (% per m^2) for individual species and growth forms (woody, grasses, succulents, forbs, bulbs, bryophytes). Grouping species has the draw-back of masking the variation of ecological strategy within a group, but it can also reveal important environmental factors influencing the structure of the vegetation (Kent and Coker 1994; van der Maarel 2005). Although they qualify as forbs, sedums were separated as a unique group (succulents) because of their structures and strategies (Sayed 2001). On each roof, between 12 and 18 quadrat plots were sampled. The number and placement of quadrats were determined by site conditions and environmental gradients, surface area, vegetation homogeneity and the statistical requirements of sampling (Kent and Coker 1994).

10.2.2.2 Substrate Sampling

The same quadrats used for vegetation surveys were sampled for substrate. Substrate depth was measured from the surface down to the filter layer. Mean depth was calculated from three measurements at different edges of the quadrat; the values from all quadrats calculated the mean depth per roof. Sampling was accomplished using a (100 mm) soil corer (Firma Schwab, Waidhofen). The roof at Killesberg was not sampled due to its steep slope. Twenty litres (20 L) were collected per roof for physical-chemical analysis, with between one and two cores per quadrat. Cored gaps were refilled with a commercially available green roof substrate.

10.2.3 Data Analysis

10.2.3.1 Ellenberg Indicator Values

By describing the range of conditions in which species occur, Ellenberg indicator values (EIVs) concurrently describe the known ecology and the capacity of those species. On a nine-point ordinal scale (1 = low; 9 = high), EIVs provide quantitative estimates of the ecological behaviour of vascular plants. Specifically, they estimate the ecological preferences of species based on their occurrence in relation to:

- L, light (relative light flux during summer).
- T, temperature (latitudinal zones and altitudinal belts).
- C, continentality (degree of tolerance to max-min temperatures with reference to a climatic gradient from coast to inland).
- M, moisture (soil moisture and water supply).
- R, reaction (soil H and calcium content).
- N, nitrogen (soil ammonia and nitrate supply).

EIVs describe the habitat conditions of species, so this chapter refers to them interchangeably as EIVs and habitat indicators. To evaluate a habitat using EIVs, Ellenberg and others recommend the use of mean EIVs along with the range of conditions for the sites surveyed (Humbert et al. 2007; Persson 1981; Radula et al. 2018). Of the 94 species recorded, 75 had EIVs assigned to them (with the exception of nitrogen, which only 25 species allocations).

10.2.3.2 Cluster Analysis

With the aim of understanding the conditions that drive species assemblage, the habitat indicators associated with the roof vegetation were used to describe different vegetation types. A cluster analysis grouped the nine roofs based on similarities in their range of EIVs, species richness and cover dominance. This latter variable permitted the *weighting* of the cover to represent species that were part of, but not dominant to, the roof vegetation. The *single linkage* (or *nearest neighbour*) method was used, which allows clusters to form hierarchically. Since EIVs are ordinal, no statistical significance can be inferred from the observations.

10.3 Results and Discussion

10.3.1 Characterising the Growing Conditions of Extensive Green Roofs in a Temperate Continental Climate

The results and discussion that follow refer directly to the habitat descriptions and ecological indicators summarised by Ellenberg et al. (1991). With their associated EIVs, the species gave an overall impression of the environmental and ecological conditions that shaped the surveyed communities. On average, the roofs surveyed were defined by species of warm, well-lit to full light environments, tolerant of and/or indifferent to freezing, extreme dryness or wet conditions and with a preference for neutral, nitrogen-poor substrates (Table 10.2). The analyses that follow refer to the mean and the range EIVs expressed by the species observed (Table 10.3) (Boxes 10.1 and 10.2).

Table 10.2 Mean results (bold) and range of variation (extreme values) of the EIVs concerning the surveyed EGR plant communities

	Min	Mean	Max
Light (L)	4	8	9
Temperature (T)	2	5.7	7
Continentality (C)	2	4.1	7
Moisture (M)	2	2.7	9
Reaction (R)	2	5.6	9
Nitrogen (N)	1	2	8

Table 10.3 Species list with EIVs from surveyed vegetation of 9 old extensive green roofs

	Ellenberg indicator values (EIVs)					
Species name	L	T	C	M	R	N
Acer campestre L.	5	6	4	5	7	6
Acer pseudoplatanus L.	4	0	4	6	0	7
Achillea millefolium L.	8	0	0	4	0	5
Agrostis stolonifera L.	8	0	5	0	0	5
Agrostis tenuis Sibth.	7	0	3	0	4	4
Allium flavum L.						
Allium schoenoprasum L.	7	0	7	0	7	2
Arrhenatherum elatius (L.) J. & C. Presl.	8	5	3	5	7	7
Campanula rotundifolia L.	7	5	0	0	0	2
Carex flava L.	8	0	2	9	8	2
Carex humilis Leyss.	7	6	5	2	8	3
Carpinus betulus L.	4	6	4	0	0	0
Cerastium arvense L.	8	0	5	4	6	4
Convolvulus arvensis L.	7	6	0	4	7	0
Coronilla varia L.	7	6	5	4	9	3
Crepis tectorum L.	8	6	7	4	0	6
Dactylorhiza fuchsii L.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Dianthus carthusianorum L.	8	5	4	3	7	2
Dianthus deltoides L.	8	5	4	3	3	2
Erigeron annuus (L.) Pers.	7	6	0	6	0	8
Festuca ovina L.	7	0	3	0	3	1
Festuca rubra L.	0	0	5	6	6	0
Fragaria vesca L.	7	0	5	5	0	6
Geum urbanum L.	4	5	5	5	0	7
Hieracium pilosella L.	7	0	3	4	0	2
Hypericum perforatum L.	7	6	5	4	6	3
Linum perenne L.	7	0	6	3	8	2
Lotus corniculatus L.	7	0	3	4	7	3
Medicago lupulina L.	7	5	0	4	8	0
Nepeta racemosa Lam.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Petrorhagia prolifera (L.) Ball & Heywood	8	7	3	3	5	2
Petrorhagia saxifraga (L.) Link.	9	7	4	2	7	1
Picris hieracioides L.	8	0	5	4	8	4
Pinus sylvestris L.	7	0	7	0	0	0
Poa angustifolia L.	7	5	0	0	0	3
Poa compressa L.	9	0	4	2	9	2
Poa pratensis L.	6	0	0	5	0	6
Potentilla argentea L.	9	6	3	2	3	1
Potentilla erecta (L.) Räuschel	6	0	3	0	0	2
Potentilla tabernaemontani Aschers.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

(continued)

Table 10.3 (continued)

	Ellenberg indicator values (EIVs)					
Species name	L	T	C	M	R	N
Potentilla recta L.	9	7	5	3	5	2
Sedum acre L.	8	6	3	2	0	1
Sedum album L.	9	0	2	2	0	1
Sedum kamtschaticum Fisch. cvar. Weihenstephaner Gold	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sedum hybridum L.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sedum rupestre L.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sedum sexangulare L.	7	5	4	2	6	1
Sedum spurium Bieb.	8	6	4	3	5	3
Sedum telephium L.	7	6	0	4	7	0
Sempervivum tectorum L.	8	0	2	2	4	0
Setaria viridis (L.) P. Beauv.	7	6	0	4	0	7
Solidago canadensis L.	8	6	5	0	0	6
Taraxacum officinale Weber	7	0	0	5	0	7
Teucrium chamaedrys L.	7	6	4	2	8	1
Thymus praecox Opiz	8	6	5	3	8	1
Thymus pulegioides L.	8	0	4	4	0	1
Thymus serpyllum L.	7	6	5	2	5	1
Trifolium arvense L.	8	6	3	3	2	1
Trifolium campestre Schreb.	8	6	3	4	6	3
Trifolium dubium Sibth.	6	6	3	5	6	5
Trifolium pratense L.	7	0	3	0	0	0
Verbascum nigrum L.	7	5	5	5	7	7
Verbascum thapsus L.	8	0	3	4	7	7
Veronica spicata L.	7	7	6	3	7	2
Vicia hirsuta (L.) S.F. Gray	7	6	5	4	0	4
Vicia sepium L.	0	0	5	5	6	5
Vulpia myuros (L.) C.C. Gmel.	8	7	3	2	5	1
Bryophytes						
Brachythecium cf. *albicans* (Hedw.) Schimp	9	3	5	2	x	
Brachythecium rutabulum (Hedw.) Schimp.	5	x	5	4	x	
Calliergonella cuspidata (Hedw.) Loeske	8	3	5	7	7	
Ceratodon purpureus (Hedw.) Brid.	8	x	x	2	x	
Dicranum scoparium Hedw.	5	0	5	4	4	
Eurhynchium praelongum (Hedw.) B., S. & F (*E. stokesii* sensu *Auct.*)	6	4	5	6	5	
Philonotis fontana (Hedw.) Brid.	8	0	6	7	2	
Polytrichum juniperinum Hedw.	8	2	?	4	3	
Racomitrium elongatum Ehrh. ex Frisvoll	8	3	6	9	5	
Scleropodium purum (Hedw.) M. Fleisch	6	4	5	4	5	

Box 10.1 Definitions for EIVs Relating to Climate

	Light	Temperature	Continentality
	Species occurrence in relation to the relative light intensity, indicating	Species occurrence in temperature gradients (Mediterranean to Arctic; lowland to alpine), indicating	Species occurrence along a gradient from the mild coast to the extremes of continental inland, indicating
1	Deep shade	Cold temperatures	Extremely oceanic, few freezing days
2	Between 1 and 3	Between 1 and 3	Oceanic
3	Shade	Cool temperatures	Oceanic to suboceanic
4	Between 3 and 5	Between 3 and 5	Suboceanic
5	Semi-shade	Temperate warm preferences	Intermediate between suboceanic and subcontinental
6	Between 5 and 7	Between 5 and 7	Subcontinental
7	Semi-shade to partial light	Warm temperature	Between 6 and 8
8	Partial to full light	Between 7 and 9	Continental
9	Full light, full sun	Extreme warm temperatures	Extremely continental, eastern

Adapted from Ellenberg et al. (1991)

Box 10.2 Definitions for EIVs Relating to Soil

	Moisture	Reaction	Nitrogen
	Species occurrence along a gradient from dry shallow soils to wet marshy ground, indicating	Species occurrence along a gradient of soil pH or reaction, indicating	Species occurrence in a gradient of fertility during the growing period, indicating
1	Extremely dry soils	Extreme acidity	Extremely nitrogen-poor, infertile soil
2	Between 1 and 3	Between 1 and 3	Between 1 and 3
3	Dry site indicator	Acidity	Infertile soil
4	Between 3 and 5	Between 3 and 5	Between 3 and 5
5	Semi-moist soils	Fairly acid	Intermediate fertility
6	Between 5 and 7	Between 5 and 7	Between 5 and 7
7	Moist or damp, but not wet, soils	Weakly acid to weakly basic conditions	Richly fertile
8	Between 7 and 9	Between 7 and 9	Between 7 and 9
9	Wet site, often saturated, poorly aerated soils	Basic or limestone soils	Extremely rich sites, such as cattle resting places

Adapted from Ellenberg et al. (1991)

10.3.1.1 Light

The light EIV describes species' occurrence in relation to the relative light intensity, where shade-loving plants have the lowest value (L1) and full-light species are L9. According to the vegetation, it is evident that the green roofs surveyed supported a wide range of light conditions with the exception of deep shade. The majority of species occurred in L7 (27 species) and L8 (23 species), and most roofs had a mean of L8. The indicator L7 refers to plants generally in well-lit places but also occurring in partial shade, while light-loving species (L8) are rarely found where there is less than 40% relative light. The herbaceous plants of full light, found only in full sun and rarely in less than 50% relative light (L9), included typical green roof plants like *Petrorhagia saxifraga* and *Sedum album*.

Other surveys focused on mature vegetation found the same results, for all systems studied. In Osnabrück, a range of L7–L8 was established for eight spontaneously vegetated gravel roofs, which included five TPG roofs (>90 years old) and three sand-gravel roofs 20–24 years old when surveyed (Bossler and Suszka 1988). In Karlsruhe, four EGRs (15–20 years old) had mean values of L7.1 (Buttschardt 2001). In Berlin, Poll (2008) observed a range of L7–L8 for 8 TPGs and 13 EGRs. In their synthesis of plant ecological studies, Köhler and Poll (2008) reported similar results. The growing conditions of shallow green roofs clearly select for light-loving species, which rarely occur in environments with less than 40% relative light. In other words, the mature vegetation of shallow roofs is suited to high-light environments that also feature partial shade but does not generally include species that require deep shade. It is striking that full-light species were in the minority, both in this and in other studies, as this runs contrary to the view that green roofs are full-light environments. The latter may be true to a certain degree, but the effects on species assemblage are likely dampened by other conditions, especially moisture availability, temperature, the effect of wind and the complex impact these conditions have on species competition.

10.3.1.2 Temperature

For these analyses, temperature is defined by species' occurrence in the European temperature gradients from the Mediterranean to the Arctic and from lowland to alpine elevations. The majority of species (22) identified here qualified as T6, which was also the mean for the nine roofs surveyed. T6 refers to a range of habitats (T5–T7), including temperate warm indicators (T5) and warm indicators (in north-central Europe only, in relatively warm low-lying areas) (T7).

In their surveys of extensive and TPG roofs, Buttschardt (2001) and Poll (2008) found similar results, with the majority of species at T6, though Bossler and Suszka (1988) reported a mean of T5.3 in Osnabrück. It is possible that species with high affinities for temperatures may prevail on older green roofs because they would have endured more hot periods than recently installed systems (Madre et al. 2014). Still, while EGRs are defined as warm environments, the absence of extreme warm indicators (T9) or species with very warm preferences (T8) may reflect the effect of exposure. While green roof analogue habitats, like mountains or coastal bluff, also feature warm temperatures, their exposure (to wind, frost, etc.) inhibits warm-loving species from establishing (Benvenuti and Bacci 2010; Van Mechelen et al. 2014). Temperature measurements of vegetation layers on EGRs in Heidelberg (Germany) recorded over 60 °C in summer and well below 0 °C in winter (Riedmüller 1994). Temperature conditions on EGRs are also influenced by the microclimate created by evapotranspiration, and this latter point is described by the next habitat indicator, continentality, which links temperature with moisture.

10.3.1.3 Continentality

Continentality refers to species' occurrence in the gradient from the mild coast to the extremes of the continental inland. In the case of Europe, this gradient runs from the Atlantic coast to the inner parts of Eurasia. On a scale of 1 to 10, C1 species occur in oceanic climates with few freezing days, while species occurring in C8 through to C10 are found far from the ocean and must be able to tolerate more extreme temperatures. In the urban context, continentality may reflect thermally enhanced situations like the urban heat island (UHI). Cities in continental climates may experience the UHI more intensely than those situated in maritime regions because the latter have more complex and windy weather systems (Kendle and Forbes 1997).

Ten of the 75 species with EIVs were indifferent to continentality (C0); the remaining 65 produced a near-normal distribution, with C5 as most prevalent. Species described by C5 are intermediate, weakly suboceanic to weakly subcontinental. The next most common value for continentality was C3, which reflects conditions that occur in most parts of Europe. Next in abundance, and the mean continentality value for most of the roofs, C4 reflects suboceanic species occurring mainly in Central Europe but spreading towards the east. This ranking featured common green roof plants, like *Dianthus* spp., *Sedum sexangulare*, *S. spurium* and *Thymus pulegioides*. Equal distribution of species was associated with C2 and C6, whereby C2 is oceanic and C6 featured subcontinental species occurring mainly in the east of Central Europe and the adjoining parts of Eastern Europe.

The lesser-represented extremes of the continentality spectrum in these findings reveal the absence of continental to extremely continental (C8, C9) and extreme oceanic (C1) species. This could imply that tolerance to freezing is an important characteristic for species persistence on EGRs and might relate to competition or the requirements of regeneration. The majority of species from the surveys in Osnabrück, Karlsruhe and Berlin was C3 to C4 (Bossler and Suszka 1988; Buttschardt 2001; Poll 2008), which suggests that mature green roof vegetation has a continental Eurasian core. The species attributed to C2 are still being used on lists across the northern hemisphere, which suggests that freezing injury is not very frequent, perhaps due to hardening (Boivin et al. 2001) or adaptive strategies that avoid freezing altogether (Thuring and Dunnett 2019). Although freeze dates are an important measure for growing seasons, UHI studies have yet to provide a clear understanding of the implications on urban ecosystems (Johnson and Shepherd 2018; Schatz and Kucharik 2016).

10.3.1.4 Soil Moisture

Soil moisture describes species' occurrences and habitats along a gradient from dry shallow soils and rocky slopes to wet marshy ground. Water on green roofs is often a limiting factor, so one would expect this EIV to characterise species of dry habitats or tolerant to dry conditions. According to the results, many species (40) had no particular preference regarding moisture (M0). Of the 67 species with allocated EIVs, most (18) were M4, under which half were classified as M3 and M5. This means that the majority of species observed includes dry site indicators and moist site indicators. The remaining twelve species were indicators of extreme dryness (M2).

The German studies observed similarly, whereby the mature vegetation of EGRs, and in some cases the TPG roofs, was classified as M4, followed by M5 and M3 (Buttschardt 2001; Poll 2008), or M3 for spontaneously vegetated gravel roofs and recent installations of EGRs in Osnabrück (Bossler and Suszka 1988). The Karlsruhe study also included biannual surveys of two EGRs and two spontaneous TPG roofs, to observe between-season changes in the vegetation with respect to soil moisture. Whereby winter vegetation of TPG roofs was M4 and summer vegetation was M3, the latter expressed an incomparably large range including species from M1 to over M4. By contrast, the vegetation surveyed on the two EGRs was M3 for both seasons, likely owing to the drainage layer. Adaptability to varying degrees and duration of soil moisture is clearly an important trait of mature green roof vegetation, perhaps more so for single-layer systems.

10.3.1.5 pH

Reaction defines the gradient of soil pH in which species can be found, and the EIV scale covers the range of extremes: R9 infers basic reaction and indicates lime-loving species, while R1 infers extreme acidity. Although the range of preferences was large, most (32) of the species surveyed indicated preference for fairly acid to neutral to slightly alkaline situations (R5 to R8), and the majority of species (eleven) fell under R7. Similar distributions were described for pH preferences on both TPG and EGRs, with the majority between R6 and R7 (Bossler and Suszka 1988; Buttschardt 2001; Poll 2008).

10.3.1.6 Nitrogen

The green roofs surveyed indicated nutrient-poor conditions with respect to available nitrogen, with the majority (32) species occurring between N1 and N3. The species attributed with infertility in these surveys were associated with the meadow-like green roofs. Still, 7 species were attributed to N7, which indicates sites rich in available nitrogen. Not surprisingly, those species were colonisers and represent ruderal life strategies (Thuring and Dunnett 2019).

The nitrogen EIV implies species' occurrence in a gradient of fertility during the growing period. Buttschardt (2001) and Poll (2008) made identical observations on their surveys of EGRs in Karlsruhe and Berlin, while Bossler and Suszka (1988) reported nitrogen-poor conditions (mean, 2.9) for TPG roofs in Osnabrück. The distribution of species across all nutrient classes suggests that nitrogen (and perhaps other soil nutrients) is not a key factor for EGR species composition. Instead, since the species composition includes the range of nitrogen tolerances (N-poor to N-rich), species competition or functional traits could be a more informative factor to take into account (e.g. nitrogen fixers, stress tolerators).

10.3.2 Grouping Mature Green Roof Plant Communities into Vegetation Types

The results above were used in a cluster analysis to determine whether similar plant communities had emerged on the surveyed EGRs. The result of clustering ecological objects sampled from a continuum is *a typology* (i.e. a system of types), which may help to identify various *object types* that can be used to describe the structure of the continuum (Legendre and Legendre 2003). The roofs surveyed were grouped according to EIV range and species number, while also taking into account cover dominance. A hierarchical cluster analysis using Ward linkage for multi-dimensional scaling was carried out. Dissimilarity data provide information on the degree of *closeness* or proximity of each unit with respect to all the other units. The dendrogram model allows clusters to form hierarchically, so that the most broadly similar objects are loosely clustered and, as the similarity criterion becomes increasingly less relaxed (towards the left), groups become formed by aggregating with one another (Fig. 10.5).

The first distinction separated the youngest and steepest roof, Killesberg, from the eight other roofs (linkage distance, 25). Those eight roofs then separated into four clusters (main distinction, linkage distance, 15), all in close membership. Within those four groups, the *species-poor Sedum roofs* cluster was widely separated from the other roofs (linkage distance, 15). The latter six roofs were aggregated into three clusters and given the heading *Sedum meadows*. The term *meadow* was chosen because of the diversity of wildflowers and grasses and the absence of

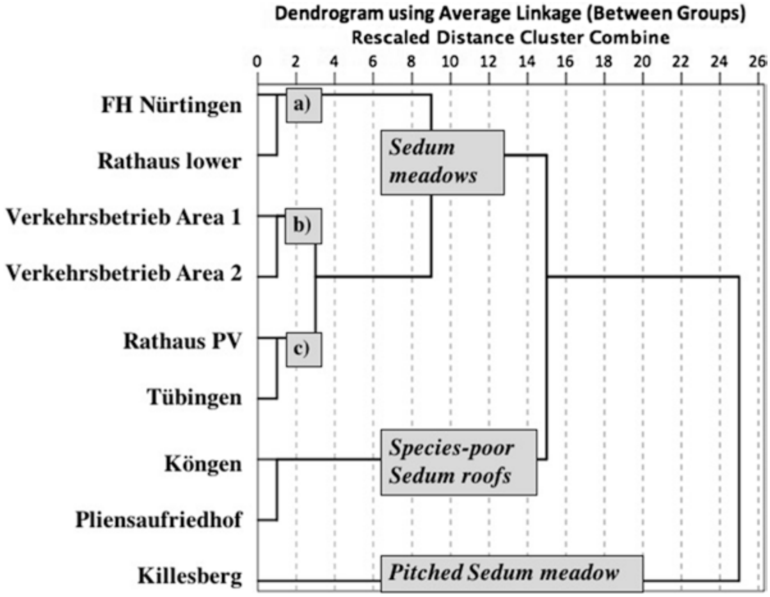

Fig. 10.5 A cluster analysis of nine old EGRs revealed three groupings based on the range of EIVs, species number and cover by non-dominant species. Roof names are given on the y-axis, and the scale of clustering coefficients on the upper x-axis indicates the level of similarity/dissimilarity between the roof clusters

woody species. As well, this term implies a degree of management, which such urban ecosystems are subject to.

10.3.2.1 Pitched *Sedum* Meadow

The green roof at Killesberg was distinguished from the other roofs by its slope (30°) and the extremely contrasting (north vs. south) aspects, which result in a considerable range of growing conditions. The south face was visibly xeric; the substrate had cracked into small horizontal rills and supported sparse *Sedum* cover, some mosses and small annual grasses. By contrast, the north face supported meadow-like vegetation with diverse floristic composition similar to subalpine meadows. The isolated position of this roof within the dendrogram can be attributed to the unique wide range of environmental conditions and consequently diverse species assemblage.

10.3.2.2 Species-Poor *Sedum* Roofs

The most remarkable and distinctive trait of the roofs of Köngen and Pliensau with respect to the other ones was their very low species counts (6, 11, respectively). On these two roofs, succulents had the highest cover (68.61% ± 21.93 and 96.74% ± 87.31, respectively), while forbs had exceptionally low numbers and cover (2.44% ± 2.73 and 1.59% ± 5.59, respectively). Both roofs lacked any cover by bryophytes, bulbous or woody vascular plants. This grouped vegetation type was therefore described as *species-poor Sedum roofs*.

10.3.2.3 *Sedum* Meadows

The roofs described as *Sedum* meadow had similar species numbers and species compositions; three clusters were distinguished according to the environmental conditions specific to each site. The relationships, both within and between the designated clusters, agree with field observations. The top cluster (a, FH Nürtingen and Rathaus-lower) is distinguished from the other clusters (b, Verkehrsbetrieb areas 1 and 2; c, Rathaus-PV and Tübingen) at a linkage distance of 9. The latter two clusters related to each other at a linkage distance of 3, and the roofs paired within the three clusters exhibited close membership (linkage distance, 1).

10.3.2.4 Floristically Diverse *Sedum* Meadow

Of all the EGRs surveyed, FH Nürtingen and the lower roof of the Stuttgart City Hall parking garage (Rathausgarage) had the greatest number of species identified (32 and 30, respectively) and also bore some subtle but unique environmental gradients from neighbouring buildings (shade, moisture). Their species lists expressed greater EIV ranges than the other roofs. These roofs also had similar values in terms of cover abundance by dominant species that were quite different from the values of other roofs. These roofs had a few mounded areas, whether landscaped or constructed by ants (*Lasius flavus*, Fabricius), which supported greater floristic diversity compared to the shallower, extensive areas that were sampled. Since these areas supported more diverse vegetation, they may have served as propagule sources and diversified the vegetation of the extensive areas. Given the high diversity and the wider range of environmental conditions that formed these plant communities, this vegetation type is described as floristically diverse *Sedum* meadow.

10.3.2.5 *Sedum* Meadow with Chives

The twin roofs at Esslingen Transport Services (*Verkehrsbetrieb*) (areas 1 and 2) had the shallowest mean substrate depth of all the roofs surveyed. Although more or less identical in installation (dates, methods) and construction, the vegetation on these roofs varied, presumably due to the different microclimates created by the variously arranged light shafts (i.e. long and narrow on area 1 versus short and blocky on area 2). Area 2 was unique among the considered roofs for its extensive coverage by chives, *Allium schoenoprasum*, which had a cover rate of 49.46% (±53.30). This species was not so dominant on area 1, but *Sedum* species and chives had the most consistent cover and occurred in all quadrats. Co-dominance by *Sedum* spp. and chives is not uncommon for EGRs (Köhler 2006) and may qualify as a distinct vegetation type: *Sedum meadow with chives*.

10.3.2.6 Sparse *Sedum* Meadow

In contrast with other roofs, the green roofs of Rathaus-PV and Tübingen both lacked shade and were totally exposed. The name given reflects the meadow flora, which was sparser than the floristically rich roofs, above the dominant *Sedum* cover. These roofs shared the highest values of structurally overlapping cover abundance, in which various species and growth forms created a vertical matrix of plant growth. Taller statured plants towered above the creeping, ground cover *Sedum* species, which maintained most of the cover.

10.3.2.7 Phytosociology of Spontaneous Green Roof Vegetation

The studies referred to above also sought to classify mature green roof vegetation according with the study of plant communities, i.e. phytosociology. How well do the plant communities of shallow green roofs, whether intentional or spontaneous, align with the broad class, *Sedo-Scleranthetea*? With regard to classifying surveyed vegetation into predefined phytosociological ranks, those efforts actually failed: either one or more of the characteristic or distinctive species were absent, or additional species led to the naming of novel plant communities (Bornkamm 1961; Bossler and Suszka 1988; Buttschardt 2001; Darius and Drepper 1983; Thommen 1988). It is, therefore, a salient point that plants on green roofs will establish species assemblages that evade our efforts in modelling or theory. Clearly, there is still much to learn about the processes and mechanisms of species assemblage on green roofs.

10.4 Conclusions

After two to three decades, the old EGRs surveyed were all dominated by *Sedum* groundcover, with varying degrees of floristic diversity above. Five main vegetation types were identified according to habitat conditions, species diversity and dominance. The various types of *Sedum meadow* may exemplify the original intent of replicating the *Sedo-Scleranthetea* plant community, whereas the *species-poor*

Sedum roof may reflect an impoverishment of this ideal. The diversity and structure of species assemblages observed on the *floristically diverse Sedum roofs* resembled the *Sedo-Scleranthetea*, certainly with relation to climate, as tall forbs and grasses benefit from wet periods, whilst *Sedum* species maintain ground cover during hot periods with intermittent drought. These findings vindicate the ecological intuition behind the habitat template used here. Still, it is essential to note that we can at best direct the vegetation, since the complex forces of succession and urban ecology are ultimately in charge.

Applying nature's model may broaden the potential of green roofs as urban ecosystems in different climates and bioregions (Sutton 2015). If this potential is to be promoted, then the green roof norms that influence industry practice must be updated to include biodiversity-related matters. A review of guidelines and standards from Germany, Switzerland and Italy found that none clarified the relationship between plant species selection, substrate composition or system build-ups (i.e. multi- and single-layered) (Catalano et al. 2018). At the same time, it has become common for green roof advocates to claim that EGRs conserve biodiversity and represent near-natural habitats, whether or not those accounts are substantiated by ecological research (Williams et al. 2014). If ecological function is deemed as important as the technical or aesthetic aspects of EGRs, then green roof guidelines must integrate relevant details into their recommendations of design and maintenance. Considering the predictions of rapid urbanisation and species extinctions (Ceballos et al. 2017), industry, regulation and academia alike should help to augment the potential for EGRs and other forms of green infrastructure to offset these trends and offer resilience.

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Chapter 11
Less Is More: Soil and Substrate Quality as an Opportunity for Urban Greening and Biodiversity Conservation

Francesca Vannucchi, Francesca Bretzel, Roberto Pini, and Heather Rumble

Abstract Soil is a key component of the water and nutrient cycles and a major contributor to global carbon sequestration. It can remediate pollution and provides habitat for almost all terrestrial plants, as well as a large proportion of terrestrial fauna. Yet, despite soils global importance, it is estimated that one third of world-wide soil is degraded (FAO, Status of the World's Soil Resources (SWSR) – main report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, 2015). In urban environments, soil is often overlooked despite its potential to alleviate problems, such as flash flooding, and its vital role in supporting vegetation, which in turn contributes to the urban landscape by, for example, reducing the urban heat island. Because of the changing nature of cities, soils undergo many disturbance actions such as manipulation, compaction and pollution. These processes degrade their important properties, leading to loss of fertility and function. Infertile soils are, however, a potentially valuable resource for the creation of species-rich, native plant communities, as the most biodiverse herbaceous vegetation is often found on infertile soils. When habitats in cities are being created, such as for extensive green roofs, a bigger research effort is required in developing soils that meet the economic and engineering needs of industry, whilst also functioning as a successful habitat.

Keywords Soil fertility · Soil microorganisms · Structural soils · Biodiversity · Urban ecology

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_11

11.1 Introduction

Urban soils are of increasing importance because of their connection with the improvement of human health in cities. As such, proper risk assessments and appropriate management of soils are needed (Li et al. 2018). The knowledge of the physical, chemical and biological quality of soils is the starting point not just to plan the management of vegetation in urban areas (Craul 1992; Tresch et al. 2018) but to better match the political and social decisions within urban planning, particularly those that are required to determine where green infrastructure, such as allotments, residential parks, playgrounds and ecological corridors, should be placed (Panagopoulos et al. 2016). Poor urban soil quality is pervasive, as reported by many soil scientists over the years. The causes cited are multifaceted, including a poor physical structure, the presence of alien materials, compaction, pounding and pollutants (Bullock and Gregory 1991; De Kimpe and Morel 2000; Tóth et al. 2008). Urban soils are sources and sinks of several pollutants. Trace metals are particularly prominent and their presence in urban soils is well documented (Yang and Zhang 2015). The presence of these trace metals leads to a reduction in soil fertility, demonstrating how urban pollutants change edaphic properties in a way that gradually degrades soils.

It is time to develop and realize a new model of life in towns and cities. This includes the idea that urban gardens, parks and other cultivated areas should not be limited to providing ornamental value; they can also be implemented to deliver a wide variety of ecosystem services, such as improving urban ecology and biodiversity and providing more versatile social spaces.

Healthy urban soils underpin a number of these ecosystem services (CEC 2006). Well-structured soils can alleviate flash flooding by absorbing water and can neutralize pollutants and sequester carbon (Rabot et al. 2018). Soil supports vegetation, which absorbs carbon and water, and captures atmospheric particulates, in addition to providing us with food and animals with habitat.

However, ecosystem service provision can be affected by polluted soils. The physical and chemical quality of urban soils and the nature of their pollutants are, therefore, important in relation to the management of urban green spaces. Soils of urban areas are heavily affected by man-made activities; brick rubble, plastic and concrete are often present in these soils, reducing the volume available for plant roots and causing nutritional deficiencies (Morel et al. 2015). These kinds of soils are often managed improperly, leading to loss of organic matter, porosity and structure, eventually resulting in erosion, compaction and root asphyxia.

Whilst these degraded soils are often seen as negative, they have their place within the ecological matrix. Low-fertility soils can provide a niche for slower-growing species that would otherwise be outcompeted by fast-growing species that require high-nutrient soils (Fig. 11.1), and these habitats are often most diverse in terms of herbaceous vegetation (Gilbert 1989, 1992; Grime 2001). Thus, low-fertility soils in cities can provide a habitat that has otherwise been lost in rural

Fig. 11.1 Low-nutrient soil sustains the establishment of a species-rich herbaceous vegetation (National Wildflowers Centre, Knowsley, Liverpool, UK)

environments: since the 1960s many soils in the countryside have been subjected to fertilizer addition and other forms of intensification.

The abundant low-fertility soils found in cities are seen as a problem because traditional horticultural vegetation such as turf and ornamental plants grow poorly on these substrates. But they are potentially a valuable resource for the creation of species-rich native vegetation in towns, particularly bespoke wildflower mixes (Fig. 11.2) that utilize ecomimicry to replace lost habitat (Bretzel et al. 2016).

11.2 Functions of Urban Soil

Soils fulfil a range of important functions including biomass production, water storage and filtering, nutrient cycling, carbon sequestration and provision of habitat for flora and fauna. To date, whilst we know that urban and rural soils have different physical properties, we do not know how these differences translate into functionality. Answering this question is of increasing importance as urbanization is growing (Greinert 2017; Rawlins et al. 2015) particularly as these functions translate to the effective delivery of ecosystem services (Table 11.1). Soil functions and their resultant ecosystem service provision depend on the intensity of human impact and on the ability of soils to support vegetation (Morel et al. 2015). When delivered, ecosystem services provided by urban soils are wide-ranging, including nutrient cycling and primary production as supporting services, water quality and carbon regulation as provisioning services and climate mitigation as a regulating service (Rawlins et al. 2015).

Fig. 11.2 Flowering herbaceous vegetation, sown on purpose in a roadside with low nutrient soil content. These plants create spots of colours and biodiversity in cities, simulating the rural landscape

Table 11.1 Main ecosystem services provided by urban soils

Ecosystem services	
Supporting	Nutrient cycles
	Primary production
	Soil formation
Provisioning	Food production
	Non-food biomass
	Reservoir of minerals
	Freshwater supply
Regulating	Water storage
	Runoff and flood control
	Pollution attenuation
	Climate
	Biodiversity
	Air purification
	Noise control
Cultural	Recreation/tourism
	Archives of human history
	Landscape
	Education

Modified from Morel et al. (2015)

Those urban soils that differ little from natural ones can be favourable for plant development and for hydrology. In these soils, organic matter content and soil structure contribute to enhance water infiltration and retention (Vereecken et al. 2010; Morel et al. 2015; Rabot et al. 2018). Rabot et al. (2018) identify porosity, macroporosity, pore distance and pore connectivity as important indicators of water movement in soil, and well-functioning soils in terms of hydrology will limit flooding and water runoff. In addition, due to their capacity to retain water, urban soils play an important role as reservoirs especially those well-structured with a high-water movement. This contributes to plant growth and productivity (Craul 1992). Soils that are hydrologically effective can support species-rich plant communities even if they are low in fertility. The resultant established vegetation contributes to enriching soil functionality and ecosystem services, improving air and water quality and reducing greenhouse gas emissions, the urban heat island (UHI) and flooding (Pataki et al. 2011), as well as providing ecological benefits in terms of flora and fauna conservation (Bretzel et al. 2016).

The goal to sustain plant development in the long-term is also pursued in engineered and constructed soils, maintaining some functions and regulating services such as water and air quality and carbon sequestration (Morel et al. 2015). Soil can sequester carbon from the atmosphere by storing organic matter; this ability depends on the degree of degradation and disturbance of the vegetation. Carbon sequestration can be improved through proper management practices or with the use of refractory materials (e.g. biochar and carbonates), allowing for the enhancement of soil C storage in response to climate change in urban areas (Renforth et al. 2011). Soil biotic activity has an important role in organic matter decomposition and in soil aggregate formation, affecting both carbon sequestration and soil structure (Usman et al. 2016). Soil moisture, temperature, aeration and nutrient content are all important properties that preserve high biodiversity and high biological activity in urban soil (Craul 1992). Soil biota can maintain these edaphic properties, contributing to positive feedbacks. Soil biota also provide other ecosystem services. The conservation of high microbial density and diversity in soil underpins effective nitrogen and carbon cycling (Dobrovol'skaya et al. 2015), which is essential to support vegetation. Although the physical and chemical rules driving biogeochemical reactions are universal, the factors (e.g. climate, nutrients, vegetation composition and land use) affecting their speed and final results may differ in urban environments. Anthropogenic activities in particular can affect nutrient transformations, for example, through changed atmospheric deposition rates and fertilization, contributing to soil contamination (Kaye et al. 2006). Coupled with the alteration of biogeochemical cycles, the continuous emissions of heavy metals and organic compounds increases soil contamination. Soils act as an important filter, limiting contamination of groundwater and improving water quality (Sauerwein 2011; Yang and Zhang 2015). However, the capability of soil to filter and adsorb pollutants depends on pollutant properties and water flow through the soil; it is not clear how the high pollutant loads of urban soils may impact this crucial ecosystem service. There is a need, therefore, for investigation into the hydrological processes occurring in urban soils and the adsorption ability of contaminated soils (Keesstra et al. 2012). In addition, the maintenance of soil properties, such as soil texture, organic matter content and the ability to adsorb cations, contributes to reduce the leaching of pollutants in groundwater (Laker 2007). Pollutant attenuation is preserved in pseudo-natural and engineered soils, thanks to the development of vegetation, through a process called phytoremediation (Morel et al. 2015). In brownfield soils, where the development of plant biomass is limited, because of the lack of nutrients, the presence of pollutants can lead to reductions in water quality. However, these types of urban soils can contribute to carbon storage and the provision of raw material, besides creating habitats for specialized fauna and flora (Morel et al. 2015).

Despite their ecological functions, about one third of global soils are degraded (FAO 2015). Generally, the soil functionality depends on the state of physical, chemical and biological properties (Hatfield et al. 2017). Soil degradation can have eco-environmental implications, including reduced urban soil quality and ecosystem health as well as limited ecosystem service provision (Yang and Zhang 2015).

11.3 The Alteration of Urban Soil Properties and the Consequences for Ecology and the Functional Application of Soils

Urbanization has modified the physical, chemical and biological properties of urban soils when compared to soils in more natural environments (Greinert 2017; Rawlins et al. 2015). The features of urban soils vary widely, ranging from relatively undisturbed soils to completely man-made soils. Urbanization alters the soil dramatically, causing low levels of organic matter, compaction and a reduction of penetrability by water, air and roots (Craul 1992; Pulford 1991). These impacts on soils have led to two new soil groups in soil taxonomy being added (World Reference Basis, WRB): technosols, which are man-made soils, and anthrosols, urban soils where the properties and functions are strongly determined by human activity (Fig. 11.3).

Soil is one of the limiting factors for the successful cultivation of plants in cities, and its alterations make it difficult to grow horticultural plants either as ornamentals or as food, because both of them require high fertility (Table 11.2). Urban gardeners who are unaware of such impacts often try to resolve the problem of poor-quality soils by overusing chemicals, such as inorganic fertilizers, thereby impoverishing both soil biota and the abundance of natural predators with a reduction of long-term fertility and pest control.

11.3.1 Alteration of Physical Properties: Texture, Porosity, Structure, Temperature

Poor quality of soils in urban areas is often related to their physical properties. For example, texture is modified by the addition of construction waste materials leading to poor structure and a lack of humus. This can lead to compaction, erosion and

Fig. 11.3 The quality and the continuity of urban soils is seriously compromised by the presence of pre-existing structures and services. This hinders the healthy development of most of the plants growing on such substrates

asphyctic conditions. In addition, where porosity is reduced, the free circulation of water and air is hindered, impacting vegetation growth but also increasing urban flood risk. One serious consequence of this is the reduction of water available for plants and the penetrability of soils by roots. Moreover, urban soils can be sinks of several anthropogenic materials, for example, bricks, concrete and plastic, which greatly reduce the volume available for roots. The presence of underground piping also reduces the available root volume, sometimes causing risks for tree stability. Furthermore, a lack of root space for urban trees often results in tree roots breaching infrastructure, such as paving, leading to increased maintenance costs. As an example, urban roadsides and roundabouts are often highly compacted, poor in organic matter and structure and polluted by nearby traffic. In these urban areas, it is possible that the fertile layer is covered by filling soil, which is even poorer in terms of structure and nutrients. Thus, the normal soil profile is completely altered or even absent (Fig. 11.4), because of mixing and spatial heterogeneity (De Kimpe and Morel 2000). Soil biota are also limited due to regular disturbance, further reducing soil function. The ability of soil to develop in urban areas is also limited; soil sealing is a typical urban process that greatly affects underground life and disrupts natural hydrology and slows the soil formation that would normally occur through weathering. Soil sealing is also responsible for UHI, directly because of the absorbing surface and indirectly because of the lack of vegetation.

The temperature of urban soils is also increased along with global climate warming but exacerbated by the UHI. Moreover, with global climate change, the soils in urban areas are predicted to be flooded for longer periods of time but will also experience longer periods of drought. Flooded soils lead to anoxic conditions, but

Table 11.2 Soil properties affecting the establishment and biodiversity of herbaceous communities in urban areas

Soil properties	Actions
pH	Alkaline soil reaction supports higher herbaceous biodiversity as in calcareous soils
Texture	Soil texture affects seedling emergence and establishment, favouring some species over others. Presence of superficial soil skeleton (stones and gravel) leaves open spaces for seed recruitment
Porosity	Porosity is related to the texture and organic matter content, contributing to water infiltration, amount of water available and degree of root penetration. Pore distribution of different size classes and shape allows to measure the structural effects of compaction
Organic carbon	Non-humificated organic carbon induces microflora to consume nitrogen stocks, reducing its availability for plants (priming effect); this affects the plant biomass
Nitrogen availability	High levels of available nitrogen (nitrates and ammonium) reduce plant diversity due to the increase in productivity of few competitive ruderals with negative effects on slow-growing plants. Nitrogen deficiency allows open spaces for more plant species to colonize
Phosphorous availability	Available P concentrations >5–10 mg kg^{-1} in soil limit floristic composition. P affects nitrogen fixation, thus enhancing microbial activities by increasing soil fertility
Bulk density	Related to the degree of soil compaction, high levels can be associated with biomass reduction
Trace metals	The metal contamination in soil leads to microflora and root inhibition, i.e. nutritional stress, and this can reduce the soil fertility

Modified from Bretzel et al. (2016)

drought also poses challenges for both flora and fauna. In these conditions, soil function is compromised. For example, earthing systems are not effective in the absence of humidity; soil temperature is also related to aetiological risk, especially in tropical cities where the climate allows longer cycles of noxious pathogens to persist (Rawlins et al. 2015).

11.3.2 Alteration of Chemical Properties: pH and Nutrient Cycles

Urban soils are generally alkaline, due to the addition of building wastes such as brick and concrete, which contain calcium carbonate. Soil pH affects the mobility of both trace metals and micronutrients, depending on their redox status: in general lead, zinc, nickel, mercury and cadmium are more mobile under acidic conditions, whereas the opposite may be the case for chromium and arsenic (Bretzel and Calderisi 2011; Tassi et al. 2018; Violante et al. 2010). Other elements necessary to the healthy growth of plants, for example, iron, manganese, boron and copper, are

Fig. 11.4 Soil mixing causes the absence of a pedological profile and the incorporation of alien polluting materials, compromising the overall soil quality

less mobile at high pH (8–9), so plants grown in cities can suffer micronutrient deficiency.

Urbanization causes a loss in net primary production (NPP), i.e. plant biomass, and a subsequent reduction in fixation of CO_2, whilst acting as a major source of atmospheric carbon and nitrogen oxides due to combustion (Lorenz and Lal 2009). Carbon and nitrogen cycles in urban soils are becoming increasingly of interest to research. As an example, the cultivation of lawns in North America uses large amounts of fertilizers and water, resulting in enhanced below- and above-ground productivity and increasing the carbon pool (Pouyat et al. 2006). Waste relocation, atmospheric deposition and plant litter are the origin of this enhanced pool of carbon and nitrogen in urban soils.

On the other hand, mixing, sealing, compacting and erosion lead to a loss of carbon and nitrogen. Mixing of the soil causes homogenization of soil layers, leading to an alteration of the biogeochemical cycles of C and N, destroying porosity and the habitat suitable for decomposer microbes. Thus, homogenization, in most cases, causes loss of soil biodiversity. Sealing restricts the exchanges of air and water in soil and hinders the growth of vegetation, leading to the absence of pedological biota. Compaction due to trampling and the passage of heavy machinery has a similar effect, as porosity is greatly reduced; the conditions for developing organisms are very limited in this instance. Removal or absence of vegetation causes soil erosion by wind, water or mechanical human action, leading to the elimination of fertile topsoil.

11.3.3 Pollution

A wide variety of contaminants produced via anthropogenic activities affect the urban environment, including heavy metals, pesticides, organic wastes, salts, radionuclides and acid deposition products. Accumulated contaminants in surface soils can be spread over the hydrosphere, atmosphere and lithosphere by water and wind.

Road networks, vehicular emissions, housing, emissions from municipal waste incinerators and many industries are the main sources of trace metals in urban areas (Thornton 1991). Trace metals are highly persistent in soils, and their concentrations in urban soils are variable; they can be more or less mobile in the soil, in relation to their geochemical form, which affects their solubility and thus their bioavailability. The threat posed by trace metals to human health and to the environment is dependent on their chemical form rather than on their total concentration (Pichtel and Salt 1998).

Besides pH, organic matter, soil texture and cation exchange capacity can all influence the behaviour of trace metals in soil, because soil is a dynamic system whose properties are subjected to short-term fluctuations.

Trace metal concentration in urban topsoil is strongly influenced by land use. Urban soils cause health risks because of their vulnerability to wind erosion, caused by their lack of structure and absence of vegetation. The site history can also influence the presence of trace metals. De Kimpe and Morel (2000) showed that reviewing the site history is a very important aspect in the study of urban soils. In the last century, cities went through massive changes, and consequently soils have changed their original use, from industrial to recreational, agricultural and as private gardens. This change in land use means that urban contaminants may be overlooked, and their associated risks not mitigated for appropriately. When urban soils are allocated for urban horticulture, all the physical and chemical properties should be analysed in order to plan successful cultivation techniques, bearing in mind that urban soils can have particular characteristics that are not comparable to surrounding rural areas and are not represented on pedological maps.

11.4 Soil Rehabilitation and Reconstruction

Arguably one of the biggest contributing factors to poorly functioning urban soils is their lack of an efficient soil food web. Many soil physical properties, including nutrient cycling and water regulation, rely upon the billions of living organisms within the soil, from microorganisms (bacteria, protozoa, fungi) to micro-, meso- and macrofauna (microarthropods, nematodes and earthworms). These organisms change the physical structure of the soil by binding soil particles together (Miller and Jastrow 2000) and creating pores, which positively impact aeration and hydrology (Brussaard et al. 1997). Additionally, they change the nutrient status of the soil, breaking down organic matter into bioavailable nutrients whilst at the same time reducing leaching (Asghari and Cavagnaro 2012).

Bacteria and fungi are thought to be responsible for most of the decomposition occurring in soils (Bardgett 2005). After decomposition, soil biota such as mycorrhizal fungi, which form intimate symbiotic associations with plants, also facilitate physical access to nutrients for plants; it is estimated that up to 75% of the phosphorous acquired by plants is provided by soil biota (van der Heijden et al. 2008).

Urban soils face several challenges in this regard. Filling soils and man-made substrates, such as green roof substrates, are often constructed from secondary aggregates. These aggregates are usually almost sterile and can require a longer time to develop a soil food web than natural soils because of excessive alkaline conditions and their low-nutrient status. Whilst compost is often added, this tends to be low-quality municipal compost, often added in small amounts. The composting process heats up the soil; heating may be beneficial in removing unwanted seeds and pathogens (David Border Composting Consultancy 2002), but then soil may not contain the appropriate community of microorganisms for its end use. In essence, this means that these soils rely upon natural colonization to develop a suitable soil food web. Until this soil food web is gained, these soils are functionally challenged.

Natural colonization of virgin soils by microorganisms is slow (Dunger et al. 2001; Kaufmann et al. 2002), but in cities there is a further particular challenge. Urban habitats are fragmented by buildings and paved surfaces, which act as a barrier against the dispersal of many soil organisms (Braaker et al. 2014). This contributes to a feedback loop, whereby dispersal barriers limit biodiversity in soils and a lack of biodiverse soils limits the number of source populations from which colonization can occur. Green roofs represent an extreme form of this, their elevation providing a further barrier to dispersal (Rumble et al. 2018); however, other urban areas, such as roundabouts, suffer from the same isolation and fragmentation (Eitminaviciute 2006).

Some urban soils, such as green roof substrates, are designed using secondary aggregates because they are lightweight and free draining, presenting a challenge for vegetation. There are two main categories of solution to this problem. The first is in developing and installing better soils to begin with, the *engineering* solution. The second is in developing ways to speed up natural colonization of soil microorganisms, the *urban planning* solution. The common engineering approach is to apply inorganic fertilizers, but this does not solve the problem in the long term, as it does not promote long-term soil development. In addition, in free draining soils, such as those found on green roofs, this can contribute to leaching (Li and Babcock 2014). A more sustainable solution would be to encourage the development of a healthy soil food web. Attempts have been made to do this in a reductionist way, in particular by developing inoculants containing key soil microorganisms. These microorganisms usually include bacteria that have been shown to improve plant growth and suppress disease, the so-called plant growth-promoting rhizobacteria (PGPRs) (Nehra and Choudhary 2015). *Trichoderma* spp. have also been applied as inoculants; these fungi have been shown to have disease-repressing properties (Hidangmayum and Dwivedi 2018; Papavizas 1985). Mycorrhizal fungi, which form a symbiotic relationship with plants, are also commonly used inoculants. These fungi donate nutrients, such as phosphorous, to the plant in return for sugars. Mycorrhizal fungi are thought to be limited in their dispersal ability (Sheng et al. 2019) so may have a particular need to be purposefully added to soils. The challenge associated with the application of these inoculants is that very little is known about the ecology of these species, even in more natural environments. The results of their application are variable, and lab results often do not translate to the field due to the complex interactions occurring with other rhizospheric organisms and due to heterogeneous environmental variables. Additionally, whilst microbial inoculants have been added to many urban green infrastructure projects, such as the green roof of the California Academy of Sciences, which has mycorrhizal fungi embedded within its coir matting (McIntyre and Snodgrass 2010), post-construction monitoring is usually limited, and controlled trials are rare. This makes the impact of the addition of these inoculants difficult to assess.

In addition to microbial inoculants, nutritional inoculants such as seaweed have also been tested for the purpose of soil remediation (Khan et al. 2009). These nutritional amendments break down more slowly than inorganic fertilizers and have the potential to support a higher diversity and quantity of soil microorganisms.

The urban planning solution has been little studied but is an important aspect to be considered. Habitat fragmentation in cities has been studied for butterflies, birds and plants (Dallimer et al. 2012), and there is some evidence that habitat corridors can enable the movement of species through urban environments (Collinge 1998). Soil organisms are a particular challenge, because many of them are relatively immobile outside the soil and most of the urban environment is soil sealed. However, even immobile species may move through the environment via aerial plankton (Hardy and Milne 1938) and via phoresy, i.e. being carried on birds (Schäffer et al. 2010) and other animals. Insular biogeography theory (MacArthur and Wilson 1967) suggests that the chances of dispersal are higher where island populations' size is larger, where distances between islands are low and where barriers between these islands are less limiting. Many of these principles have been demonstrated in cities (Collinge 1998). Thus, urban planning could be utilized to optimize the movement of microorganisms through the landscape. However, we simply do not know enough about the biogeography of either soil organisms or cities, and there is much work to be done in this field. Very little research has been conducted to explore the soil communities of residential back gardens in cities, and these could be a surprisingly important reservoir for soil microorganisms within an urban landscape.

It is often argued that developments within this field are limited by a lack of knowledge. However, many of the environmental constraints faced by urban soils could be alleviated with a higher willingness to invest in good-quality parent materials that include at least some biologically active soil. In addition, urban areas provide a blank canvas in terms of experimenting with different parent materials, construction techniques and urban planning forms; a break from the homogeneity of current building practices would enable cities to become living labs so that researchers, civil engineers and architects can determine what works best in cities.

11.5 Case Studies

11.5.1 Establishment of Biodiverse Herbaceous Vegetation on Low-Nutrient Substrates

Soils associated with urban redevelopment sites generally consist of a low-fertility mix (subsoil, building material) which is gradually colonized by weedy native and exotic grasses and forbs adapted to these soil conditions. Research was carried out in Sheffield (UK) on a post-industrial site to determine whether a visually more attractive meadow-like vegetation of native and exotic species could establish by oversowing with only limited changes to the soil. The site was sown with 17 species of forbs with 6 different soil cultivation treatments (cut off the existing vegetation; cut off + cultivation (to 10 cm); glyphosate herbicide; spray glyphosate + cultivation; burn existing vegetation; burn + cultivation). Analysis showed that the soil was alkaline (pH 8.5) and highly compacted (bulk density 1.6 g cm^{-3}). The organic matter content of the soil was 6.8%, and the plant available NH_4-N, PO_4-P and K were 0.7, 9.1 and 164.9 mg kg^{-1}, respectively. Forb establishment was superior following spring, rather than autumn sowing. The most successful soil cultivation treatment was the combination of burning and cultivation. The species that grew best were all native European species associated with grassland habitats dominated by C3 plants, winter-growing grasses. These were *Centaurea scabiosa* L., *Knautia arvensis* (L.) Coult., *Malva moschata* L. and *Primula veris* L. A percentage of these species was large enough to flower in the second growing season (Bretzel and Hitchmough 2000).

Reducing the substrate fertility and at the same time promoting biodiversity in urban landscaping can be realized by mixing recycled waste materials into an alternative green roof substrate. In a study carried out by Vannucchi et al. (2018), de-inking paper sludge is added as a pellet to substrates filled with compost and tephra in different percentages, in order to select the proper mix suitable for the development of species-rich plant community on an extensive green roof. The research highlights that the conventional substrates, composed of tephra and compost, are generally dominated by pure stands of planted *Sedum* spp. This type of plant cover reduced the chance of colonization and propagation by other plants. The presence of the pellet limited the *Sedum* development, thanks to the limited nitrogen content, leading to the germination of annual microthermal species in the free gaps, during autumn to spring, as well as enriching the plant community in species and functional groups (Fig. 11.5). In addition, the pellet also retained water, keeping its shape over time, conferring to the substrate a good water holding capacity and aeration. Particularly, the substrate composed by pellet, compost and tephra (27%, 8%, 65% v/v, respectively) turned out to be suitable for the establishment and naturalization of herbaceous plant community, rich in species and attractive for pollinators.

Fig. 11.5 Annual species co-occurring with *Sedum* spp. on green roofs. The low nutrient substrate, composed of paper sludge, limits the spread of *Sedum* species, allowing annuals to occupy suitable empty niches; in the foreground *Calendula arvensis* (Vaill.) L

11.5.2 Developing Soil Microbiota for Green Roofs

Green roofs are an excellent model for discussing both the challenges associated with developing healthy urban soils but also the opportunities presented by doing so. The flat roof space of cities is large and underused. Theoretically, almost any habitat can be recreated on a green roof. In most cases, these areas are undisturbed by humans and could, therefore, provide important refugia for habitats lost through urban sprawl.

However, green roofs are currently limited by their nutrient-poor status (Molineux et al. 2009) and by drought (Rumble and Gange 2013). Drought occurs because of the substrate is designed to be free draining (Grant 2006) and is often less than 15 cm deep (McIntyre and Snodgrass 2010). Soil nutrients are limited by sterilized parent material, low quantity and quality of organic matter and drought.

Whilst we design technosols to fulfil certain physical characteristics, we neglect the biological characteristics, instead relying on nature to provide a soil food web. Yet healthy soil could enable more sustainable plant growth on green roofs and reduce the impact of drought. Over the last 10 years, we have conducted experiments on green roofs to determine whether the biological component of Technosols can be included in their design by adding inoculants; our results hint strongly at the potential paths forward.

Our initial studies aimed to determine if *Trichoderma* spp., bacterial PGPRs and mycorrhizal fungi could enhance green roof plant growth. Many green roofs comprise of *Sedum* spp. blankets or plugs, and these are relatively slow to establish (3–10 years). Some roofs never gain a good cover of vascular plants and are instead dominated by mosses (Emilsson 2008). Whilst these can be aesthetically pleasing, they are often not what was specified and can therefore be problematic for the industry; moreover, these roofs are limited in their ecosystem service provision. Our aim was to determine if vegetation development could be sped up.

We found that on mature green roofs, inoculants had little effect on plant growth (Rumble and Gange 2017). We surmised that this was because our green roof was already 7 years old at the time of application and that, although the incumbent soil biota community was not stable over time (Rumble and Gange 2013), it was well established enough to resist perturbation by our added inocula. We therefore repeated the experiment on a new green roof, where we hypothesized that no incumbent soil community existed.

In our new green roof experiment, we found that the addition of soil biota suppressed plant growth (Rumble et al. in prep). In particular, the addition of PGPRs with mycorrhizal fungi reduced plant growth; PGPRs have not only been demonstrated as aiding plant growth but also as *helper bacteria*, facilitating the colonization of mycorrhizae (Medina et al. 2003). Whilst this result seems negative, it has demonstrated an important point that will greatly aid in the search for new inocula. In fact, it demonstrated for the first time that there is a functional relationship between mycorrhiza and *Sedum* spp. and that colonization may be supported by helper bacteria.

The fact that plant growth was suppressed in this instance is, perhaps, not surprising. Methods to trap mycorrhizae preferentially capture aggressive colonizers, and there is little evidence that these species are those that are most beneficial to plants (Bennett and Bever 2009). Moreover, bait plants are often cosmopolitan species, such as *Plantago lanceolata* (Sýkorová et al. 2007), which have different ecological needs if compared with *Sedum* spp., which typically live in challenging, low soil environments like rocky outcrops. Recent advances in DNA analysis have challenged the dominating principle of general microbiology that *everything is everywhere* (O'Malley 2008) and demonstrate that mycorrhizal fungi at least have their own biogeography (Řezáčová et al. 2019), so plant-fungi relationships could be more specific than previously thought. Our results demonstrate that there could be more specific mycorrhizal species for *Sedum* spp. in the wild and that PGPRs could effectively aid their colonization in an applied setting.

Thus, we need to look to new methods to develop healthy soil ecology by using the principles of biogeography and ecomimicry (Nash 2017). If we are to use green roofs to recreate natural habitats, we need to investigate the specific soil biota needed for our desired community by looking to their natural analogues, focussing not only on the plants we desire but also on the soil biota needed for them to be successful.

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Part II
Planning and Implementation of Green Infrastructure

Chapter 12
How Urban Agriculture Can Contribute to Green Infrastructure in Japanese Cities

Noriko Akita

Abstract Urban agriculture has drawn much scholarly attention in recent years. In Japan, urban agricultural traditions go back 400 years, to the Edo period, and persist even today. Although urban farmland has various ecological and social benefits, it is still unstable to position it as part of the green infrastructure of a modern city; for spatial, ecological and social-functional dimensions. First, it is unclear whether the amount and location of urban farmland is adequate to call it the "infrastructure" of the city. Secondly, pesticides and fertilizers are used on farmland, which causes environmental pollution. Third, since farmland is privately owned land and considered to be a site of economic production, it often lacks the features of public space. This study surveyed 22 local governments within 20 km of Tokyo city centre and organized by three survey methods. The first evaluates the relationship between the quantity and location of urban parks and urban farmlands. The second evaluates the regulation and rules of pesticide use in urban farmland. The third survey analyses Japanese municipalities' farmland policies and identifies the functions that local communities expect from urban farmland. These results indicate that urban farmland complement city parks with quantity and location, consider the effects of pesticides on local residents, and performs sufficient functions of public. It can be said that urban agriculture effectively contributes to the realization of multifunctional urban green infrastructure.

Keywords Urban farmland · City park · Public function · Local community · Farmland policy

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_12

12.1 Introduction

Urban agriculture has drawn much scholarly attention as green infrastructure in recent years. For instance, Barthel and Isendahl (2013) analysed urban agriculture's historical function in cities' food supply systems and proposed that urban farmland is a type of green infrastructure that contributes to the resilience of cities. Duvernoy et al. (2018) showed that urban farmland in medium-sized cities functions as green infrastructure that contributes to the sustainable growth of cities, the supply of urban markets, and citizens' increased feelings of social inclusion. Lin et al. (2015) showed that urban farmland is actually functioning as green infrastructure. Schilling and Logan (2008) analysed that urban agriculture can effectively serve as green infrastructure for the transformation of urban structures. In cities with relatively few green open spaces, there is an increasing emphasis on the multifunctionality of green infrastructure (Hansen and Pauleit 2014). Urban farmland does increase opportunities for green and social interaction. Community gardens, which are often used as agricultural land, function effectively as a tool for social inclusion(Armstrong 2000). Secure public access to green spaces has significant physical and social benefits. Wolch et al. (2014) argued that everyone is entitled to the same public health benefits through green spaces and that urban green spaces should not be regionally biased. Nassauer and Raskin (2014) proposed to position urban vacancy as green infrastructure by turning it into urban farmland. Pickett et al. (2001) and Aerts et al. (2016) supported the ecological importance of farmlands in urban space. Lovell and Taylor (2013) suggested that multifunctional green infrastructure could contribute to the sustainable social and ecological health of cities. Rosa et al. (2014) defined the existence of farmland in the city as contributing towards a more liveable and healthier urban environment; it enhances the overall quality of the urban landscape, supports climate change adaptation policies, and increases the economic value of land.

Despite the fact that urban farmland is often proposed as a form of green infrastructure in the literature, it is still unstable to position it as part of the green infrastructure of a modern city. The reason can be explained in three dimensions: spatial, ecological, and social functions. From a spatial perspective, it is unclear whether the amount and location of urban farmland are adequate to call it the 'infrastructure' of the city. In order to say that it is an 'urban infrastructure', it is necessary for it to have a certain impact on the urban structure. Ecologically, agricultural land uses pesticides and fertilisers, which can cause environmental pollution. Unfortunately, the Japanese farmer still continues to use old-style farming that uses agrochemicals. There are also concerns about urban farmland's impact on local residents. From a functional perspective, since farmland is privately owned land and is considered to be a site of economic production, it often lacks the features of public space. Accessibility is also an important requirement for green infrastructure.

On the other hand, city parks are commonly understood as central elements of green infrastructure. For instance, Tzoulas et al. (2007) identified green roofs, city parks, and green corridors as key elements of green infrastructure, and Haase et al.

(2017) asserted that city parks contribute to the sustainability of urban environments, economies, and societies. These claims are in line with other literature's findings stating that urban green infrastructure includes all of a city's 'green and blue spaces', including parks, cemeteries, yards and gardens, urban allotments, urban forests, wetlands, rivers, lakes, and ponds (Gómez-Baggethun and Barton 2013). Others have also identified private gardens and lawns as urban green infrastructure (Cameron et al. 2012). In contrast with city parks, urban farmland has a different function which is production. The purpose of the land use and the type of user are also different. The existence of urban farmland makes a significant contribution to enhancing the functioning of green infrastructure.

The style of urban agriculture is a little different in Western and Asian countries. In some Western countries, after the decline of urban agriculture about 100 years ago, a new leader in urban agriculture, called 'nouveau farmer', who is young and has little experience in agriculture has been leading the activities (Real Estate Foundation of BC 2013). On the other hand, in Japan and other Asian countries, agriculture has been continued in cities even before modern times. Agricultural methods remain traditional and old style, and the vegetables produced are *landraces* (local breed). These include vegetables that have been grown in the same area for 400 years. This is a characteristic of urban agriculture in Asia. Is it possible to position farmland as a green infrastructure even in urban agriculture where such old- and traditional-style farmers are responsible? There is a good point because agriculture has continued without decline. Residents are accustomed to the existence of farmland. The existence of landraces can contribute to the improvement of the city's identity and value. In areas where urban agriculture is thriving, some families move in because they can get fresh local vegetables every day. The existence of full-time professional farmers contributes to the creation of diversity in terms of urban land use and space. This study explores the possibility that urban farmland managed by full-time professional farmers, namely, traditional-style farmers, may be a piece of the green infrastructure of the city through the case study in Japan.

12.2 Overview of Urban Agriculture in Japan

12.2.1 Historical Background

Japan has historically featured mixed land use, and farmland is, therefore, present within many large Japanese cities. There are no strict growth boundary systems such as those adopted by Western countries, and even as urbanisation progresses, farmland remains in the centre of the city. For example, Tokyo, Osaka, Kyoto, and Nagoya have produced their own local vegetable varieties for centuries. These vegetables often bear the names of their place of origin. The existence of these unique products can contribute to the improvement of the city's identity and value, as already mentioned above. For example, Tokyo's formally recognised 'Edo Tokyo' vegetables bear names such as ‘Nerima radish’, ‘Shinagawa turnip’, ‘Waseda ginger’, and ‘Haijima leek’ (Tokyo Metropolitan Agricultural Cooperative Central Association 2019). About 50 vegetable varieties have so far been registered as ‘Edo Tokyo’ vegetables. These vegetables are grown not only in the suburbs but also in the city centre. This history has created a situation where full-time professional farmers grow vegetables, even in the centre of Tokyo, one of the world’s leading megacities. In similarly large cities, such as New York and London, urban agriculture declined about 100 years ago, recently regenerated, and is largely led by new young farmers, volunteers, and non-profit organisations (Reynolds 2014).

The presence of agricultural land in urbanised areas is a historically common land use pattern in Asia (Yokohari et al. 2000). Urban agriculture has offered great improvement in food security to the urbanites. However, the presence and productive use of urban farmland in heavily urbanised areas have long been considered undesirable (Sorensen 2005). In Japan, full-time professional farmers are engaged in agriculture as a means of livelihood, so the farmland area is relatively large. As a result, there was criticism that land was not sufficiently supplied for the general population who needed housing. In addition, mixed land use was considered undesirable because soil dust and agricultural chemicals tend to cause conflicts between local residents and farmers.

12.2.2 Farmland as Residential Land During Periods of High Economic Growth

Urban farmland received the large-scale rural-to-urban migration of Japanese people during the decades of high and sustained economic growth following World War II. Throughout the 1960s and 1970s, urban sprawl in Japan intensified and prompted the central government to enact the City Planning Act (1968). This act defines the areas where urbanisation is promoted as ‘urbanisation promotion areas’ and areas where urbanisation is restricted as ‘urbanisation control areas’. Orderly urban development was promoted by dividing the city according to the different potentialities for development. This was a measure to improve urban growth management and a way of designating growth boundaries. This policy was especially adopted in metropolitan areas around megacities such as Tokyo, where development pressure was particularly strong. Through this legislation, urban farmland was largely, but not entirely, included in ‘urbanisation control areas’ and protected from urbanisation and residential development. Some urban farmland was, however, left behind in the ‘urbanisation promotion areas’.

Over time, however, the pressure to urbanise and develop urban farmland increased again, and urban farmland within urbanisation promotion areas was viewed as an obstacle to an orderly urbanisation. The central government enacted new legislation in 1991 to address this issue. This legislation introduced a new zoning system that included ‘productive green zones’. Under this legislation, land within these zones is exempted from property taxes, and the farmers who own it must maintain the land as farmland and continue farming for more than 30 years. These measures significantly reduced the total area of urban farmland in Japan but ensured the preservation of some urban farmland in the long term. As a result, in Japan, stable urban farmlands were left in the centre of the city. It is a unique situation in Japan that farmland managed by full-time professional farmers, not community gardens, exists in urbanisation promotion areas. However, the results of this study can highlight important implications for the development of urban agriculture.

12.2.3 Changing Evaluations of Urban Farmland

After the introduction of the 'production green areas' system, the shortage of land in urban areas persisted, and urban farmland was, sometimes, still evaluated negatively. From about 10 years ago, however, evaluations of urban farmland have been changing significantly. Urban consumers have come to demand safe and fresh food and have changed their lifestyles, leading to locally produced vegetables being cultivated and sold as high-value-added products. In some areas, farmers and restaurants collaborate to promote local vegetables that residents might not know about or regularly consume (Kokubunji City 2020).

In response to such changes in the social environment, in 2015, the central government enacted the Urban Agriculture Promotion Basic Act, which aims to promote urban agriculture on the grounds that urban farmland performs many important social and ecological functions. This law is co-developed by the Ministry of Land, Infrastructure, Transport and Tourism in charge of urban areas and the Ministry of Agriculture, Forestry and Fisheries in charge of agriculture. The law defines how to formulate plans for promoting urban agriculture and the actors that promote urban agriculture. There is no description of the specific activities of farmers such as the use of pesticides and agricultural machinery. The Urban Agriculture Promotion Basic Act defines that the function of urban farmland is not only to supply of fresh vegetables to urban residents but also includes comprehensive measures like disaster prevention, education, and community formation. Following its enactment, many basic municipalities are currently making efforts to formulate a basic plan for urban agriculture promotion based on the law.

12.3 Research Framework

12.3.1 Research Approach

The purpose of this study is to examine the potential of urban farmland as a green infrastructure managed by full-time professional farmers from three aspects: spatial, ecological, and social function. First, the spatial aspect will be analysed by comparing the farmland with city parks. City parks are already well-established as green infrastructure. This involves comparing the area and location with the city parks and examining whether it can exist as an infrastructure of the city. Next, from an ecological perspective, this research focuses on the rules for using agricultural chemicals in urban agriculture. In addition, it considers how to deal with dust and noisy agricultural machinery that cause conflicts with neighbouring residents. Finally, it analyses the policies of local governments in order to clarify the social functions of urban farmlands.

12.3.2 Case Study

This study focuses on the metropolitan area surrounding Tokyo, the most populous and highly urbanised city in Japan. It targets municipalities within 20 km of the city centre because these municipalities face intense urbanisation pressures and almost the entire area covered by this study has been designated as an urbanisation promotion area by the 1968 Act mentioned above. A total of 35 municipalities meet this condition, 13 of which have been excluded because they do not include urban farmland. As a result, 22 municipalities have been selected for analysis. The need for green infrastructure is higher in densely populated urban areas. The total population of the study area is approximately 7.87 million people distributed over 58.6 ha representing an average population density of 134.4 people per ha. In Japan, the population density of designated densely inhabited districts (DID) is set at 40 people per ha, so the population density of the proposed study area can be considered extremely high. Since the basic plan for agricultural promotion is formulated in units of local governments, in this study, one local government is used as one unit for analysis.

The data used are as follows:

1. Municipalities' total population and area, gathered from Tokyo Metropolitan Government data from 2015
2. City park total area, i.e. the total area of 'block parks', 'neighbouring parks', and 'district parks' based on data published by Japan's Ministry of Land, Infrastructure, Transport and Tourism (2016 – the latest dataset available)
3. The total area of open green space, that is, the area of green open spaces other than city parks, based on data published by the Ministry of Land, Infrastructure, Transport and Tourism (2016)

4. The total agricultural land area, based on data from the *Tokyo Statistical Yearbook* (2017 – the latest dataset available)
5. The status of notification of pesticide use based on the Agricultural Chemicals Control Law (Ministry of Economy, Trade and Industry)
6. The basic plan for urban agriculture promotion, as formulated by each local government, based on the Urban Agriculture Promotion Basic Act

The distribution of farmland has been studied using land use subdivision mesh data from data published by Japan's Ministry of Land, Infrastructure, Transport and Tourism (2016). The mesh is made up of 100-m^2 blocks, considering both 'paddy fields' and 'other farmland' as urban farmland.

12.4 Results

12.4.1 Comparing the Functions of Urban Farmland and City Parks

Wilson (1986) developed a philosophical discussion of humanity's affinity for nature and the need for protection. Maller et al. (2005) emphasised the importance of 'contact with nature' to improve people's health. Fair accessibility to green spaces is also important from an environmental justice perspective. Based on these theories, city parks have been evenly distributed and installed so that everyone has equal access. On the other hand, since farmland is owned by individuals, it will increase or decrease according to the market principle and landowner's intentions. It is difficult for the government to intervene. In particular, Japanese urban farmland has been passed down for generations, and farmers' attachment to the land is very strong. They are proud of the farmland they have worked for generations. Therefore, there is a strong resistance to letting go of the land. Also, the price of land in an urbanised area of a megacity like Tokyo is so high that municipalities cannot afford to buy it. This is a barrier to positioning farmland as green infrastructure. At present, there is a recognition that urban farmland is primarily a place for the production of land-owning farmers; the public nature and fairness of accessibility to the urban farmland are usually not considered.

The current land use in urban areas of Japan is stable, and there is no significant increase or decrease in parks or farmland areas. Therefore, it is possible to analyse the amount and layout of urban farmland compared to urban parks, which are a typical space for urban green space infrastructure.

Figure 12.1 shows a diagram of scattered areas representing the city parks and agricultural land in the 22 case study municipalities analysed. The target area of the survey is represented by the local governments located within 20 km from the city centre around Tokyo Metropolitan Government office. It is interesting to note that there is a definite negative correlation between city park areas and farmland areas. The correlation coefficient is −0.68, i.e. a relatively high negative correlation

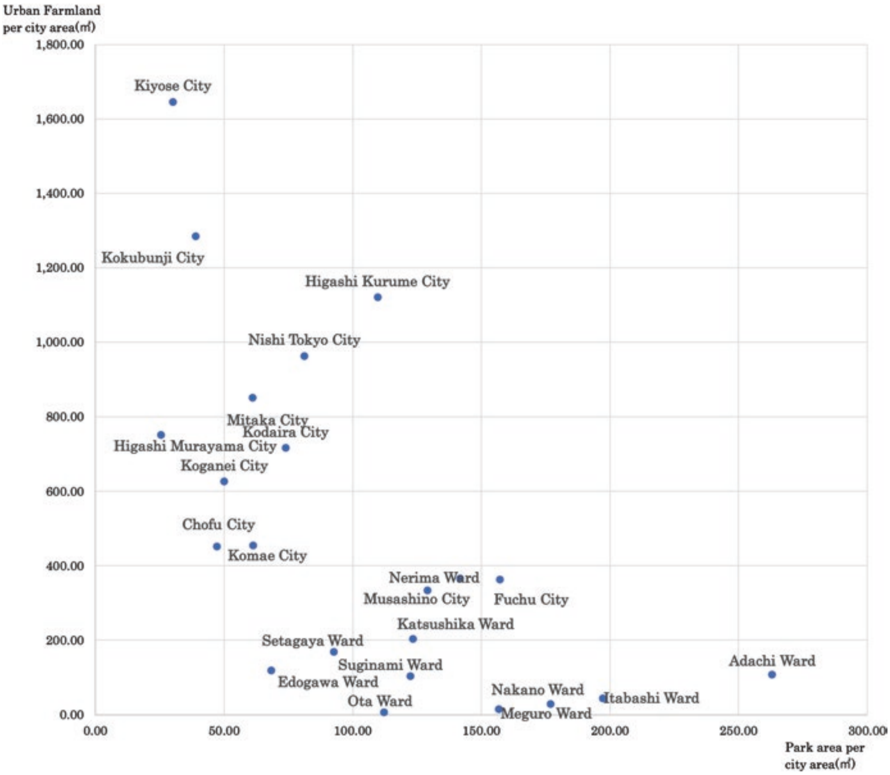

Fig. 12.1 Scatter plot of per capita urban parks and agricultural land areas for 22 municipalities within 20 km of Tokyo

($r = -0.675$, $t = 3.88$, $p < 0.01$). This shows that a municipality with a large park area has a small farmland area and a municipality with a small park area has a large farmland area. The target areas for analysis in this research are all within 30 min by train from the centre of the city, and there are very high urbanisation pressures and high land prices. This result means that urban farmland complements urban parks, both in terms of area and location. Tenojiya et al. (2017) have already pointed out the complementarity of urban parks with such urban farmland in a study of local governments in Chiba prefecture, located to the east of Tokyo. However, this study revealed that similar results could be obtained in central Tokyo.

12.4.2 Pesticide Usage Rules, Conflicts with Residential Areas

In Japan, there is no need to report on pesticides used in normal agricultural activities. For this reason, the rules for the use of pesticides are set mainly from the viewpoint of protecting the safety of farmers and reducing the residual pesticides in foods. Since farmers mostly buy pesticide through agricultural cooperatives, it can be said that agricultural cooperatives are in a position to advise farmers (Sakurai 2015).

For the urban agriculture, which is close to residential areas, there are different standards for pesticide use. In 2013, the Ministry of Agriculture and Fisheries issued the notification 'use of agricultural chemicals in residential areas' and set special standards for the use of agricultural chemicals on urban agricultural land. The contents are mainly the following three points. First is the prevention of pesticide scattering. It is recommended to use granular pesticides that do not easily scatter. If there is a need for pesticide spraying, farmers should choose a windless day. The second is to inform neighbouring residents in advance about spraying pesticides. If the farmland is near a school, it is required to inform the school and parents in advance. Third is a record of pesticide use. It is required that farmers record the type and amount of pesticides used and that the record be kept for a certain period. The use of pesticides threatens the safety of neighbouring residents, but residents also complain about pests gathering on vegetables.

Interviews with urban farmers found that the most serious rule was to inform the neighbouring residents about the use of pesticides. It is a psychological burden for the urban farmers to write letters that clearly inform the neighbourhood of the dates of pesticide use, the amount to be applied, the types of pesticide, and the dangers. However, this procedure is unavoidable in order to build a trusting relationship with neighbouring residents. This rule extorts urban farmers to only use the minimum amount of pesticides.

The above situation is also clear from examining the intended use of agricultural chemicals, which is reported yearly by the Ministry of Economy, Trade and Industry. Figure 12.2 shows the purpose of using agricultural chemicals in Japan, and Fig. 12.3 gives the same data for Tokyo. The nationwide proportions in Fig. 12.2 show the trends in common pesticide use. Farmland accounts for 47.1% of pesticide use, which is almost half of the total, and when the ratio of paddy fields and orchards is added, 80% or more is due to agricultural use. In Tokyo, on the other hand, home

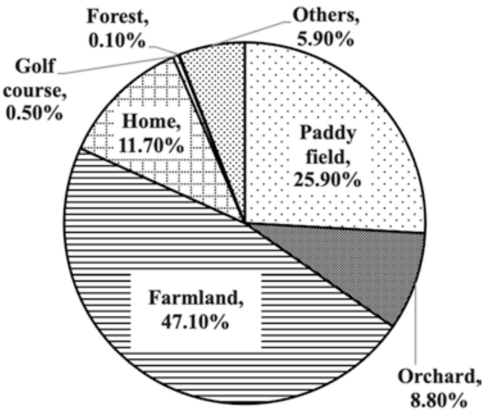

Fig. 12.2 Usage of agricultural chemicals nationwide in Japan

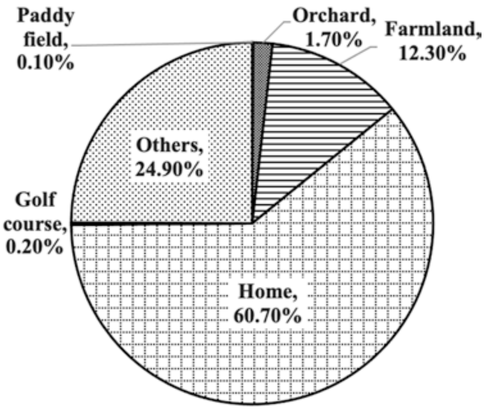

Fig. 12.3 Usage of agricultural chemicals in Tokyo

Table 12.1 Annual pesticide usage per farmhouse

Area	Nationwide	Tokyo
Total amount of pesticides used (t)	236,454	2733
Agriculture ratio in pesticide use	81.8%	14.1%
Pesticide amount for agricultural use (t)	19,3419.4	385.4
Number of farmers (thousands)	1164.1	4.9
Amount of pesticide used per farm (kg)	166.2	78.6
Cultivated area (ha)	4244,000	6690
Pesticide usage per area (t/ha)	17.9	2.4

Source: Ministry of Internal Affairs and Communications Statistics Bureau (2018) and Ministry of Economy, Trade and Industry (2014)

use accounts for 60.7%, whereas paddy fields account for 0.1%, orchards account for 1.7%, and farmland accounts for only 12.3%. Home use is presumed to be the use of pesticides in the kitchen or garden. This data shows that the use of pesticides on urban farmlands is very controlled. Table 12.1 is a calculation of the amount of pesticide used per farmer based on the data in Figs. 12.2 and 12.3. The average for the whole country is 166.2 kg per farmhouse per year, while in Tokyo it is 78.6 kg, which is less than half of that. Furthermore, the amount of pesticide used per cultivated area is surprisingly small compared to the national average. The total amount of agricultural chemicals used per ha is 17.9 tonnes in Japan, while it is 2.4 tonnes in Tokyo. This is 13.4% of the national average. This does not mean that the productivity of urban farmland is low. It is understandable that urban farmers are making efforts to reduce pesticide use.

12.4.3 Analysis of Municipalities' Urban Farmland Policies

Of the 22 local governments targeted by this study, 12 already possessed urban agriculture promotion plans as of March 31, 2020. This is because the Urban Agriculture Promotion Basic Act was just framed in 2015, and not all local governments have completed the formulation of an urban agriculture promotion plan. This study analysed 12 municipalities' plans and a total of 95 policies. These 95 policies have been categorised according to the 24 policies proposed by the Japanese Ministry of Agriculture, Forestry and Fisheries to promote urban agriculture. A single policy statement of a local government may contain more than one piece of policy content. In this case, it is divided into two categories. As a result, the 95 comprehensive policies have been broken down into 177 individual policies in total.

Firstly, these 177 policies were divided according to three categories: agricultural production-related policy, farmland-securing policy, and not directly connected to agricultural production policy. As mentioned above, Japanese urban agriculture is mainly conducted by full-time farmers. Agriculture is their means to earn their livelihood. Therefore, even in the case of urban agricultural policies, the improvement of agricultural productivity is considered to be prioritised, as is the case with ordinary agricultural policies. However, in the analysis results, policies for improving agricultural productivity comprised 41.8%, while policies not directly connected to agricultural production comprised 47.5%, and it was revealed that many urban agricultural promotion policies were adopted for purposes other than improving agricultural productivity. Farmland-securing policies accounted only for 10.7% of the total. It is not easy to acquire new farmland because land in the urban area is extremely expensive. For this reason, it is considered important to control the current reduction of farmland area.

What kinds of policies are adopted that do not directly lead to the improvement of agricultural productivity? Figure 12.4 shows the content of policies that do not directly lead to the improvement of agricultural productivity. Of these, the most

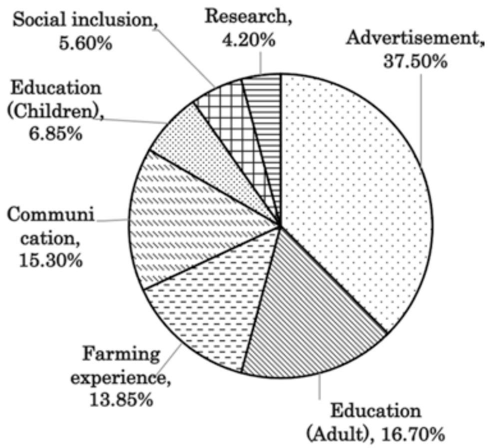

Fig. 12.4 Content of policies that do not directly lead to the improvement of agricultural productivity

common refers to advertisement (37.5%) – i.e. policies designed to provide citizens with information on urban agriculture. This is because urban agriculture is actually not well known by local residents yet. More than 10 years before urban agriculture became active, there was little interaction between urban farmers and local residents. Private companies also had no positive interaction with the locals. Economic activity and resident life were separate. However, as the importance of corporate social contribution began to be emphasised, local industries began actively working on building relationships with local residents. Agriculture is an activity with strong regional characteristics, and it is essential to build good relationships with local residents. Urban farming can sometimes cause conflicts within local communities. For example, soil dust or noisy agricultural machinery can disturb the residents. Therefore, for the acceptance of urban agriculture, it is essential that neighbouring residents understand its functions and benefits. This is almost the same purpose as the communication policies.

Education was the second most commonly adopted policy. This includes education for both adults and children. Urban agriculture provides urban residents with new learning opportunities, such as food education and lifelong learning. Experience is also an important function of urban agriculture. In particular, the experience of harvesting provides the joy of interacting with precious nature in the city. Further, 5.6% of local governments' policies were related to the social inclusion functions of urban agricultural land – e.g. policies that set aside times and places for elderly people and people with disabilities to participate in society. These results indicate that urban farmland is already well-positioned to become a site of both agricultural production and social value in urban agricultural promotion policies. This is an essential feature of urban green infrastructure.

12.5 Discussion

Japanese urban agriculture is characterised by being driven by professional full-time farmers. Most Japanese farmers are not young people who are interested in organic farming but are, instead, older people who continue traditional farming. They have been farming in the same land for generations. For this reason, they have a strong attachment to the land and have continued to farm without selling the land, despite its value. As a result of farmers continuing their activity in the city, although unintended by the local governments, there was a negative correlation between the area of the city park and the area of the urban farmland in the municipalities around the centre of Tokyo. It can be evaluated that the urban farmland has a sufficient function as green infrastructure both in terms of quantity and location. Also, a surprisingly small amount of pesticide use was revealed. Urban farmers make great efforts to increase productivity while reducing pests, but they do so while minimising pesticide use. Many urban agricultural policies adopted by local governments were not directly linked to improving agricultural productivity, for example,

Fig. 12.5 Unattended small vegetable shop on urban farmland. (Photo credit: the author)

policies aimed at education and social inclusion. These are important functions of farmland, but, on the other hand, they are also a burden for farmers.

Based on the results of these analyses, it is possible to consider, again, the possibility of urban agricultural land in Japan as urban green infrastructure. Norton et al. (2015) and Bowler et al. (2010) claim that city parks have the function of green infrastructure that cools the city. Urban farmland, which has the same green open space as urban parks, complements the area of green space in the city and functions as green infrastructure. In defining a multifunctional form of green infrastructure, Lovell and Taylor (2013) cite the multifunctionality of the landscape as it was originally applied to the agricultural environment. In fact, the agricultural promotion policies developed by local governments reflect the multifunctionality of agriculture. Andersson et al. (2014) point out that local stewards are very important in providing ecosystem services for urban green infrastructure. It can be said that the urban farmers in Japan play this role. Producing agricultural products in cities can be also evaluated as functioning as a green infrastructure from the perspective of reducing carbon dioxide emissions (Grewal and Grewal 2012).

About 15 years ago, a small change was made in urban agriculture in Japan. Intelligent farmers who were born on urban farms, grew up in the city, and graduated from universities majoring in agriculture were born. They inherited the farmland that has been passed down for generations. While they were traditional farmers, they also possessed the characteristics of nouveau farmers. They work on city-adjusted farm management (Pölling et al. 2017). Since they have sufficient scientific knowledge to practice agriculture, they were able to implement pesticide reduction with correct knowledge. They also understood that communication with local residents was important. They believed that the most important thing for new urban agriculture was trust with the surrounding, local people. This is why urban agriculture can fulfil its public function. They saved time in their agriculture and contributed to education and social inclusion.

Around urban farmlands, we often see things that symbolise the relationship of trust between urban farmers and local residents, such as unattended small vegetable shops with only a small box for money (Fig. 12.5). These vegetables are almost never stolen. There is an amazing variety of vegetables lined up. Not only vegetables but also flowers and nuts are sold. Growing vegetables of various varieties takes time. However, urban farmers choose the vegetables to grow, while considering the tastes of local residents. It seems to be based on the philosophy of sharing the blessings of the land (Wilson 1986). It can be said that such a background pushed the enactment of the Basic Law for Urban Agriculture Promotion by the central government.

12.6 Concluding Remarks

The history and culture of urban farmland have long been passed down to Japan since the Edo period, about 400 years ago. Japanese farmers have a strong attachment to the land. For this reason, even in the centre of Tokyo, farmers do not let go of the land, and there are many places where agriculture has continued until now. The patchwork-like mix of agricultural and residential areas was not considered desirable for land use in urban areas. However, urban agricultural land has a complementary relationship with the urban park in terms of area and position, and in municipalities with few urban parks, the urban agricultural land acts as an area of green space. Urban farmland was in a position to be green infrastructure for the city both in terms of quantity and location.

From an ecological point of view, the biggest issue with urban farmland is the use of pesticides. For this reason, urban farmland is considered to have both positive and negative aspects. However, the use of pesticides, which is essential for professional agriculture, was limited in urban agriculture. This is not a quantity limit but a moral-based rule. It is the rule that if you use pesticides, you must inform the local residents and schools in advance. This rule was a strong brake on pesticide use by urban farmers. As a result, urban farmland can be assessed as far more ecological than rural farmlands. In addition to this improvement, many local governments have described the social functions of urban farmland in their urban agriculture promotion plans. It can be seen clearly that urban farmland is expected to fulfil an important social function as green infrastructure for cities. From the results of this study, it can be concluded that urban farmland plays a certain role as green infrastructure of the city in terms of its physical characteristics, ecological aspects, and social functions.

In terms of limitations and scope for future research, this study only covers municipalities within 20 km of central Tokyo. Research on other large cities and suburbs is also needed. However this study also suggests that urban agriculture in central Tokyo could drive pesticide reduction in agricultural field. Urban agriculture would provide not only enrichment of the urban green infrastructure but also the well-being of farmers and local communities.

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Chapter 13
Anticipating an Urban Green Infrastructure Design for the Turkish Mediterranean City of Antalya

Meryem Atik, Veli Ortaçeşme, and Emrah Yıldırım

Abstract Green infrastructure is an emerging approach to make cities sustainable, healthy and more liveable. Based on a strategically planned network of natural and semi-natural areas in urban, peri-urban and rural landscapes, green infrastructure aims to provide sustainable urban development and to link green and blue spaces at both urban and regional scales.

In this study, a green infrastructure design system is anticipated for the city of Antalya. A set of green infrastructure components are identified and used to delineate a system which could take into consideration connections between actual ecological hubs, people and nature and past and present.

The results show that hubs and lines created by overlapped green infrastructure typologies potentially provide connectivity between city and ecology as well as between people and nature in the city of Antalya, Turkey. Antalya and its urban landscapes have a high potential for a green infrastructure design, but in order to integrate the green infrastructure application into urban planning, a holistic approach will be needed involving municipal, regional and state authorities, local stakeholders as well as citizens.

Keywords Urban landscape · Connectivity · Climate change adaptation · Resilient cities

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_13

13.1 Introduction

The word infrastructure refers to an underlying foundation for a system; green infrastructure (GI) refers to a network of green and blue foundations of human settlements. GI is considered to be an interconnected green space network including natural areas and features, public and private conservation lands and other protected open spaces that are planned and managed for their natural resources and values and for the associated benefits to the population (Benedict and McMahon 2006; Di Marino et al. 2019).

GI is an emerging approach to make cities sustainable, healthy and more viable and to reduce the impact of climate change, social injustice and diminishing natural resources. It is seen as an effective planning tool to improve and support urban ecosystems, to contribute to the conservation of biodiversity, to reduce the effects of climate change and to improve the well-being of urban inhabitants.

The concept of GI stands for interconnected networks of all kinds of green spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life (Benedict and McMahon 2006; Hansen et al. 2017; Pauleit et al. 2017). Based on systems of natural and semi-natural areas planned at strategic level, GI delivers a wide range of ecosystem services such as water purification, air quality, space for recreation and climate change mitigation and adaptation (European Commission 2013, 2019).

Regardless of its local settings, urban green infrastructure is defined by multifunctionality and connectivity (Badui et al. 2019). Andreucci (2019) pointed out that the opportunities for framing GI as a multifunctional network that plays a key role in the life of the city are immense.

Multiple benefits of GI have already been widely recognised and studied in the literature: impact on human health and well-being (Kim and Miller 2019; Venkataramanan et al. 2019; Navarrete-Hernandez and Laffan 2019), rain and storm water management (Meng and Hsu 2019; Mullins et al. 2020; Li et al. 2020) and supporting ecosystem services (Sebesvari et al. 2019; Ramyar et al. 2020). Conger and Chang (2019) identified the environmental benefits of coastal green infrastructure as being mainly twofold: flood protection and defence against erosion. The biophysical features of green spaces in urban areas help cities adapt to climate change through the provision of cooler microclimates and reduction of surface rainwater runoff (Gill et al. 2018).

Climate change is one of the most critical challenges to urban societies today. It amplifies the already existing pressures of anthropogenic activities on the urban environment, especially in Mediterranean cities. Urban sprawl in the Mediterranean coastal areas increases the vulnerability of human settlements to the impacts of climate change in the absence of a well-designed urban planning and management system. Urban areas are already facing increasingly frequent heat waves, droughts and floods, as well as health-related effects of climate change. Adjusting natural and human systems in urban areas is therefore vital to mitigate the effects of climate change and to support resilient urban environments.

Multifunctionality within GI helps to integrate the environmental, social, cultural and economic benefits of urban green areas and enables a more efficient use of space (Cannas et al. 2018; Ahern 2011). GI has become a popular basis for ecological planning, for sustainable land use and for providing ecosystem services in urban areas (Benedict and McMahon 2006; Kwak 2016; Ramyar et al. 2020). Best GI practices in local governance, especially when combined with traditional *grey* infrastructure, can achieve greater urban sustainability and resilience and are recognised for their value in adapting to the impacts of climate change (Sturiale and Scuderi 2019).

In Turkey, urbanisation played a significant role in the second half of the twentieth century. Migration from rural areas to cities created many disputes including green space problems. The municipalities responsible for urban planning and management have been unable to provide enough open and green spaces for city dwellers. The principal legislation concerning urban planning in Turkey is the Land Development Law, which includes foresights for urban land uses including green spaces. Within the historical development of the legislation, the common approach towards urban green space planning has been to provide a certain amount (measured in m^2) of public green space per capita (Ortaçeşme 2005).

Instead of networking green-blue landscape features, urban master plans in Turkey are based on physical layout rather than biophysical layers. Green areas have been handled as single isolated patches scattered around the building blocks in cities. A successful urban open green space development has been measured only by the extent of public green provided. However, rapid growth of Turkish cities requires a new vision for urban planning and systematic integration of open green areas into urban development.

Although urban biodiversity has long been studied by the scientific community in Turkey, green infrastructure is a new subject line. The first attempt at GI was the Smart and Healthy Turkish Cities Initiative (2004), aiming at increasing sustainability for urban settlements and creating more liveable urban areas (Tülek and Mirici 2019). Recently, green infrastructure solutions have been proposed to face climate change in Turkish cities (Hepcan 2019); moreover, the Urban GreenUP project (Urbangreenup 2020) for the city of İzmir is grounded on nature-based solutions and takes into account the interconnected aspects of urban life.

Cities have been viewed as single physical entities, and safeguarding their natural settings has long been neglected in Turkey's urban planning and development processes. Increasing demand for housing and tourism development, especially in the Mediterranean coastal cities, led to environmental degradation due to the lack of integrated policies in the planning and management of urban areas. In this framework, GI offers an essential potential for liveable and sustainable Turkish cities.

The aim of this chapter is to evaluate Antalya's urban and peri-urban landscapes by taking into account the natural and cultural values of the existing green areas and surface water systems when developing a green infrastructure network. Such an integrated GI network will improve the connectivity between the actual ecological hubs of the city, people and nature and past and present and will enhance and maintain the sustainability of urban and peri-urban areas. We believe that setting up a landscape scale green infrastructure design will empower and vitalise nature and green areas in the city, support holistic policy interactions and, more in general, help in many ways the sustainable urban development in Antalya.

13.2 Materials and Methods

Antalya city, located on the south-western coast of Turkey, was chosen as the study area because it represents a typical Mediterranean city (Fig. 13.1). Regarding GI components, the study area encompasses a wide variety of natural and semi-natural areas as well as rich biophysical landforms in the city as well as in its periphery.

Antalya is a coastal city, built on a travertine terrain at 35–50 meters a.s.l. Its wide array of biophysical and biological traits, such karstic landmarks (i.e. travertine platforms, canyons, dolines and limestone pavements), sea cliffs, beaches, wetlands and reed beds, together with its complex water network made of creeks, rivers and waterfalls provides a broad diversity of landscape around the city. The Mediterranean climate with very hot and dry summers and rainy and temperate winters strongly shapes local plant communities. Native vegetation includes Turkish pine (*Pinus brutia* Ten.) forests and sclerophyll maquis. The species diversity of local urban vegetation is increased by the occurrence of many ornamental plants and cultivated crops.

The city was founded by the Pergamon King Attalos II during the second century BC and was subsequently ruled by Macedonians and Seleucids, the Roman Empire, Byzantines, Seljuks and Ottomans (Onat 2000). Traces of the city's history are still visible in its cultural imprint and also help to better understand its surrounding natural environment.

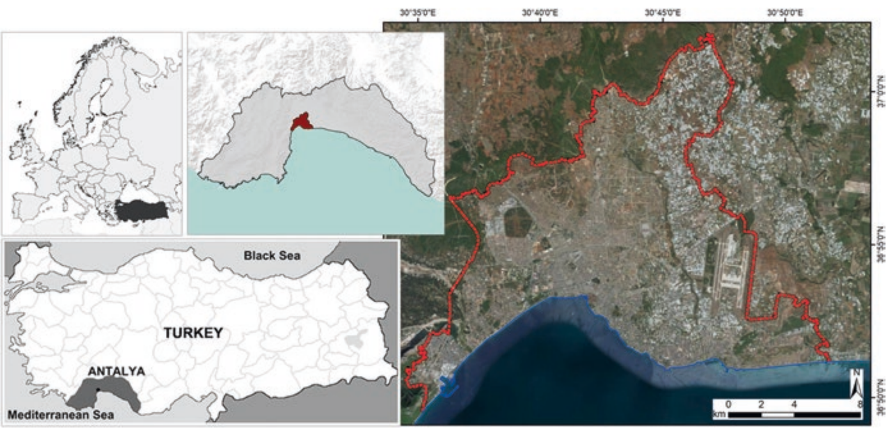

Fig. 13.1 Location of Antalya city

Antalya is a fast-growing city of nearly 2.5 million people. Tourism is its most important economic sector with over 15 million foreign visitors in 2019, while agriculture is second, with Antalya supplying almost 75% of the entire greenhouse production of Turkey. Urban sprawl experienced a strong acceleration after the 1980s along with a boom in tourism and the consequent fast expansion of the city, which has been detrimental to natural and agricultural areas and caused the degradation and overexploitation of green areas and natural ecosystems.

Adapted from Benedict and McMahon (2006) and Pauleit et al. (2017, 2019), our study aims to identify a set of green infrastructure typologies, characterising Antalya both in 1957 and 2019, in order to use them for future green infrastructure design of the city.

Valuing the connectivity between the city and its surrounding natural and semi-natural areas, between people and city and between past and present can be considered a key strategy to detect information and other useful insights for a GI design and planning. We analysed connectivity between actual ecological hubs on the bases of the relationship between natural features to semi-natural and built-up cultural areas; connectivity between people and nature was based on the physical accessibility of green infrastructure to citizens; and connectivity between past and present was grounded on the cultural and natural significance of green infrastructure components.

Spatial data from aerial photos elaborated by the General Directorate of Mapping (HGK 2019) for the year 1957 and Google Earth satellite images (Google Earth 2019) for the year 2019 were used to define green space distribution. Geographically referenced spatial data were interpreted through Esri ArcGIS and ArcMAP software.

13.3 Green Infrastructure Typologies of Antalya City

Based on the main land use patterns, eight groups of green infrastructure typologies were identified for Antalya. In order to see the status quo of the city and to set a precise connectivity between past and present, green infrastructure typologies were analysed in two time series, i.e. 1957 and 2019. This time frame was chosen because urban sprawl in Antalya started during the 1950s. A quantitative analysis of landscape change is important to understand how the territory looked like prior to urbanisation, to assess the current state of the art and to identify the most valuable options for future green infrastructure design and planning for the city (Figs. 13.2 and 13.3, Table 13.1).

Fig. 13.2 Coastal, natural, semi-natural and agricultural landscapes in Antalya city: Düden waterfall and *falezes* (**a**), Konyaaltı quarter (**b**), Lara sand dunes (**c**), Yamansaz marsh (**d**), Kırcami (**e**)

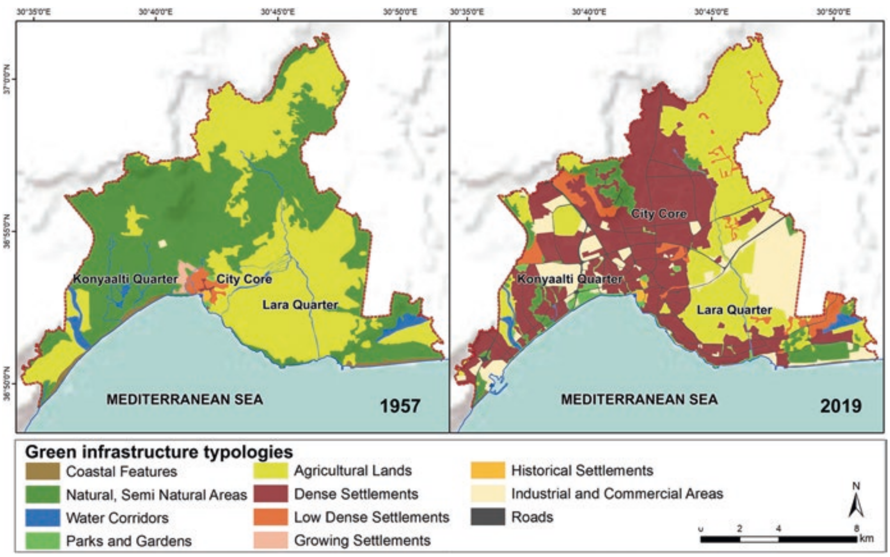

Fig. 13.3 Green infrastructure typologies in 1957 and 2019

Table 13.1 Evaluation of change in green infrastructure typologies: comparison between the years 1957 and 2019

Green infrastructure typologies	1957 Area (hectares)	2019 Area (hectares)	Change (%)
Coastal features	336.41	116.52	−65.4
Natural, semi-natural areas	11,924.78	1602.63	−86.6
Water corridors	553.18	308.69	−44.2
Parks and gardens	28.95	359.42	1141.6
Agricultural lands	10,533.23	7334.36	−30.4
Settlements			
Dense settlement	22.92	8856.13	38,540.8
Low-density settlement	235.84	1095.85	364.7
Growing settlements	115.25		−100.0
Historical settlements	34.97	59.63	70.5
Industrial and commercial areas	20.99	3305.72	15,648.6
Roads	3.28	775.42	23,570.2

13.3.1 Coastal Features: Coastline, Beaches and Sea Cliffs

13.3.1.1 Antalya Falezes

Sea cliffs, locally named falez, a term derived from the French *falaise*, meaning steep rocky cliff, represent one of the most remarkable landmarks of the coastal morphology of Antalya city. Formed by the erosion of limestone rock outcrops, the vertical and abrupt *falezes* reach up to 35–45 m a.s.l. (Fig. 13.2a).

This sea cliff system characterises a 12-km-long coastline that connects the sandy beach of Lara on the east to the pebble beach of Konyaaltı on the west of the city (Fig. 13.3b). This long coastal system bordering Antalya represents an exceptionally long blue-green-blue belt. It improves the quality of the city landscape and strengthens the resilience of the urban environment by creating a remarkable buffer zone where built-up land meets the sea.

13.3.2 Natural and Semi-natural Areas

13.3.2.1 Lara Sand Dunes and Dune Forests

Coastal sand dunes represent a vulnerable and dynamic landform resulting from the interaction between sea and land as windblown material was carried and deposited over a long period of time, a process that started after the last glacial event. The Lara sand dunes (Fig. 13.2c), covering a 10-km-long and 250-m-wide surface (Ortaçeşme and Atik 2012), represent a natural landscape unit that survived within the developing city. Located on the east part of Antalya, Lara sand dunes are tightly connected with the Lara dune forest further inland which is a sanctuary not only for native woody plants, such as *Pinus brutia* Ten., *Pinus pinea* L., *Ceratonia siliqua* L., *Tamarix smyrnensis* Bunge, *Pistacia lentiscus* L., *Vitex agnus-castus* L., etc., but also for several plants linked to dunes such as the sea daffodil, *Pancratium maritimum* L., which commonly grows along the Mediterranean coasts.

13.3.2.2 Yamansaz Marsh

Marshes are low-lying lands often saturated with groundwater where rain and surface water can also drain. They form valuable wetland systems with high biological diversity, play an important role due to their high level of wilderness and have an important function for storm water management and infiltration. The marshes of Yamansaz (Fig. 13.2), whose Turkish name means *appealing reed*, are the only coastal wetland ecosystem left in the city of Antalya (Ortaçeşme et al. 2002).

13.3.2.3 Remnant Forest Patches and Maquis

Remnants of forest patches still occur interspersed throughout the city, mostly surrounded by buildings and other infrastructure. Typically dominated by *Pinus brutia* Ten., these forest nuclei host species-rich undergrowth with plenty of native woody species such as *Quercus coccifera* L., *Phillyrea latifolia* L., *Rhamnus alaternus* L., *Pistacia lentiscus* L., *Osyris alba* L., *Daphne gnidium* L., *Daphne sericea* Vahl, etc. Dense nuclei of evergreen maquis vegetation adapted to local dry and hot climatic conditions were still widespread in 1957 in many sectors of the city now occupied by dense settlements. The last nuclei are mainly concentrated on the northern edge of Antalya (Fig. 13.3, Table 13.1).

13.3.3 Parks and Gardens

The Atatürk Culture, Düden, Zeytinpark and Karaalioğlu parks are the most important urban green areas of the city. The Falez Coastal Park provides a near-natural connection between the Atatürk Culture, Karaalioğlu and Düden parks and forms the natural link between the coast along the city itself and the Mediterranean Sea. Apart from Kaleiçi, the old town of Antalya, and some residential areas, the buffer role played by the Falez Coastal Park offers advantages and opportunities in terms of urban biodiversity and landscape diversity and strongly improves the linear connectivity between the coast and the best-preserved natural and semi-natural areas of the city.

Atatürk Park is the largest public green space of the city and hosts a large number of native and introduced ornamental plants. Established in 1940s, Karaalioğlu Park represents a symbol of green area planning of the city. Both Atatürk and Karaalioğlu parks offer a beautiful panorama of the Taurus Mountains and the Mediterranean

Sea. Vakıf Çiftliği representing the typical example of traditional olive groves is a valuable green area appreciated for its cultural history.

13.3.4 Water Corridors, Valleys

13.3.4.1 Düden River, Düden Waterfall and Seven Streams

The Düden River originates from the Kırkgözler springs (*40 water sources*), located some 11 km northeast of Antalya city. Its waters are now conveyed to Antalya through a 10-km-long artificial channel that was constructed in 1961 by changing its original course. In the heart of the city, the water of Düden (meaning *underground river* in Turkish), rises to the surface, becomes visible and ends up with the 40-m-high Düden waterfall pouring into the Mediterranean Sea (Şen et al. 2019).

The Düden waterfall is the only one remaining of the seven streams that once conveyed water from Taurus Mountains down to the city for irrigation, drinking, cleansing, urban cooling and utility (Şen et al. 2019). Çimrin (2007) reported that one of these seven streams passed through the central neighbourhoods of Değirmendere, Balbey, Kaleiçi and Yenikapı providing irrigation water for the traditional gardens of Antalya.

13.3.4.2 Boğaçay River

Boğaçay is the largest river crossing Antalya city from north to south. The Turkish name means *bull stream*, a reference to the wild and turbulent flow of its waters. The catchment area of this 25-km-long river is around 833 km^2 (Dipova 2010), and it forms an important natural water source for the city today and in the future.

The continuous input of coarse material carried by the Boğaçay River caused the formation and the seaward expansion of a wide sand-gravel barrier separating the plain from the sea. Due to historical river dynamics, the current lagoon mouth has become a river channel fed by karstic springs and groundwater (Dipova 2010).

The coastal fertile flatlands created by the sediments of Boğaçay River were used for agricultural purposes, and rice was grown up here until the 1960s. Later on, most of the local wetlands were drained to fight malaria, and crop culture was intensified to obtain other agricultural products, such as corn and cotton.

The local wetlands in Konyaaltı, once a rich coastal habitat, known as a hunting ground of wild birds until the 1970s, existed until the construction of the Antalya port. The building of the port (1972) was the starting point for the destruction of a large part of the local wetlands, and by the 1990s–2000s, this part of the city was designated for dense settlement growth. Nowadays, only some traces of former wetlands, shores and river corridors can be seen.

13.3.4.3 Sarısu Stream

At the west end of Antalya city, Sarısu *yellow water* represents a stream corridor hosting a small-sized reed bed and some remnants of wetland surfaces. According to Dipova (2010), geological evidences show that with the rise of sea level after the last glacial maximum, parallel to the evolution of local territory, the materials brought by the rivers began to form delta fillings. The Sarısu stream probably presents the former exit mouth of a lagoon created by Boğaçay river.

13.3.4.4 Valleys and Canyons

Other landmarks of Antalya are the steep and narrow canyons shaped by local limestone outcrops. Some sectors of the Kadınyarı stream still provide some good examples of what the territory of Antalya looked like before the rapid urban expansion. This stream also hosts high levels of species diversity, in which local habitats are still functioning and contributing to the regulation of urban water cycles.

The area of Akdeniz University campus hosts undisturbed examples of tufa rocks which form the most typical outcropping rock of Antalya. Tufa rocks can be found especially in the canyons (Sayan and Korostoff 2009) and are one of the most original elements of the karstic landscapes of the Mediterranean region and hence worthy of being preserved together with the plants and plant communities associated to them.

13.3.5 Agricultural Lands

The presence of agricultural lands in urban and suburban areas is of greater value with respect to cultural heritage and testify the traditional land use patterns in Antalya prior to its urbanisation. They provide food products, suitable habitats for urban plants and animals, a free filtering layer for storm and rainwater and a commodity for local income and employment.

Agriculture is the second source of income in the Antalya region after tourism. Kırcami is the last quarter still hosting farming activities left in the periphery of the city. The agricultural practices are rather labour-intensive and provide the vegetable production for the city. This area represents a transition zone between the city and the countryside. Although currently affected by the intense land use changes (Figs. 13.2 and 13.3, Table 13.1), this area still plays an important role for food production. It contains large land surfaces that can provide a great opportunity for planning of urban GI for Antalya city.

13.3.6 Settlements

The settlement history of Antalya goes back to ancient times. The city was established as a naval base around 159–138 BC with the name of *Attaleia* subsequently transformed to Antalya, using one of the best natural harbours of the Pamphylia region (Güner 1967; Güçlü 1997). Owing to its commercial importance, from the eighth century onwards, Antalya was invaded by Arabs, Rhodians and Venetians and in 1207 was taken over by the Seljuk Turks. Between the twelfth and thirteenth century AD, Antalya was an important trade centre until it became a part of Ottoman territory in 1390 AD (Atik et al. 2008).

Historical settlements consist of the old town of Kaleiçi and its periphery with very low-density and detached houses in 1957 and the city core, while in 2019 the majority of the city's surface is covered with recent dense settlement with high-density blocks. The speed of urbanisation in the last 60 years has been extreme, destroying large natural areas (Fig. 13.3, Table 13.1).

13.3.7 Industrial and Commercial Areas

The first industrial and commercial activities in Antalya started by the establishment of the Antbirlik Cotton Weaving Factory in 1952, the Ferrokrom Factory in 1958, the airport in 1960 and the Kepez Power Plant in 1961.

During the 1970s, Antalya started to be an important tourism destination, and in 1974 the very first integrated tourism plan took place in the south of the region. The Tourism Incentive Act of 1982 strongly accelerated the building of tourism facilities and induced an even more intense migration of people into Antalya, for employment opportunities. Nowadays, most of the commercial areas within the city are hotels, restaurants, entertainment and shopping centres serving tourism.

Industrial and commercial settings include private companies, governmental institutions and tourism facilities with open green spaces and gardens. Although they are not open to public use, these green areas play an active role in urban ecology (Fig. 13.3).

13.3.8 Roads

Asphalted roads (i.e. motorways, state highways, provincial roads, village roads) are the basic transportation elements in Turkey. However, roads and paths for the mobility of people and vehicles may function as green corridors if they were supported by roadside planting.

Due to the rapid urban sprawl accelerated by prevalent economic goals, many natural ecosystems in and around the city have been lost, degraded and heavily modified. Coastal landmarks such as *falezes,* sand dunes and beaches in Antalya city have undergone strong reduction as did natural and semi-natural areas since 1957 due to urbanisation driven by tourism and recreation (Figs. 13.2 and 13.3, Table 13.1). Water corridors are crucial components of the urban ecosystems and green infrastructure. However, in the last 60 years, two fifths of the inner-city water network have been altered through drainage, covered by buildings, fragmented or canalised.

13.4 Results and Discussion

Green infrastructure incorporates both the natural and the built environment. To anticipate an urban green infrastructure design for Antalya city, green infrastructure typologies were clustered into design components according to Pauleit et al. (2017) (Table 13.2) and delineated in a design layout as in Fig. 13.4a. The analysis of

Table 13.2 Design components for green infrastructure and principles of connectivity

		Connectivity between		
		Actual ecological hubs	People and nature	Past and present
Green infrastructure typologies	Design Components	*Level of naturalness*[a]	*Access to open green areas*[b]	*Cultural and natural significance*[c]
Coastal features	Core green areas	Natural	Strong	Natural significance
Natural, semi-natural areas	Core green areas	Natural	Medium, weak	Natural-cultural significance
Water corridors	Water corridors and valleys	Natural	Medium, weak	Natural significance
Parks and gardens	Core green areas	Semi-natural	Strong	Cultural significance
Agricultural lands	Core green areas	Semi-natural	Weak	Cultural significance
Dense settlement	Built urban fabric	Cultural	Strong	Neutral
Low-density settlement	Potential areas	Cultural	Strong	Neutral
Historical settlements	Potential areas	Cultural	Strong	Cultural significance
Industrial and commercial areas	Potential areas and built urban fabric	Cultural semi-cultural	Strong	Neutral
Roads	Potential areas	Cultural	Strong	Neutral

[a]*natural* having particularly high levels of naturalness, *semi-natural* partly cultivated and partly natural, *cultural* being produced or shaped by man

[b]Access scaling based on the linear distance between settlements and core open green areas: *strong* 0–500 metres, *medium* 500–1500 metres, *weak* 1500–2500 metres

[c]*Neutral* has neither natural nor cultural significance

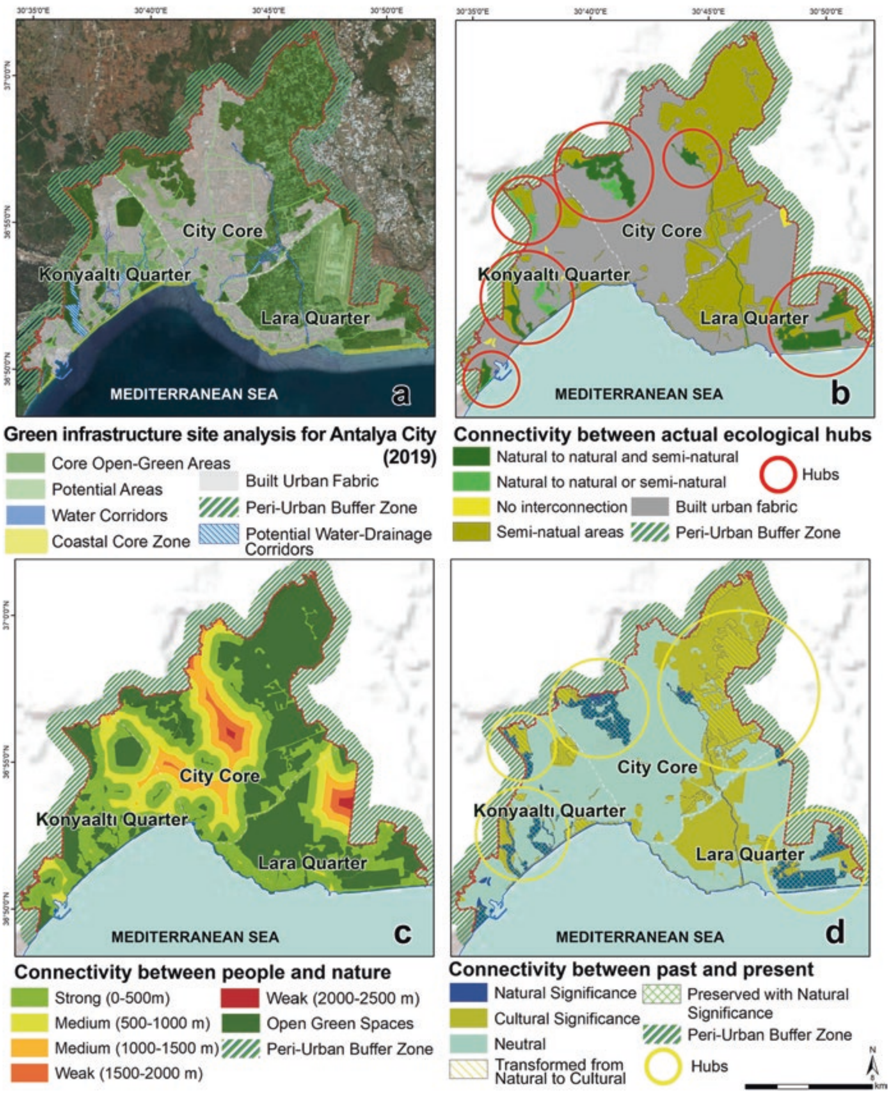

Fig. 13.4 A green infrastructure site analysis for Antalya City (**a**) and designing for connectivity between actual ecological hubs (**b**), people and nature (**c**), between past and present (**d**)

design components and their clusters together with natural features as well as urban history showed that Antalya city has three main quarters that initially provide a network of urban green and blue systems (Fig. 13.4a). The quarter of Konyaaltı was built along the coastal barrier of a lagoon made of the material brought by the Boğaçay River and other watercourses.

Regarding the potential of GI components, Lara quarter, located at the eastern part of Antalya city, has the largest unspoiled green areas (Fig. 13.4a). Özmen

(2015) affirmed that fine-grained materials were carried to the sea by the Aksu and Köprüçay rivers and formed the Lara coastline. As a result of low slope base topography and prevailing winds blowing from the sea, the Lara sand dune system was one of the most important coastal ecosystems of the region long before urbanisation. Local deposition patterns allowed the formation of a lagoon system behind the sand barriers. Today, the only remnant of this previously larger lacustrine system is the Yamansaz marsh.

In the city core, the roads act just as a design component of the built urban fabric. Only in the northern and north-eastern periphery of the city, the combined occurrence of large agricultural areas, low-rise buildings and evolving traditional land use patterns embodies green infrastructure components.

Antalya city is close to the Taurus mountain range, and its forests give a regional identity to the city and outline the natural contours of the urban expansion. Even more importantly, this mountain range embraces the city, acting as a peri-urban buffer zone for a green infrastructure system (Fig. 13.4a).

13.4.1 Connectivity Hubs in the Green Infrastructure of Antalya City

Green infrastructure draws its strength from its focus on connectivity – between natural lands and other open spaces, between people and between programmes (Benedict and McMahon 2006). Regardless of its local settings, green infrastructure is defined by multifunctionality and connectivity. Pauleit et al. (2017) described connectivity as a physical and functional linkage between green spaces at different scales and from different perspectives. Connectivity also depends on the nature and quality of green spaces, and in this study, connectivity is considered as a network of ecological hubs, people and nature and past and present.

One of the core principles of GI relies on the green space network, i.e. the structural, ecological, social and functional connectivity that leads cities to sustainability. A set of principles was evaluated for each type of connectivity. The connectivity between actual ecological hubs for Antalya was defined, based on high levels of naturalness as well as the existence of semi-natural and cultural green areas in the city (Table 13.2, Fig. 13.4b).

Connectivity between the built components of the city and natural and semi-natural areas is important for developing ecological networks and for improving and protecting urban biodiversity. Hubs of connectivity between city and ecology facilitate protection cores for habitats and important species. Here, the interconnection between natural and semi-natural areas is taken into account. An intact link between two or more natural areas improves the connectivity between actual ecological hubs, implying that natural systems benefit from wildlife and human. These places also have the capacity to bring people into contact with nature all around the city periphery (Fig. 13.4b).

The connectivity between people and nature was based on the idea of physical accessibility to green spaces since a strategically interconnected green infrastructure promotes quality of life in urban areas. Hereby, a linear distance between settlements and built urban fabric was scaled between 0 and 2500 meters to define the most prevailing public access zones to core green areas, coastal zone and water corridors in GI components of Antalya (Table 13.2, Fig. 13.4c). Regarding the physical accessibility to coastal features, natural and semi-natural areas, water corridors, parks and gardens, the anticipated GI system for Antalya offers strong access to the public except from dense built-up areas (Fig. 13.4c).

Cultural values are attached to all aspects of urban life and history, while natural values foster conservation of biodiversity inherited from the past. Cultural and natural significance were taken into account in the appraisal of the connectivity between past and present. Natural significance refers to unique natural areas of high biodiversity that have survived and still exist today (e.g. forests, sand dunes, maquis), in other words, natural areas identified in both 1957 and 2019. Cultural significance takes into account the continuity and consistency of traditional land use patterns from the past to present day. Some localities with natural maquis or forest in the past which have turned to be rural and agricultural areas today represent the connectivity between past and present (Fig. 13.4d).

Based on a strategically planned network of natural and semi-natural areas in urban, peri-urban and rural landscapes, GI aims to develop sustainable urban and rural areas based on the idea of linking green and blue spaces. In this study, a GI design system was anticipated for Antalya city. A set of GI typologies for 1957 and 2019 was taken as reference to define design components according to Pauleit et al. (2017, 2019). This also allowed us to see changes, losses and particularly to update the potential of the city for GI.

A well-connected green space network is the key for the success of a GI system that relies on the creation of linkages at different scales. The connectivity analysis between ecological hubs, people and nature and past and present allowed us to identify hubs and corridors within the city's GI system. Here, hubs referred to the core areas, where multiple scales of connectivity evolve. A key role for the connectivity between the city and the natural to semi-natural areas is potentially played by the Lara quarter. Lara dunes and dune forests of high naturalistic value provide connectivity between past and present. Similarly, there are other combined important hubs around the city centre and Konyaaltı (Fig. 13.5).

Hansen et al. (2017) emphasised that connectivity involves both structural and functional connections between green spaces, in order to create added value from an interlinked system. Benedict and McMahon (2006) stated that a green infrastructure network connects ecosystems and landscapes in a system of hubs, links and sites. Hubs anchor green infrastructure networks and provide space for native plant and animal communities, as well as an origin or destination for wildlife, people and ecological processes moving through the system. Pauleit et al. (2017) set principles for green infrastructure planning addressing integration, multifunctionality, connectivity, multiscale and multi-object approach. Our attempt here is to test the connectivity approach to outline the capacity of Antalya city for GI development and assess

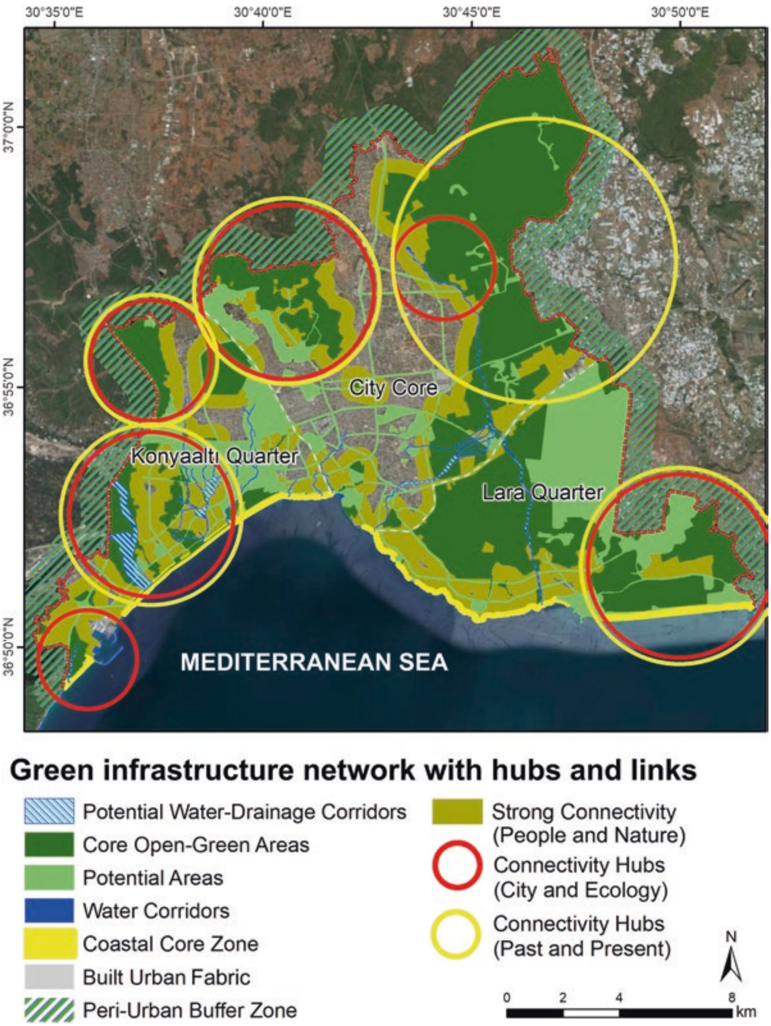

Fig. 13.5 A green infrastructure network for Antalya city with hubs and links

to what extent these typologies come together and if they allow us to build up a city-scale system.

In this study, hubs and corridors that could constitute the components of a GI network for Antalya city were identified by investigating the connectivity between people and nature, past and present and between actual ecological hubs. The almost 25-km-long coastline system including the Lara and Konyaaltı beaches and the *falezes* delineates a zone of multifunctional benefit for recreation, tourism and protection of coastal biodiversity as well as city's cultural and visual identity (Fig. 13.5). On taking planning actions, links of strong connectivity between people and nature can be strengthened by various ways. Here, better connection of core green areas with residential areas and also with potential areas can be achieved by a green network of roads and roadside planting.

GI highlights the importance of open and green space as parts of interconnected systems that are protected and managed for the ecological benefits they provide (Benedict and McMahon 2006). Antalya city still has wetlands, dunes, waterfalls and attractive coastal landscapes with a high natural and ecological value (Ortaçeşme and Atik 2012) and possesses an important potential for developing an effective GI with its natural physical elements, water resources, valleys, agricultural areas and cultural elements (Manavoğlu and Ortaçeşme 2015).

A green infrastructure initiative is most crucial for climate change adaptations in the Mediterranean cities. Antalya is characterised by Mediterranean climate with arid and hot summers and mild and rainy winters. According to the climatic average data between 1930 and 2018, the highest temperatures in Antalya can go up 45 °C (Meteroloji Genel Müdürlüğü 2020). Due to local climate and topography, extreme rainfalls may cause intense surface flows and floods (Özmen 2015). Kafalı Yılmaz (2008) reported that Antalya experienced natural disasters with floods, hail and tornadoes almost every year between 1995 and 2004. In 1998, a 3-day-long flood, storm and tornado disaster whose intensity scale was comparable to a tropical cyclone hit the centre of Antalya.

Heavy precipitation causing floods and tornados and high temperatures reduce the life quality of urban dwellers and increase the importance of benefits provided by a green infrastructure that could help to mitigate the negative effects of climate change. Antalya city is fortunate to have important green infrastructure components – coastal zone, river and valley corridor networks, hubs of natural and semi-natural areas and peri-urban buffer zone – which could be integrated into a GI mechanism to assist in adapting to climate change (Fig. 13.5).

Due to the ongoing climate change, GI has been regarded as a key approach to water management in urban areas. In Antalya, it would be wise to benefit from former water corridors in the city to maintain ecological connectivity in the urban environment. Many of the inner-city streams and corridors that once flowed across the whole city feeding it like the blood vessels in the human body, have been covered up or dried out during the last 50 years due to the urban development (Şen et al. 2019). In fact, some rivers that still help to discharge flooding water and supply suitable habitats for urban flora and fauna squeezed into the urban fabric; the Düden waterfall is one of the last such remaining natural assets of the inner city.

The Sarısu, Boğaçay and Düden rivers and many other small creeks are also potentially important water and GI resources. These water corridors form the blue infrastructure of Antalya city and enable the interconnection of GI components (Fig. 13.5). The underlying capacity of water corridors in the Konyaaltı quarter provides opportunities for biophysical connectivity between core green areas, new green areas and built urban fabric.

Even though dried up and disappeared during urbanisation, hydronyms of *lost* water features can provide useful hints to finding opportunities for building a blue as well as green infrastructure. Examples include the etymology of the following city quarters: Güzeloluk or *beautiful water channel*, Kızılarık or *crimson stream*, Soğuksu or *cold spring*, Pınarbaşı or *fountain head*, Düdenbaşı or *waterfall head* and Gürsu or *abundant water*. All these vernacular names remind us of the past occurrence of water sources and blue corridors. On the other hand, toponyms such as Yeşilköy *green village*, Yeşilova *green plain*, Yeşilbahçe *green garden* and Yeşilyurt *green homeland* suggest that these areas were devoted to agriculture; they might still have good potential for a green infrastructure.

Diversity in natural and semi-natural landscape units enhances the species richness of urban flora and fauna. Göktürk (1994) identified 1023 plant species growing there, 863 of which are native to Antalya. The connectivity between Antalya city centre and surrounding natural and semi-natural areas can be defined by many hubs with peri-urban buffer zones around the city (Fig. 13.5).

Urban GI is an indispensable prerequisite for human well-being in cities. The approach is applicable to the safeguarding, planning, construction and maintenance of green spaces as well as to the management and maintenance of urban nature (BfN 2017). With regard to GI system in the cities, the main legislation concerning urban planning and green spaces in Turkey is the Land Development Law (LDL). Adopted in 1985, the LDL defines green spaces as active green space such as parks, children playgrounds and sport fields open to public. According to this legislation, city master plans have to provide at least 10 m^2 of public green space per capita considering the projected population (Ortaçeşme 2005).

Land use planning in Turkey extends from a top-down, state-led government process to regional and local levels and involves a great number of institutions where physical developments and land use decisions are based on LDL no. 3194 (Atik et al. 2015). The metropolitan municipality of Antalya is responsible for planning and design of the city. However, the complexity of urban planning is mainly based on physical layers rather than ecological ones; the multitude of legislations and especially the high demand for urban land are limiting factors for new approaches using GI networks in city planning. In this context, a strategically planned network of GI would help to incorporate ecological connectivity, social integration and spatial coherence for Antalya city and can offer a multifunctional tool for urban planning. As mentioned by Magaudda et al. (2020), GI can lend itself to light, flexible policy frameworks addressing multilevel governance.

In the new vision of a city that is sustainable and resilient, green areas assume even greater importance as multifunctional resources for the city and its inhabitants (Sturiale and Scuderi 2019). Within urban centres green spaces constitute critical environmental capital that needs to be strategically planned (Gill et al. 2018). With this present study, we have tried to identify the potential for building a GI system in the Mediterranean city of Antalya, a city whose urban landscapes have great potential for a GI design. As a beginning, to place GI priorities on the agenda for planners and local municipalities, we have tried to define the existing components that a GI system for Antalya might utilise. To create a successful GI, however, complex, multilevel and adaptive strategies as well as a holistic approach will be needed that involve urban, regional and state authorities, stakeholders and the wider public in incorporating the integrated green infrastructure approach into urban planning.

Acknowledgements We would like to thank our reviewers for their kind and constructive comments and for their helpful inputs to the study. We give special thanks to Graham Fairclough and Jeroen De Vries for their earlier revisions and valuable contributions to this chapter.

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Chapter 14
Multifunctional Ecological Networks as Framework for Landscape and Spatial Planning in Italy

Serena D'Ambrogi and Matteo Guccione

Abstract Faced with increasingly frequent environmental emergencies and related challenges (climate change, biodiversity loss, natural habitat destruction and fragmentation, soil consumption), this paper argues that overall territorial resilience can greatly benefit by developing innovative landscape planning solutions to address territorial management concerns. A specific land management option, the Multifunctional Ecological Networks or Green Infrastructures, offers an advisable approach for territorial regeneration and wasteland reuse especially in urban and peri-urban areas. This approach integrates strategic objectives based on area multifunctionality and sustainability of actions into planning activity at different landscape scales. By taking into account the *genius loci* of each context and maintaining a clear vision of the preservation of biodiversity and Natural Capital, the Multifunctional Ecological Network approach represents a key resource in landscape planning that can strategically balance many different needs. This contribution offers a comparative analysis of a number of Green Infrastructures introduced as landscape and spatial planning tools at regional and provincial (metropolitan area) scales to examine the potential benefits of implementing Multifunctional Ecological Networks.

Keywords Ecosystem services · Fragmentation · Integration · Ecological connectivity

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_14

14.1 Introduction

Increasingly frequent environmental emergencies and their related challenges require thoughtful and coordinated responses. In this paper we argue that innovative landscape planning solutions designed to address key territorial management issues can critically enhance the potential for territorial environmental resilience. It is essential to recognize the progressive process of territorial degradation and fragmentation causing both increased loss of Natural Capital and the impoverishment of the landscape.

The objective of Natural Capital conservation therefore assumes strategic importance in preserving landscape features and functionalities. The process of natural environment fragmentation, due to anthropogenic causes, perceived as (Guccione and Peano 2003: 11):

> […] a process that generates a progressive reduction in the areas of natural environments and an increase in their insulation [through which] the natural areas become spatially segregated and progressively isolated fragments, inserted in a territorial matrix of anthropogenic origin.

represents a primary cause of biodiversity loss and pressure on Natural Capital. Urban and productive settlements, technological and mobility infrastructure, soil consumption and drastic simplification of agricultural landscapes are among the main causes of functional ecological alteration/weakening of landscapes in Italy (Comitato per il Capitale Naturale 2019).

The integration of Natural Capital into spatial planning tools, especially concerning the planning of wide areas, is therefore one of the strategies indicated (Comitato per il Capitale Naturale 2018) for the achievement of EU and national targets to recover and restore degraded ecosystems, to improve ecological connectivity and to reduce soil artificialization and sealing. Moreover, such integration would effectively enhance the resilience of the territory and environmental quality in terms of landscapes and community life, counteracting densification trends, especially in the urbanized areas. The implementation of concrete land transformation management policies could be pursued by reinforcing the promotion of interventions aiming at environmental restoration and at the reduction of soil consumption and ecosystem fragmentation, by using options *in harmony with nature* as nature-based solutions (NBS) and green infrastructures (GI) (EC 2013a) compared to grey infrastructures (Comitato per il Capitale Naturale 2018).

A planning and territorial development approach, based on an integrated and strategically planned system of natural and semi-natural areas, should consider the close relationship between the loss/preservation of biodiversity and landscape functionality. This approach is important in order to preserve a stock of adequate and multifunctional resources (also in terms of strategies and organizational, operational and management skills) to respond to the different vulnerabilities and to enhance the resilience of the territory. This planning approach could be very useful, especially in the most urbanized areas and in peri-urban contexts at the global level, as strategic places to achieve objectives for the protection of Natural Capital, due to the ecological footprint generated by the production and consumption of areas both internal and external to those contexts (Comitato per il Capitale Naturale 2019).

14.2 The Multifunctional Ecological Network

The ecological network concept has been proposed as a useful means to integrate biodiversity conservation into sustainable landscape development (Opdam et al. 2006). To be ecologically sustainable, landscape elements should support ecological processes and flows required for landscapes to deliver ecosystem services to present and future generations. In multifunctional human-dominated landscapes, biodiversity conservation needs a coherent large-scale spatial structure of ecosystems, and ecological networks can provide a critical framework for ecosystem design.

Especially in the context of both climate change and land use consumption challenges, the capacity of ecological networks to meet biodiversity conservation objectives depends also on support resilience within this appropriate matrix of landscapes, both in and between the core areas sites (as biodiversity main sources), thus enabling basic ecological processes and favouring biodiversity (Aubertin and Rodary 2011).

The regulating principle of ecological networks originates from one of the fundamental principles of Landscape ecology, where the configuration of ecosystems influences processes and flows that occur in landscapes and, in particular, the biotic flows that define the biodiversity of a landscape (Todaro 2010). Ecological networks therefore aim to recover and maintain functional ecological connectivity and environmental continuity of regions and landscapes at different scales and can be understood as a spatial expression of landscape connectivity (Jongman et al. 2004). This network of features and functions is planned and arranged for multiple goals, such as improving landscape quality and diversity, enhancing territorial resilience and enabling adaptation to climate change (CEE 2009). This acts as a *multifunctional ecological network* (henceforth: MEN), aiming to connect ecosystems and regions (Malcevschi 2010) within a multipurpose ecosystem scenario to support sustainable territorial development (Guccione and Peano 2003).

MEN becomes a supporting infrastructure that provides more than one service/function within a wide area (region and/or province NUTS3 of EUROSTAT codes), combining global sustainability needs with local sensitivities and vocations (Malcevschi 2010). Such structure combines ecological requirements (biodiversity protection and ecosystem structure rebalancing) with territorial demands to increase overall system resilience. MEN becomes a structural and functional system able to support different regional and sectorial policies in a coherent framework to enhance synergies in support of environmental quality. Such a scenario combines territorial needs with needs of landscapes and ecosystems and makes best use of the opportunities provided by human activities (Malcevschi 2010).

This eco-territorial network guarantees the connection between threatened natural patches separated and isolated from each other by man-made structures such as roads and cities. This network further guarantees the possibility of aiming at a new ecosystem scenario in which lost functions are regained through the reconstruction of new ecosystem units that can perform multiple functions corresponding to new development model, thereby reducing pressure on the natural environment (Malcevschi 2010).

In recent years, the relationship between the natural and human environment is becoming better understood. It has become clear that natural spaces or areas outside of protected areas can, and do, provide vital services essential to human health and well-being, to economies and to cultural identity, in addition to providing ecological connectivity that supports protected areas. The ecosystem service approach maximizes the benefits provided by other (green) infrastructure and adds more tangible value to existing green spaces (Gavrilidis et al. 2017).

GI, as a multifunctional ecological network, brings together both the need for strategic planning of green and open spaces with ecosystem service approach. It promotes the multifunctional nature of spaces and the benefits that appropriate management approaches can deliver. In addition, it recognizes the need to plan land uses for specific purposes such as farming, nature protection and development, whilst also providing tools and methods to identify needs and opportunities to enhance the environment and its functions.

GI is also a key strategy in the European territorial and landscape policies aimed at reconnecting vital natural areas to human elements and activities and restoring and improving their functional roles. Thus, GI represents an essential planning approach to enhance the quality of life that simultaneously protects the Natural Capital, especially when its constituent elements are currently not protected by national laws nor recognized by the planning systems (John et al. 2019). To join these two goals, GI has four main broad roles: protecting ecosystem state and biodiversity, improving ecosystem functioning and promoting ecosystem services, promoting societal well-being and health and supporting the development of a green economy (European Commission's Directorate General Environment 2012).

As a network connecting the environment in a high-quality ecosystem, GI can generate a noteworthy stimulus to the economic life of a territory, large or small, and become an important component of development strategy and territorial planning that emphasizes aesthetic aspects based on *biosemiotic* mechanisms and processes (Barret et al. 2009; Farina 2011). A multifunctional GI that offers a range of different ecosystems may lead to the qualification of new areas or the rehabilitation of degraded ones (Guarino and Pisano 2011).

The multifunctional nature of GI means that it delivers multiple services to meet multiple needs (Fig. 14.1). The types of GI required depend on the specific human and environmental needs of the individual area: inner cities, for example, may require space for recreation and climate services such as reducing heat island effect and managing rainfall run-off; rural areas may require wilder habitats to improve connectivity between core wildlife areas such as Natura 2000 sites or buffering of

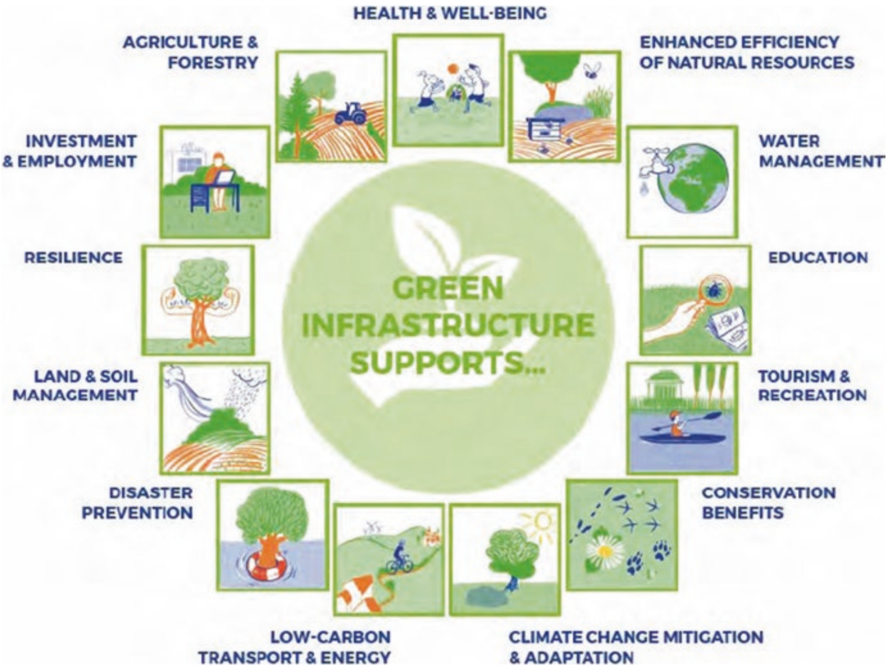

Fig. 14.1 Groups of benefits of Green Infrastructure (from John et al. 2019)

agricultural land to reduce pesticide and fertilizer run-off or to improve pollination and sustainable pest control (John et al. 2019).

In this approach, landscapes and green space systems should be planned taking in mind multifunctionality and considering local needs and values (or the *genius loci*), as well as and how these can be best delivered and preserved by GI elements (John et al. 2019).

GI approaches to land use and landscape planning promote the widest range of functions and services that can be performed with the same goal and that unlock the greatest number of benefits. Such approaches enable us to use the land in a more sustainable way, identifying where land can provide multiple benefits, to better manage the many and often conflicting pressures of housing, industry, transport, energy, agriculture, nature conservation, recreation and aesthetics. GI also highlights where it is important to retain and protect single or limited land use functions and services such as primary production or high-value nature areas (Landscape Institute 2009).

14.3 The Multifunctional Ecological Network at the Regional Level in the Landscape Plans

The intensive use of land and natural resources and the impacts generated on ecosystems have made it increasingly urgent to move beyond the sectoral approach in spatial and landscape planning toward a more integrated and multidisciplinary approach (Todaro 2010).

In this process, the role of landscape ecology is particularly important not only for landscape planning but above all for spatial planning and territorial management processes (Mougenot and Russel 2002). This principle is based on the idea that landscape elements and dynamics are generated by the interaction of natural features with human activities (Jongman 1995).

In Italy, the landscape plan, in accordance to the Legislative Decree n. 42/2004, represents the main planning tool at the regional level. Landscape plans are entrusted with the task of defining transformations compatible with landscape values, recovery actions and requalification of the buildings and areas subject to protection, as well as the interventions aiming at landscape enhancement in the perspective of sustainable development. In addition, as the National Biodiversity Strategy and the European Landscape Convention highlight, the landscape approach is an indispensable element in the pursuit of biodiversity protection objectives. The implementation of the indications contained in the landscape plans have direct and indirect impacts on the lower territorial scales, i.e. provincial, metropolitan and municipal administrative levels.

The four regional planning tools (Puglia, Toscana, Piemonte, Friuli Venezia Giulia) currently in force are consistent with the indications of the Code of Cultural Heritage and Landscape (art. 135 and following of Legislative Decree n. 42/2004). They are characterized by an innovative system of networks that supports landscape and biodiversity in different ways. At the same time, they assume different functions related to provision of landscape services by optimizing projects and strategies already in place and by integrating actions made either by the plan itself or by other sectors and programmes.

In fact, ecological networks are already in place, using a variety of tools at both the regional and provincial levels. However, these networks have not been considered a central supporting territorial infrastructure and thus have not been considered as a value to be respected, a source of services and, above all, a system bearing a high morphological potential for interconnection with the most specific elements of the region (settlements, infrastructures, etc.) and capable of generating mutual benefits (Malcevschi 2010).

These plans, because of their different components, integrate three different frameworks within the notion of landscape: an aesthetic-perceptual framework, an ecological framework and a structural framework. The landscape as a multifunctional system reveals place identity formed over time through the development of relationships between human settlements and the surrounding territory and interprets in procedural forms the relationships between *ecological landscape* and *cultural landscape*. This structural approach to the landscape does not therefore privilege specific conservation areas; instead, it addresses the landscape in its overall dynamics by studying generative and co-evolutionary rules over the course of the long term and thus represents the most effective approach to MEN planning and management.

The Regional Multifunctional Ecological Network (RMEN) of the Puglia Region, in force from 2015, represents one of the five territorial projects for the regional landscape provided by the Territorial Landscape Plan. The RMEN takes up the essential elements of the Biodiversity Network and integrates them with other contents of the Territorial Landscape Plan to implement a structural ecosystem function for the entire regional territory that governs relations between ecosystems and their associated aspects with a more specifically landscape and territorial character. Aspects related to biodiversity and more generally to the conservation of the Natural Capital and its protection, as the subject of specific sectorial policies identified and described in the Biodiversity Network, assume a primary role in this approach (Regione Puglia 2015b).

These integration elements of the RMEN are linked to territorial projects that address the relationship between urban and agricultural areas (*Patto Città-Campagna*), the infrastructural system for soft mobility and the valorization and requalification of coastal landscapes to promote multifunctionality of the biodiversity network integrated with sectorial policies (environmental, hydrogeological, agroforestry, touristic, etc.) affecting this environmental context (Regione Puglia 2015a).

Both the RMEN as a multipurpose design scenario and the Biodiversity Network for more specific indications on biodiversity are essential and binding references for the provincial and municipal level territorial planning and for the institution of the RMEN at local level.

The Regional Landscape Plan (henceforth: RLP) of the region of Toscana, in force from 2015, recognizes the strategic role of the system of protected areas and sites of the Natura 2000 network. However, in line with the indications of both the National and Regional Strategy for Biodiversity, it highlights the need for the complementary implementation of a more *open* system to support biodiversity as represented by the regional ecological network. The conservation of biodiversity based on isolated political initiatives and through the safeguard of a selection of protected areas, or *island protection* (Battisti and Romano 2007), is therefore flanked by transversal policies aimed at improving the quality and ecological permeability of unprotected territory through the identification and comparison of common objectives with agricultural and forestry policies and soil and water protection policies, as well as urban planning and landscape objectives.

Following the indications of the Regional Biodiversity Strategy, the Regional Landscape Plan has been built by combining geomorphological, rural and urban invariants with ecosystem invariants, defined as *ecosystem features of the landscape*. The ecological network has been built as a *network of networks*, incorporating the environmental suitability evaluation and the identification of the structural and functional elements of forest and agriculturalecosystem networks, supplemented by potential networks in marsh, river, coastal and rock ecosystems. In the landscape plan, this *network of networks* is therefore intended as the ecosystem invariant aimed to achieve biodiversity protection objectives at the landscape scale (Lombardi et al. 2016).

In the case of the Regional Landscape Plan of the Piemonte Region, in force from 2017, a Landscape Connection Network defined on the basis of the strategic Environmental Valorization Network project has been identified as an instrument for the integrated implementation of three networks: the regional ecological network, the historical-cultural network and the social fruition network. The Landscape Connection Network considers the strategic actions envisaged by provincial and local plans and programmes, as well as by the management bodies of protected areas. These strategic actions are focused on the actions concerning the ecological core areas as well as river contexts, based upon the experience acquired through the Operational Territorial Project for the Po River and in connection with initiatives promoted by river contracts and the planning tools of catchment area.

This network identifies and integrates the main elements of the ecological network, the historical-cultural network and the social fruition network in terms of functions and use regulations. The first of these networks constitutes an integrated system of interconnected natural resources and identifies as basic elements core areas, ecological connections, project areas and areas of environmental requalification aimed at ensuring basic conditions for the sustainability of transformation processes and for the conservation of biodiversity throughout the region. The second includes a set of systems for the valorization of the historical and cultural heritage, and the third is based on a set of historical-cultural and natural destinations, linked together by representative regional landscape itineraries. The integration of the three networks represents one of the strategic projects to be developed using sectoral and provincial planning tools.

Regarding this *network of networks*, the Regional Landscape Plan systematically supports protective actions aimed at reducing negative impacts and barriers, whilst supporting recovery, reconnection and the enhancement of accessibility and social usability (Regione Piemonte 2017).

The strategic part of the Regional Landscape Plan (RLP) of the Friuli Venezia Giulia region, in force from 2018, envisages the creation of three networks (ecological, cultural heritage and slow mobility) combining key elements that characterize the deep structure of the regional territory (ecological factors and cultural heritage) with the slow mobility network. This system allows for the integration of the complex mosaic of the regional landscape at a broad scale to allow for more proactive and effective actions (Regione Friuli Venezia Giulia 2018a).

The ecological network of the RLP is intended to act as an interconnected system of landscapes and to safeguard biodiversity and is structured by both a Regional Ecological Network (REN) and a Local Ecological Network. The REN is aimed at ensuring connectivity for natural and semi-natural ecosystems, assuming that ecosystems not isolated from each other are able to guarantee landscape quality and ecosystem service functions. A study based on the ecology of a limited number of species (target species) was conducted to identify appropriate connecting functions for different parts of the regional territory and thereby identify these with REN elements. In the same way, the main connectivity corridors have been identified. Even if these areas do not necessarily require connection elements, they still represent optimal connection paths for animal species between core areas.

The REN consists of large homogeneous territorial units called *ecotopes* that cover the entire regional territory and that assume different ecological functions. Although, as described above, *ecotope* design is based on elaborations developed at the landscape level, it is clear that the strategic importance of certain elements for the permeability of the territory, such as the main rivers, goes far beyond local limits to affect the whole regional territory. Regional strategic ecological elements, consisting of a set of several *ecotopes*, form an entity recognized as regional green infrastructure by the European Green Infrastructure Strategy (Regione Friuli Venezia Giulia 2018b).

In the RLP of Friuli Venezia Giulia, slow mobility is articulated as an instrument of connection with two other strategic networks, the cultural heritage network and the ecological network. This connection, which offers the possibility to enjoy the landscape in an integrated and sustainable way, is implemented by defining the hierarchies of the network at different levels. On a regional scale, the network makes it possible to link the region's multiple landscapes and to interconnect different landscape areas at border and transregional levels. This network promotes fruition of historical-cultural and natural heritage through the exploration of the landscape features distinctive to Friuli Venezia Giulia (Regione Friuli Venezia Giulia 2018c). More in detail, the network of cultural heritage includes not only elements bound by law but also some categories of buildings with historical-commemorative values for the surrounding territory and characteristic of these regional landscapes (Regione Friuli Venezia Giulia 2018d).

14.4 The Multifunctional Ecological Network at the Provincial Level: The Metropolitan Cities

In Italy, Law 56/2014 introduced the category of metropolitan cities, new territorial entities that share the same administrative boundaries as the provincial entities (NUTS3 of EUROSTAT Classification). Law 56/2014 provides for the establishment of the 10 metropolitan cities of Rome, Turin, Milan, Venice, Genoa, Bologna, Florence, Bari, Naples and Reggio Calabria, alongside four metropolitan cities identified by the autonomous regions Sicily and Sardinia: Cagliari, Catania, Messina and Palermo. The law was put into effect as recently as January 1, 2015, and it was from this date that the metropolitan cities assumed authority over the homonymous provinces.

These new administrative bodies, where 36.2% of the Italian population resides, aim to encourage the same sustainable development issues during the unification and merging of municipal administrations. Law 56/2014 simplifies local government and returns to the cities the potential role of driving national economic systems in the light of new challenges through sustainable strategic development and an increase in the overall resilience of the metropolitan territory. The metropolitan cities, which were created to ensure a better management of land and urban processes with a supra-municipal dimension, are therefore also major players in the management of soil consumption processes. Data analysis for the 14 metropolitan cities shows that the soil consumed in metropolitan cities represents 21.4% of the soil consumed in Italy (ISPRA 2017).

In some of the cities concerned by the Law 56/2014, however, the provincial area does not appear to be an adequate and homogeneous territory. In fact, in many cases, these municipalities do not appear functionally correlated to the provincial capital, as in the case of the alpine areas near Turin or the Aspromonte mountain range of Reggio Calabria. In other cases, such as the metropolitan area of Milan, the territory of the former province appears too small to manage the dominant role of the central area. Therefore, on paper, the original provincial dimension seems useful to define the metropolitan areas boundaries, but municipalities, or groups of municipalities, contained within previous provincial areas have the option to stay or break away from the new metropolitan area (ISPRA 2017).

The functions of the metropolitan cities in addition to those of the provinces include the provincial territorial planning and coordination as well as the protection and enhancement of the natural environment. Metropolitan cities are obliged to adopt a strategic plan for the metropolitan area (updated annually) constituting guidelines for actions made on the municipal level within the metropolitan territory, including actions delegated or assigned by the regional level. The strategic plan is therefore the fundamental act of guiding long-term action for the metropolitan city as well as coordinating forecasts and strategies already in place in the metropolitan area.

Another instrument of territorial governance is the Metropolitan Territorial Plan, used for general planning of the territory encompassed by the metropolitan city. This plan, drawn up in accordance with the guidelines and objectives of the Metropolitan Strategic Plan, is the reference framework for the knowledge and interpretation of the metropolitan territory. The plan should include the assessment of plans and projects with environmental value and should be a reference for urban planning and sector planning within the competence of municipalities and metropolitan cities. In almost all the metropolitan cities, preparation activities of the Metropolitan Territorial Plan have been launched. Pending conclusion of the drafting and approval process, the Provincial Territorial Coordination Plans of the corresponding provinces remain in force.

In the light of the analysis carried out on the documents of the Metropolitan Strategic Plans and the preparatory documents of the Metropolitan Territorial Plans of Turin and Genoa, it is clear that the theme of protection of the natural capital has particular importance. Documentary analysis indicates close attention paid to key environmental issues, including sustainable territorial development and overall resilience of the metropolitan system. Ecological networks, including the main ecological core areas represented by Natura 2000 sites and protected areas and primary ecological corridors (Fig. 14.2), play a structural role and are recognized as a means of ensuring the protection of biodiversity integrated with territorial development. A multifunctional ecological network is therefore conceived as an intersectional operation and as a general resource and reference to promote ecological and landscape requalification and to enhance the territorial resilience to which all the sectors are called upon to collaborate.

In fact, in the presence of the 536 Natura 2000 sites within the territories of the 14 metropolitan cities, i.e. 20.5% of the total of those present in Italy (ISPRA 2017), the actions to safeguard and enhance the Natural Capital are extended to other elements of the green territorial infrastructure as defined by the EC (EC 2013b). In an integrated MEN vision, planned GI will play a critical role by conserving and enhancing the natural capital and the ecosystem services, providing an effective tool to tackle climate change and limit soil consumption, revitalizing integrated agriculture in urban and peri-urban contexts, maintaining landscape quality, reducing risk exposure to possible extreme natural events, improving the quality of life and air and generating positive benefits in economic terms (Comitato Capitale Naturale 2019).

Fig. 14.2 The Tevere river in the Rome Metropolitan Area (Photo credit: P. Orlandi)

14.5 Conclusions

From this analysis, it comes clear that the integration of the Natural Capital into the landscape and spatial planning tools, especially for large areas, is prominent in recent regional and provincial planning strategies. This appears true for the Metropolitan Territorial Plans of the metropolitan areas as well as for the landscape plans which, in line with the European Landscape Convention, consider the territorial system as a unicum in terms of composite elements and governing systems, whilst recognizing different levels of value and ecological importance.

In this context, the role of MEN and GI is increasingly significant as a vital means to promote environmental restoration of mainly urban and peri-urban environments in connection with natural and semi-natural ecosystems. This may also be achieved through the implementation of the ecosystem-based adaptation solution (ecosystem-based approaches and NBS), which aims at strengthening resilience and reducing the vulnerability of territories to environmental emergencies and addresses related challenges through integrated actions.

Urban green space networks and natural and semi-natural ecosystems outside urbanized areas are, in fact, rich in biodiversity and allow urban systems to be more sustainable, helping to counter many challenges including air pollution, noise pollution, climate change, heat waves and hydrogeological disruption. For these reasons, the GI approach is strongly advocated at the European level, from the EU Biodiversity Strategy to the recent programme Enhancing Resilience of Urban Ecosystems through Green Infrastructure (EnRoute) (Comitato Capitale Naturale 2019). By identifying the improvement of sustainable urbanization as a priority for the European Union, NBS enacts actions to counter current problems related to air pollution and climate change, as well as to encourage greater territorial resilience over time. Many NBS play a multifunctional role, supporting sustainable urban planning, reducing energy costs and mitigating stress in urban areas (Comitato Capitale Naturale 2019).

As part of an increasingly shared integrated approach/management, in the context of the 2021–2027 community programming of cohesion policies, the Prioritized Action Framework (PAF) strategic multiannual planning tools will provide an essential resource. This framework aims to provide a comprehensive overview of measures needed to implement the EU-wide Natura 2000 network and its associated GI, specifying financial requirements for these measures and linking them to corresponding EU funding programmes. In line with the EU Habitats Directive, as the source for the Natura 2000 network, measures to be identified in the PAFs shall be designed (EC 2018: 2):

> […] to maintain and restore, at a favourable conservation status, natural habitats and species of EU importance, whilst taking account of economic, social and cultural requirements and regional and local characteristics.

These regional strategic programming documents will include Habitats Directive conservation objectives into sectorial policies through effective mainstreaming and promote more effective resource mobilization to finance priority measures for the conservation and restoration of species and habitats of community interest.

For the national dissemination of good practices related to implementing ecological networks and green infrastructure at both regional and provincial levels, the Italian Institute for Environmental Protection and Research (ISPRA) has developed an ambitious communication programme that has successfully promoted ecological network considerations in all regional and provincial regulatory instruments throughout Italy. This programme is further supported by RETICULA, an online technical-scientific journal that disseminates news related to ecological connectivity, planning practices, management tools and environmental governance by promoting synergies among academics and planners.

The convergence between ecological networks and participatory and negotiated planning methodologies as observed in Italy also offers an intriguing perspective. The river contract, an instrument already well known in this field, should assume a form specifically dedicated to ecological networks (ecological network contract). This type of agreement could lead, in the short term, to a more widespread recognition of the value of and need for MEN planning and could multiply implementation opportunities, with the direct involvement of local stakeholders helping to guarantee the efficacy of these actions over time.

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Chapter 15
The Foodscape as Ecological System. Landscape Resources for R-Urban Metabolism, Social Empowerment and Cultural Production

Sara Favargiotti and Angelica Pianegonda

Abstract In recent years, attention has grown on the importance of the food heritage-related themes within landscape, cultural and social dynamics. This paper presents a theoretical introduction explaining the concept of foodscape as an integrated system of ecological network, connected to the role of local food production for the recovery of abandoned areas. The processes of land recovery and transformation find an opportunity in urban agriculture to improve the cities' quality of life by interpreting the food cycle process as a system able to produce social innovation and inclusion through new technologies, establish a strong relationship with public and private stakeholders, reconnect society with their landscape identity and geographical characteristics, make initiatives economically sustainable and scalable and build up a comprehensive and flexible framework to guide cities to implement adapted strategies with multifunctional use at different scale. The real-time experiences of the SATURN EIT Climate-KIC research project in the Trentino region are the condition to test, map and verify the theoretical positions, and the main ongoing outcomes will be briefly presented. With this overview the contribution freshly explores the landscapes and the food production dynamics aiming to reintegrate the natural assets within the city climate change impact strategy.

Keywords Urban and rural linkage · Green infrastructure · Climate change · Landscape reserves · Socioecological connectivity · SATURN EIT Climate-KIC

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_15

15.1 The Cultural Value of Food Ecology for Urban/Rural Regeneration

Limited food culture and the food availability are among the drivers of socio-economic inequalities in many territories. It is also true that food culture and the immaterial heritage of gastronomy culture can be considered as the common denominator in which a local community can identify and express itself. Food culture refers to the practices, attitudes and beliefs as well as the networks and institutions surrounding the production, distribution and consumption of food. It encompasses the concepts of "food" declined at various scales (such as foodscape, food design, food chain) and includes the fundamental understandings a group has about food, historical and current conditions shaping that group's relationship to food and the ways in which the group uses food to express identity, community, values, status, power, artistry and creativity. How could food culture become a common good to drive cities' regeneration and sustainable urban development?

In 2000, the European Landscape Convention defined "landscape" as "an area as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" (ELC 2000). The human and social perception of the anthropic landscape is placed at the centre of the interpretation as well as of the actions in the territory. On the other hand, according to Santagata et al. (2011), "Cultural commons refer to cultures located in time and space – either physical or virtual - and shared and expressed by a community", where collective histories, memories and traditions of communities are playing the main role. Cultural commons are defined by the confluence of three dimensions: culture, space and community (Santagata et al. 2011). It is a system of intellectual resources available on a given geographical or virtual area, shared by a group, which can generate one or more social dilemmas. Ideas, creativity and styles of a community, knowledge, beliefs, rites and customs and shared and participated productive techniques contribute to the making of a cultural commons (Santagata et al. 2011). Therefore, landscape can be related to cultural commons by offering a precious resource to drive sustainable, integrated and responsible design processes to regenerate, restore and renew urban, peri-urban and rural areas, often obsolete or abandoned.

Municipalities at different scales and in different contexts in the Trentino alpine region are operating on common good as an old/new dimension of public space welfare (Favargiotti et al. 2020). Beyond unsustainable top-down approaches, a stronger support towards bottom-up initiatives has lately become a more usual governance practice. Recently re-created communal institutions are devoted to preserving local tradition and support the micro-local social structure based on trust and reciprocity (Gretter et al. 2018). Many of these projects involve agricultural practices in urban contexts (e.g. urban farming, orchards, flower gardens) or regeneration processes in rural contexts with special attention to natural and cultural resources. These initiatives have expanded the concept of "common good" not only to materials but also to those intangible or digital goods that citizens and administrators feel important for individual and collective well-being (Gretter et al. 2018). The interest of these initiatives lies on a new inter-municipal sharing logic to connect spread settlements' constellations. Indeed, when the spatial perspective is missing since the beginning of the process, failure is likely to happen.

Interest of citizens and associations is more oriented to the production of food, and the preservation of biodiversity through the demand for vegetable gardens and definition of green (with bushes and trees) or blue (along water courses) corridors gives the opportunity to generate new life in places that have been abandoned or improperly used. This approach has a twofold use for the municipal governance: first of all, it is an option to enhance the civic sensibility and save financial resources. Further recognition for usefulness of a renewed common's approach has been formally acknowledged with the creation of a specific event where city councillors award the title of "ambassadors of commons" for those citizens actively involved in running these initiatives. These experiences highlight how inclusive engagement of users and local communities in urban/rural areas through "commoning" practices achieves better outcomes (Neo and Chua 2017). Local knowledge and participation can produce new values but also social and spatial safeguard, such as abandonment avoidance, community empowerment and project accountability. Providing public services grounded in local participation and based upon symbiotic relationships offers an alternative paradigm for marginal territories, at once equitable, economical and environmentally sound.

Facing these challenges, the Province of Trento – within the framework of SATURN research project – focuses on regenerating and valorising abandoned and underused inner areas to enhance new productive and recreational landscapes. This territory is pivotal for developing a strategically planned network of natural and semi-natural areas, including features in rural and urban areas which together – functionally and ecologically interconnected – ensure diverse advantages for nature, as well as ecological services. Even here, in recent years, food has once again become a central topic in political and public debate. Food scandals have caused people to pay more attention to the healthiness of products, and a greater awareness on agri-food supply chain issues. It is broadly shared by all that the way in which food is produced, distributed and consumed has significant consequences for the environment, affecting the fertility of the soil, the quality of the water and air, the state of the climate and the loss of biodiversity, as well as impoverishment of the food culture and of the landscape (Forno, in AA.VV 2019a) (Fig. 15.1).

Foodscapes, as ecological systems, come from the definition of ecology as the study of the interactions between organisms and their environmental sphere. By transposing this concept to the food cycles in the dynamic and evolving process of the landscape, foodscapes emerge as a potential vector to unite different characters (cultural, social and environmental elements) of the anthropic and natural spheres. Foodscapes can be found at different scales of the landscape, from the macro-territorial scale of agricultural crops to the urban agriculture with the cultivation of edible plants in parks, gardens and private balconies. The ambition is to combine the ecological networks with a sustainable food production by supporting and enhancing the agricultural paths as elements of the green infrastructure (GI) network. The growing initiatives of local food production (e.g. km 0, slow food, ethical

Fig. 15.1 Public urban gardens in Mesiano hill, Trento. (Photo credit: Giuseppe Gorfer 2019)

purchasing groups), a wider awareness about food life cycle and the need for more organic food are driving the citizens to a more responsible and sustainable consumption of products (European Commission 2011). These dynamics also support the reduction of CO_2 emission, the minimisation of food waste and the regeneration of abandoned areas for local organic food production. Focusing on the dynamics of food cycles in urban and peri-urban areas, the food ecology can be considered a way to balance the relational interest and space for social and cultural values (in addition to and beyond the monetary values) but also the medium to address circular economy, sustainable regeneration and community empowerment.

15.2 Mapping and Analysing the Food Dynamics for a More Sustainable Territorial Development

The future state of systems, communities and individuals has always been of interest for decision-makers, as well as policymakers, practitioners and scientists. Nowadays, in the age of Anthropocene, this topic is extremely urgent and poses new governance challenges. Risk assessment is more difficult due to the increasing complexity, especially concerning the capability to forecast events or to reliably guide decision-making (Miller 2015). The main threats that affect Western countries, like climate change, environmental degradation, globalisation, security, migration, automation, crisis and poverty, are characterised by non-linear, unpredictable and unstable dynamics (Favargiotti 2019). Lately, the interest in empty spaces, vacant lots, depopulated villages and obsolete areas in cities and territories and on their recovery is now an inevitable phenomenon in European urban planning, as emerging dilemma to the well-known debate on the impacts of growing cities and soil consumption in urbanisation.

United Nations has stated that "with more than 80% of the world's goods and services now produced in urban areas – and 80% of future growth expected to occur in cities by 2030 – it is not an exaggeration to assert that the economic and social futures of whole countries, regions, and the world will be made in cities, today's nests of emerging futures" (UN 2016). Yet, urban growth patterns and geographical trajectories in Europe are uneven: whilst many city regions are growing, others are stagnant or even shrinking. The human approach to land management is driven by the power of ownership and often based on the interests of a single sector. This results in a fragmented landscape purely dependent on the decisions of governance acting on minimum funding and with no great interest in people's engagement (Fig. 15.2). The methods used on land management have an interrupted and often not well thought through approach to environmental challenges. Within this framework, the ongoing processes of land recovery and transformation find an opportunity in urban agriculture to improve the quality of life within cities and for its sustainable growth, by interpreting the food cycle process as a system able to produce social innovation and inclusion through new technologies, establish a strong relationships with public and private stakeholders, reconnect society with their landscape identity and geographical (urban, rural, regional, territorial) characteristics, make initiatives economically sustainable and scalable and build up a

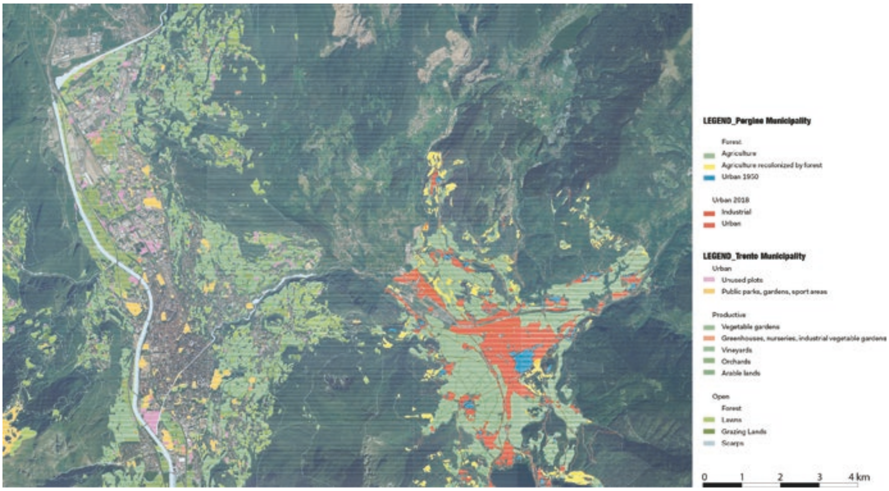

Fig. 15.2 Thematic map based on land use layers of the municipalities of Pergine Valsugana and Trento. (Source: Portale Cartografico Trentino, Fabio Frisanco elaborations and Municipality of Trento open source data. Credit: Marco Ciolli and Sara Favargiotti 2019)

comprehensive and flexible framework to guide cities to implement adapted projects of multifunctional use at different scale. This means society can no longer rely solely on natural goods and services to provide a sustainable basis for future generations.

Those conditions are clearly highlighted as priorities by the 2030 UN Agenda for Sustainable Development Goals (SDGs) (United Nations 2015). Additionally, according to the ASviS Report 2018 "Europe is not doing enough. Although the European Union is by far the most advanced area of the world in terms of socio-economic and environmental wellbeing, the area with the most stringent environmental and labour protection regulation, and where the rule of law is most secured, a quarter of its population is at risk of poverty and social exclusion, inequalities do not appear to be declining and unemployment and underemployment are very consistent, especially in certain countries" (ASviS 2018). Therefore, understanding and qualifying the impact of those transitory urban space patterns in medium and large cities and their metropolitan areas are a fundamental concern as the growing challenges need urgent measures to ensure human well-being and cities liveability and to reactivate the rural-urban metabolism (i.e. r-urban metabolism). Approximately 60% of the existing ecosystem services – such as provisioning of food and drinking water, nutrient cycling and climate regulation – are severely degraded or are managed in an unsustainable way as it has been assessed by the Millennium Ecosystem Assessment in 2005. This means society can no longer rely solely on natural goods and services to provide a sustainable basis for future generations (Favargiotti 2019).

Although Europe can be considered as an urban continent, with 72.5% of EU-28 inhabitants living in cities (Eurostat 2018), there are regions where these percentages are far lower, as in the case of the alpine area. The Autonomous Province of Trento, an Italian alpine region whose dynamics will be explored later, is classified as an intermediate region (Eurostat 2018) where about 70% of the population live in villages with less than 25,000 inhabitants. Therefore, understanding and qualifying the impact of those transitory urban space patterns in medium and small cities, as well as hamlets, are a fundamental concern as the growing challenges need urgent measures to ensure human well-being and cities liveability and to reactivate the rural-urban metabolism specifically addressed to the food systems.

The Food R-Urban Metabolism (RUM) is a tool – implemented by the Trentino hub in the SATURN framework – to collect, map and analyse the biomass flows related to food cycle in order to connect and to enhance sustainable relations between urban and rural areas. It refers to the definition of urban metabolism as the "collection of complex sociotechnical and socioecological processes by which flows of materials, energy, people, and information shape the city, service the needs of its populace, and impact the surrounding hinterland" (Musango et al. 2017), trying to achieve the relation among urban and rural dynamics. RUM examines the complex relations between physical and social processes in the Trentino alpine area aiming to connect and to enhance sustainable relations between urban and rural areas by analysing and mapping the biomass flows related to food cycle. Therefore, RUM examines the quantities and fluxes of substances that are produced, transformed, exchanged and discarded within a region. This allows collecting data both from statistical models and from empirical evidence. As an example, data on biomass produced by woodlands can be computed through existing models given the surface and the typology of trees is known, whilst data on the amount of recycled food waste can be collected through direct interviews with local NGOs or stakeholders. The aim is to guide and support local administrations in the adoption of more sustainable territorial planning policies by using RUM as decision-making support at the local level.

The governance in urban and rural landscapes, as well as the productive and multifunctional interlinks and the RUM of the territories, is explored through a real-time case studies in the Trentino region developed at the EIT Climate-KIC SATURN, an EU research project examining a "System and sustainable Approach to virTuous interaction of Urban and Rural LaNdscapes". SATURN is a joint project between three European hubs: Göteborg (Sweden), Trentino (Italy) and Birmingham (United Kingdom) to initiate a coalition of cities to improve rural-urban interactions. The different patterns of landscapes and societies examined across the three hubs are reconnected through a multilevel approach that determines the level of stakeholder engagement and the progress of circular economies. Using the landscape lens, this contribution aims to collect innovative experiences that address the necessary changes required to meet the fundamental twenty-first-century global challenges of environmental restoration, climate change and the SDGs. This approach will undertake an innovative "value" assessment of nature and landscapes, offering the opportunity to appreciate all the interdependencies of social, economic and planetary well-being within a holistic landscape vision.

15.3 Urban and Rural Landscapes: Virtuous Linkages in the Alpine Ecosystems

The Autonomous Province of Trento is one of the northernmost territories of Italy. Its size is of about 6200 km^2 organised in 176 municipalities and with an overall population of 538.604 (ISTAT 2020). This territory has a vast surface of natural fields designated for an agro-silvo-pastoral production equal to 408,871 ha on the total of 620,712 ha province surface (Provincia Autonoma di Trento 2008). Currently, only 8767 ha are devoted to organic production (Provincia Autonoma di Trento 2019), even if, in the entire province, the 15.6% of the export manufacturing industry depends on the food, drink and tobacco sectors (Camera di Commercio, Industria, Artigianato e Agricoltura di Trento, 2019, second semester data). The variety of cultivation is low, due to the prevalent specialisation on apple orchards (in the lower area) and vineyards (mostly in the foothills of the surrounding mountains) (Fig. 15.3). A recognised productive role in the upper altitude is very limited due to the scarce utilisation of pastures and limited private forestry activities. Most of these areas are managed by public or collective bodies (such as cooperatives) whose main aim is not the profit: almost 60% of the overall surface (around 370,000 ha) is

Fig. 15.3 North-east hill in Trento. (Photo credit: Giuseppe Gorfer 2019)

collective property with designated rights called *uso civico*, a customary right embedded within the properties of communities and villages (Gretter et al. 2018).

Within this context, Trentino's territorial challenge for its sustainable future development consists on the activation and regeneration of obsolete or abandoned areas as potential reserves to multifunctional landscapes for community, microclimate, productivity and excellence. A change of perspective in the opposed relations, between city and country, leads therefore to an integrated vision of the peri-urban territory that assumes a vital and active role with new productive functions and attractions. This happens in Trentino, where the complexity of the geomorphological conformation requires a holistic approach to the urban policies and spatial design, able to properly represent the different challenges and specificities of the territory.

These challenges are addressed by the SATURN "System and sustainable Approach to virTuous interaction of Urban and Rural LaNdscapes" research project, funded by EIT Climate-KIC, in which Trento and partners from across Europe are developing new integrated approaches to deal with the urban, peri-urban and rural landscape, in response to the evident need for new ideas in the context of the deepening climate emergency and the need to address air quality, food and water security (Nikologianni et al. 2020). The objective is to offer a comprehensive framework for cities to redesign their natural and productive landscape through the elaboration of a toolbox for sustainable local food production, youth engagements in art and educational activities and business models for small food enterprises. The Trentino hub included three adjacent territories: the Municipality of Trento, the

Municipality of Pergine Valsugana and the territories of the Comunità Rotaliana-Königsberg.

15.3.1 *The Municipality of Trento, the Municipality of Pergine Valsugana and the Comunità Rotaliana-Königsberg*

These three realities are territories with a peculiar topography, consisting of valleys and high mountains. Trento is the largest city with 118,902 inhabitants (ISTAT 2020) on a municipal territory of about 158 km^2. The overall density is of 742 inhabitants per km^2, and the pressure on urban and peri-urban areas is 9 times higher than the province urban density. The Municipality of Trento is settled in the valley floor of the river Adige, and it lies between 194 and 2239 m asl; 20% of its territory is classified as agricultural and 50% as forest or pasture land, meaning that very few spaces are left to urbanisation. The city directly communicates with the other two realities, and they have a close interdependent connection mainly characterised by economic and employment issues. In the northern area of Trento, along the Adige valley, is located the Rotaliana-Königsberg community, made up of 6 small municipalities for a total of 30,767 inhabitants (ISTAT 2020), and its territory is spread from 196 to 2124 m asl. The Municipality of Pergine Valsugana is located in a valley on the eastern side of Trento, and it is the third largest municipality in the province by number of inhabitants, with its 21,548 (ISTAT 2020). It is about 54.33 km^2 and is located between 409 m asl and 1990 m asl. The population number has almost doubled since the 1970s. The traditional forest and agri-pastoral activities significantly changed both quantitatively and qualitatively in the last 70 years.

On these territories, the challenge is to identify the adaptation strategies to ongoing changes for inner urban settlements with a focus on sustainable local food production. One of the main objectives is to offer multifunctional green infrastructure able to support accessibility and connectivity of marginal areas (development of slow-mobility pathway network), urban agriculture as regeneration tool (mapping state-of-the-art, enhancing participation), communication and participation (involving citizens in developing green areas, introduce participative design of open spaces) and multifunctional and transdisciplinary connections (among territorial scales and landscapes systems). Within SATURN are analysed, and partially supported, the initiatives that aims to relocate locally the production of agricultural goods. Most of these initiatives are characterised by personal choice of entrepreneurs and citizens who are willing to develop organic farming. Further opportunities could be granted with cultivation of new crops and varieties using different methods and utilising different soils and plots, whenever possibly made available by public bodies. At the turn of 2020, a popular initiative referendum was held to request the creation of a *Biodistretto* (literally an organic district) for the entire Autonomous Province of Trento. The consultation was successful. The referendum's results, confirming that many of the producers are already converting to organic farming methods, demonstrate the key role of the private/public involvement, as well as the constantly rising interest from both citizens and consumers. The multifunctional agriculture is foreseen to play a relevant role also in the ecological and social spheres. The inspiring example of the *Biodistretto* in a nearby valley, named Valle dei Laghi, shows how these territories could be considered as agri-food reserves, in particular for the organic production.

The Trentino pilot areas are taken into account as a whole integrated system in the final vision of the SATURN project, going beyond administrative and territorial boundaries. The ongoing study of mapping and analysing the different green areas is oriented to produce a whole picture of forests, crops and gardens that create the ecological networks connecting urban and rural areas. The role of the forest, agricultural and urban ecosystems will be highlighted with a special focus on biodiversity conservation and food production. The final goal is to create a network of green areas in which edible plants are integrated as main elements of the landscape. In this vision, a sustainable food production – as an environmental, social and economic integrated system – becomes an integral part of the ecological network of the territory where foodscapes and green infrastructure overlap and coincide, to adapt to climate change and ecological needs.

15.4 Integrated Networked Ecologies: Beyond the Administrative Borders

A better interconnection between urban areas and suburbs can generate solutions integrating climate, social and economic elements (Gomez-Baggethun and Barton 2013). The preliminary results of the experimental and ongoing research addressed in the Trentino hub highlight the positive effects that the ecological connection between urban and rural areas could have in the urban environment, as well as in the whole region. Besides considering the numerous impacts of cities on climate (primarily in relation to emissions and consumption of natural resources), other problems linked to the rapid urbanisation lie on the social side such as crime, homelessness, youth unemployment and segregation. It also focuses on the benefits from the economic and business models that drive the innovative approaches on the agri-food sector and from the governance of natural resources and the enhancement of socioecological systems.

The combination of the empirical analysis with the applied operations in the SATURN research initiatives has the purpose to supporting the territories in the delivery of climate and SDGs targets by developing a rural-urban strategy that implements concrete actions for a healthier and sustainable development at a different level. The landscapes and the food production activities can be effective strategies to reintegrate the natural assets within the city climate change impact strategy and to expand and feed its model by creating a wider initiative in different pilot areas and regions. The proposed methodology and experimental processes can be adopted in order to connect blue and green infrastructures (BGIs) to enhance the landscape's ecological value. BGIs are fundamental in rural-urban areas; in fact, they allow to benefit from different ecosystem services and to develop resilience to extreme climate phenomena (European Commission 2015; Cohen-Shacham et al. 2016). For example, in case of heavy rains, it is possible to manage runoff thanks to devices such as pervious pavements, rain gardens, rain tanks and retention basins. BGIs can moreover support the mitigation of the heat island effect, through the diffusion of green roofs and vertical greening systems (Andreucci 2017). It is also possible to consider that the green infrastructure ensures that cities are not holes in the ecological network but, rather, a support for biodiversity (Spirn 2013). Edible gardens and urban orchards and gardens can be recognised as good supports in this sense (Chiesura and Mirabile 2016). As a matter of fact, urban gardens allow to shorten the food supply chain, increasing the sustainability of the system, of the food market and of the city. For this reason, the SATURN project encourages the spread of organic agriculture and supports the creation of an eco-organic region in the Province of Trento.

The main remarks outlined by the ongoing actions in the SATURN pilot areas show how an integrated and multi-scalar approach offers the opportunity to recognise the social, ecological and economic values of marginal and peri-urban areas by achieving the following goals:

- To enhance ecosystem services and resilience: ecosystem services can involve carbon storage, ecosystem preservation, waste reduction, buffers and livelihoods.
- To boost local production and markets: foster rural-urban areas economic development with innovative and small-scale business models (entrepreneurship), e.g. food, agroforestry or biomass.
- To support governance models: public-private partnerships and new innovative public involvements
- To develop strategic visions for sustainable food chain development by mapping actors, experiences and product cycles with an integrated and holistic approach (cross-disciplinary, cross-sectoral).
- To address the SDGs and the broader environmental aspects in responses to international agenda (ELC/SDG's IPCC, COP) and local plans.

The development of an alternative and innovative governance for local agro-natural resources is fundamental to achieve a multifunctional development of the territory to protect and valorise natural resources, land management and ecosystem services. These actions improve the resilience of the territory, for example, by increasing the variety of cultivated species, it is possible to contribute to a more circular adaptation of the system. Besides environmental benefits, there are opportunities to enhance the social and cultural values of food by improving sustainable production, addressing policy on waste prevention, reducing of organic waste and valorising the immaterial heritage of food culture (Space 2011). This could be achieved by involving a wide public of active figures such as innovation niches, cooperatives, associations, citizens, administrators, technicians, practitioners, journalists and artists. In some cases, the spread of innovative practices collides with the multiple presences of different norms and rules regulating agricultural production, biodiversity conservation, mobility, water uses and urban development that are generating a chaotic situation not capable of addressing a holistic process of local sustainable development. Notwithstanding these not-supportive multisectoral layers, in the Rotaliana area, the local population is starting to question about which futures can be drawn for the local territory, thus creating a positive ground where transformation processes can start. The institutional proposal to transform local production into an organic district has not been positively received by the entire local communities, yet. The involvement of young population could possibly help to tackle this issue. There is a strong presence of young people involved in organised groups seeking to develop more sustainable lifestyle systems, including organic food production in their areas. Before the Covid outbreak, these groups were actively applying strategies, suggested by SATURN, being eager to implement innovative approaches in agri- food development. Although put on hold, this keenness is now being rewarded by funding, as post-pandemic restart projects get underway in various committed communities.

The valorisation of abandoned or not well-governed areas is an important challenge in the development and creation of ecological connections within a territory (Doherty and Waldheim 2016). This action is planned for to detail the connection among the different landscape patches and their dynamics. A better knowledge of past dynamics together with an in-depth analysis of socio-economic factors is crucial to identifying and designing future planning strategies and policies to couple local needs with ecological resilience of the territory. In the Municipality of Pergine Valsugana, the importance of former agricultural areas is tied to their traditional cultural, social and landscape value (e.g. dry-stone walls) as well as to their role of local biodiversity (e.g. ecological connection of urban, agricultural and forested areas). Here, the maintenance of the forest and the enhancement of natural ecosystems in the urban and rural environment show how much relevant are the biodiversity conservation and the food production for the creation of ecological networks. The food production, based on organic farming, tends, wherever possible, to reuse abandoned territories or calling for collective growing spaces. Local entrepreneurs who want to valorise their properties can be encouraged by the initiative and start a virtuous process that will boost well-being and social inclusion, with opportunities at individual scale for women, youth or disadvantaged categories, both in food production, environment management and cultural-recreational activities (Fig. 15.4).

In the Municipality of Trento, there are similar ongoing processes (EUSALP 2017; AA.VV 2019b; Favargiotti et al. 2020) where the enhancement and valorisation of abandoned and underused open areas offers the opportunity to enhance new productive and recreational landscapes (European Environment Agency 2016). These areas are pivotal for developing a strategically planned network of natural and semi-natural areas, including features in rural and urban areas which together – functionally and ecologically interconnected – ensure diverse advantages for nature, as well as social benefits and economic prosperity for humans (ecosystem services). Most of these activities are playing a multifunctional role: these initiatives, on a micro-scale, support actions of mitigation to climate change, risk protection (mainly

Fig. 15.4 Abandoned terraced landscapes in the Municipality of Pergine Valsugana. (Photo credit: Angelica Pianegonda 2019)

from floods and storms) and support ecological connectivity and biodiversity conservation alongside helping to valorise itineraries at different altitude and for different targets (Fig. 15.5). The realisation of a comprehensive mapping of the entire green systems in Trentino pilot areas, from rural agricultural areas to urban public and private garden, produced a wider analysis of the ecological connectivity. In this vision, the natural elements defined as urban BGI such as green network, urban gardens and orchards, ecological corridors, urban forestry and public parks have been included (Codemo et al. 2018). The vertical gardens have also been considered as elements of ecological connection as they contribute to the urban biodiversity. This analysis supports specific projects driven by local cooperatives to develop new productive areas in rural-urban settlements with a renewed sensitivity to adaptation strategies to ongoing changes. This is the case of the Fondazione Crosina Sartori Cloch, where innovative agricultural techniques and methods with a social intent will be tested.

The proactive dynamics related to the food cycle system may positively affect the impact's reduction on emissions, climate and halting the local capacity of resilience. Therefore, the community engagement and the grassroots involvement in transforming food systems are fundamental as outlined by the Milan Urban Food Policy Pact (AA.VV 2015). The relaunch of urban and peri-urban sustainable agriculture is possible by facilitating contact between producers and consumers with open dynamics and tools. Experiences show how relevant is the creation of a network among producers and consumers, giving visibility and stimulating short food

Fig. 15.5 Valsugana local railway in relation to the east hill in Trento. (Photo credit: Giuseppe Gorfer 2019)

supply chains and direct sales but also sharing information and awareness-raising on natural foods and healthy lifestyles, on protecting the health of producers and consumers and on the use of quality local products in schools and in the tourism sector. These are the goals addressed by the pilot case *Nutrire Trento* ("Feeding Trento") by identifying ideas and solutions to improve the quality of the food for the city and provide healthy food that adequately remunerated all actors in the food supply chain. In order to coordinate and connect the various initiatives, a digital platform (www.nutriretrento.it) has been implemented to allow people to simultaneously visualise the actors and the places in the Trento short supply chain: producers, markets, shops, cooperative purchasing groups and urban or community vegetable gardens (Forno, in AA.VV 2019a).

The ongoing experiences in the Trentino region address and support the theoretical position of this contribution where the foodscape can be seen as part of an urban green infrastructure network. It is a field of investigation where the concept of urban resilience and climate adaptation (Van de Ven et al. 2016) can be applied. Thanks to the real-time research initiatives, it is clear how this approach can contribute through an integrated sustainable production to achieve climate mitigation, well-being and quality of life. The design perspective across the different scales (territorial, urban, architectural) should be based on values such as social integration, food security, enhancement of environmental and ecosystem services (protection against erosion, support of bee pollination, tourism and biodiversity), supply of local products throughout the food value chain, creation of jobs in a perspective of sustainable development and circular economy for urban and territorial regeneration.

Acknowledgements The theoretical approach, scientific position and conclusions of this contribution have been collectively elaborated by the two authors Sara Favargiotti and Angelica Pianegonda. Author names are listed in alphabetical order. Chapters can be attributed to the lead writer as follows: 1 and 2 to Sara Favargiotti; 3 and 4 to Angelica Pianegonda. The wider research contents and concepts have been developed in the framework of the EIT Climate-KIC "SATURN" research project by the whole team: Alessandro Betta and Alessandro Gretter (PI) (Fondazione Edmund Mach, IT); Mattia Andreola, Marco Ciolli, Sara Favargiotti, Francesca Forno, Angelica Pianegonda and Paolo Zatelli (University of Trento, IT); Elisa Morganti (Hub Innovazione Trentino, IT); Kathryn Moore and Anastasia Nikologianni (Birmingham City University, UK); Nick Grayson (Birmingham City Council, UK); Bodil Elmqvist and Anna Ternell (PE Teknik och Arkitektur, SWE); Martin Berg and Martin A. B. Pedersen (City of Göteborg, SWE); and Anders Nilsson (Region Västra Götaland, SWE). More information are available in the official website https://eventi.fmach.it/saturn. The authors acknowledge funding from the EIT Climate-KIC in the frame of "SATURN – System and sustainable Approach to virTuous interaction of Urban and Rural LaNdscapes", Climate Innovation Ecosystems research project, 2018–2021.

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Chapter 16
Policies and Planning of Urban Green Infrastructure and Sustainable Urban Drainage Systems

Daniele La Rosa and Viviana Pappalardo

Abstract Green infrastructure (GI) is increasingly recognized as a planning and design approach to ensure the provision of a broad set of ecosystem services in cities, as well as a way to make the concept of urban resilience fully operational. Multifunctionality is the most recognizable feature of GI, ensuring the provision of different ecosystem services and benefits, including storm water regulation, the reduction of social vulnerability, green space, air quality, mitigation of urban heat island effect and landscape connectivity. GI design has recently embraced resilience purposes and started to generate different urban policies that try to address a wide range of environmental issues. Among the different types of urban GI, sustainable urban drainage systems (SUDS) represent solutions that use natural processes to comply with the principles underlying the adaptive flood management, enabling the shift towards a more sustainable handling of storm water. This chapter focuses on different approaches concerning the adoption of GI in cities and particularly focuses on SUDS. Various policy tools (regulatory instruments, market-based incentives, educational and training programs) are introduced. By comparing experiences that promote a nature-based drainage approach to address urban transformations, this chapter also analyses barriers, challenges and lessons learned about the implementation of GI and SUDS in both new and existing urban developments.

Keywords Urban planning · Ecosystem services · Sustainability · Urban policies · Ecology

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_16

16.1 Urban Green Infrastructure and Relevance for Urban Planning

Green infrastructure (GI) is a network of different ecological elements – both natural, semi-natural and artificial – that can be planned, designed and implemented at different spatial scales and is able to provide a wide set of services, contributing to the human well-being (Ahern 2007; Hansen and Pauleit 2014). According to another definition, urban GI is considered as a strategic planning approach that aims at developing networks of green and blue spaces in urban areas (Maes et al. 2019).

From a theoretical point of view, GI often embodies resistance thinking (Folke et al. 2002), while the now well-documented and pervasive global environmental perturbations of the Anthropocene – related to climate changes – have produced different policies which respond to environmental issues and build upon resilience theory (Lister 2015). Furthermore, GI is offering interesting field for the integration of other scientific disciplines, such as urban ecology (Hostetler et al. 2011) or ecosystem service science (Zhang and Muñoz Ramírez 2019) as concepts able to reflect and highlight the multiple services provided by the GI in cities. GI has been also considered as (Hansen and Pauleit 2014, pp. 516):

> […] a melting pot for innovative planning approaches in the field of nature conservation and green space planning

Similar to the human-made infrastructure – the grey infrastructure – GI represents a functional and physical system supporting urbanized areas (Wang and Banzhaf 2018). Especially in cities, GI should strive to integrate green with grey infrastructure, e.g. for sustainable storm water management, and be developed in a socially inclusive process to involve all relevant stakeholders.

Landscape Institute (2013: 3) reports an enlarged definition of GI that considers green and blue features inside and outside the city:

> GI assets range from country parks, lakes and woodlands to urban interventions such as green roofs and street trees. They can be specific sites at the local level or broader environmental features at the landscape scale within and between rural and urban areas such as wetlands, moors and mountain ranges.

These ecosystems thus play a fundamental role in health, well-being and social safety (Wild et al. 2017). Multifunctionality represents the most innovative aspect of GI (Ahern 2007; Tzoulas et al. 2007), as ecosystems and other elements integrated in the GI are able to deliver a wide set of urban ecosystem services, including CO_2 sequestration, reduction of air pollutants and noise, regulation of microclimate and heat island effect, oxygen production, water run-off regulation, water filtering, pollination, support to biodiversity and provision of cultural and recreational values (Calderón-Contreras and Quiroz-Rosas 2017; Pappalardo et al. 2017a).

In urban contexts, GI includes also peripheral and rural ecosystems that can have positive effects on the nearby cities especially when looking at large and broad metropolitan systems. Ecosystem services can therefore be provided by ecosystems located far from the traditionally planned city border. Typical examples of these ecosystems include wider (semi-)natural areas that mitigate the flood events or the rural/peri-urban farmlands providing food and recreational services to the cities' inhabitants. Neglecting peri-urban ecosystems in urban and regional planning may increase the flooding risk (Mysiak et al. 2013) or cause social inequalities in the provision of green spaces and cultural services (Geneletti et al. 2017).

GI can play a relevant role for complex challenges of urban planning towards higher levels of urban resilience for contemporary and future cities. GI is seen as a framework through which to help create more sustainable and resilient urban environments (Mell 2009). Indeed, the relevance for spatial planning is evident in one of the first definitions of GI by Benedict and McMahon (2006: 1), which indicated GI as:

> […] the ecological framework for environmental, social, and economic health – in short, our natural life-support system.

The reference to a framework to be used to reconnect existing and formally planned open spaces in cities represents an important opportunity to include different types of open spaces and ecosystems within existing urban fabric and grey infrastructure. The surfaces referred to grey infrastructure have been named with a number of different terms, such as *non-urbanized areas*, *unbuilt*, *friche*, *vacant land* or *terrain vague* (Morales 1995; Phelps and Silva 2018), and can include land still hosting a dense vegetation cover that has not been subject to any transformation process but might be developed in a near feature (La Rosa and Privitera 2013).

Recently, such spaces have been increasingly recognized and discussed despite often being overlooked and, more importantly, ill-acknowledged by urban planning as areas able to deliver a wide spectrum of multifunctional benefits and ecosystem services for urban and peri-urban residents (Phelps and Silva 2018) and therefore to increase urban resilience (Childers et al. 2015; García and Vale 2017). The objective of planning, managing and improving the surface, the quality and the functioning of GI is of growing interest for public administrations aimed at sustainable development. Indeed, GI offers a great potential to increase the overall liveability of cities and restore deprived districts through urban regeneration solutions making use of different forms of greenery, improve the quality of life for citizens, reduce urban violence, decrease social tensions and increase cohesion (Fan et al. 2017).

Many approaches and urban policies for GI have been proposed (Lennon 2015), but a much limited number has been officially launched, tested and ultimately implemented (Di Marino et al. 2019). A consolidated translation of GI in planning processes still remains complicated (Matthews et al. 2015; Catalano et al. 2018) and far to be fully achieved, especially in some geographical contexts which are less advanced in terms of green integration in cities.

16.2 The Crucial Role of Urban Green Infrastructure for Water and Climate Regulation

GI research typically focuses on the two most challenging issues that cities encounter in the face of climate change and extreme weather-related events: heat and flooding (Derkzen et al. 2017). In urban areas, due to the clustering of people combined with densely built-up structures and sealed surfaces, the impact of heatwaves and heavy rainfall events is magnified, so that the investigation of GI benefits has become increasingly important. The next subsections briefly introduce two of the most relevant ecosystem services provided by GI to cities: water and climate regulation.

16.2.1 Water Regulation

Water regulation is a crucial service for contemporary cities, and the literature on ecosystem services and flood prevention and management is conspicuous (Barbedo et al. 2014). In their review on urban ecosystem services, Gómez-Baggethun et al. (2013) underlined the role of run-off regulation to improve urban resilience and the quality of life in cities. Water-flow regulation has a significant economic value, as avoided costs for property damages (buildings, infrastructures, commercial forests and agricultural lands) or for increased dependence on water purification technologies can come from run-off mitigation. Flooding events often have adverse consequences for human health, causing deaths directly by drowning or from diseases due to water contamination. Other victims of floods may suffer from psychological and emotive illness (Ohl and Tapsell 2016). Moreover, when the lack of regulation of water-flow services is tackled by the substitution of built infrastructure in place of (semi-)natural ecosystems, further costs for society may arise (Gómez-Baggethun et al. 2013).

The processes related to the rainfall-run-off transformation in natural basins and urban catchments are quite complex. The surface run-off generation is highly influenced by land use and land cover, which impact on natural water systems and water balance and particularly interfere on processes of interception, surface retention, infiltration, evapotranspiration and resistance to overland flow (McGrane 2016). The main effects of urban development on surface run-off are the replacement of vegetation by more impermeable features like buildings, paved surfaces and roads. Interception of rain by vegetation is also reduced. These changes dramatically alter the quality and quantity of surface water run-off, especially when extremely intense precipitation events do occur.

The consequence of these processes is that a higher proportion of rainfall is transformed into surface-water run-off, which results in increased peak flood discharges and degraded water quality through the pickup of urban street pollutants (Haughton and Hunter 1994). Volumes and stream peak flow rates are increased by the concentrated surface water run-off that enters streams and rivers. The likelihood of flooding increases, and environmental damage can result from faster water flows, greater amounts of sediments and urban pollutants washed into streams and warmer run-off waters. Particularly in urban areas, the capacity of a drainage system can be overloaded in case of heavy rain events, and the surcharged sewer flows can be combined with natural water run-off and can generate urban flooding (Falconer et al. 2009).

GI is able to regulate water run-off through different natural processes. The permeable soils under canopies allow water to seep through, while some rainwater is intercepted by leaves and then released into the air through evapotranspiration. Allowing storm water to infiltrate open ground can improve its quality, reduce the volume of surface run-off and reduce peak streamflows. Even if the built environment seals the ground from rainwater, it has been suggested that urbanization also creates some new pathways for recharge. In vegetated areas, only 5–15% of the rainwater runs off the ground, with the rest evaporating or infiltrating the ground (Bolund and Hunhammar 1999). In cities without vegetation, about 60% of the rainwater is instead led off through storm water drains. This will of course affect both the local climate and the levels of groundwater reservoir.

For these reasons, spatial planning and urban management strategies must be designed to consider, protect and – where possible – increase ecosystems' capacity to regulate water flow and increase urban resilience. Planning should identify natural ecosystems or design new spaces where the water can flow, infiltrate or be stored for a given time, before being conveyed through the drainage systems or directly entering streams and rivers.

16.2.2 Climate Regulation

Among the ecosystem services provided by GI, climate regulation is of great importance in cities, where the microclimatic benefits of urban vegetation can contribute to the mitigation of the urban heat island effect. Climate regulation has relevant positive impacts on the energy demand of buildings, as demonstrated by a growing body of research and experimental measurements (Konarska et al. 2015) and confirmed under different climate conditions and building types (Palme et al. 2017). Vegetation contributes to regulate the urban temperature through three main actions: shading the built environment, modifying the airflow around it and directly lowering the outdoor air temperature through evapotranspiration processes (Hwang et al. 2017).

Shade effect performed by trees reduces the amount of solar energy a building absorbs and therefore reduces their cooling energy use. Calcerano and Martinelli (2016) evaluated the optimal arrangement of trees around a fictitious stand-alone building located in Rome (Italy) and prone to typically Mediterranean climatic conditions, in order to maximize energy savings in the cooling season. The simulations revealed that arranging the trees along east and west walls is the most favourable option, with predicted energy savings ranging from around 11%, when only one tree is placed on the centred east position, up to around 45% when five trees are arranged around the building. In a similar work, Hwang et al. (2017) used remote sensing to identify the existing placement of trees around houses in three US cities with different climates. Data issuing from high-resolution imagery and LiDAR were used to extract information concerning houses and parcel orientation, tree size, shape and location with respect to the houses. Then, these variables were used as an input for energy simulations to appraise the shading effect on the annual energy demand of a standard-sized house according to the existing configuration and to possible alternative arrangements. Deciduous and evergreen trees were used in order to test models, and the outcomes of the simulations showed that the optimal tree arrangement along the west and east walls would introduce average additional energy savings of about 22 ± 2.4 kWh per parcel annually with respect to the current arrangement of the trees.

The vegetation of the GI also generates a sheltering effect, slowing down winds close to the buildings, thus reducing the convective heat losses and the infiltration rates; this is particularly interesting in windy, cold and frequently overcast sites. Liu and Harris (2008) considered the effect of deciduous shelterbelt trees on wind in Scotland and proposed some best-practice rules to arrange the position of the trees around buildings to maximize their shelter effect. Authors proposed that shelterbelt trees should be planted along the entire lengths of the buildings, be perpendicular to the prevailing wind, have a medium porosity (about 40%) in order to provide a good wind speed reduction over a long distance and also include a line of shrubs at their basis.

Vegetation also cools down the air temperature around buildings, and this has an indirect effect on the need of energy required for air conditioning within the buildings. When these two processes act at city or district level, the positive cooling process induced by vegetation can generate relevant electrical energy savings (Wang et al. 2019), with performances that can be further increased by the evapotranspiration effect (Hsieh et al. 2018). Shahidan et al. (2012) investigated the effect of urban vegetation by focusing on the reduction in the dry-bulb temperature due to evapotranspiration and by quantifying the consequent variation in the cooling load of buildings. Authors simulated several possible scenarios with different numbers of trees and different canopy densities, showing that doubling the number of trees would generate a mean reduction in the maximum outdoor air temperature ranging from 0.9 °C to 1.2 °C.

16.3 Sustainable Urban Drainage System

Urban sprawl is the main responsible for the alterations of run-off in basins; consequently, urban planning can deeply affect the hydrologic response of catchments (Pappalardo et al. 2017b). In urban catchments, the management of surface water flooding is crimped by the characteristics of urban drainage (Kazmierczak and Cavan 2011). Understanding potential effects of urban development on the drainage system represents a crucial issue in any planning process since its early stages (Miguez et al. 2015). In fact, under alterations of run-off peaks and volumes and not only during extreme weather events, conventional storm water drainage systems can be pushed beyond their drainage capacity and may lead to more frequent and intense floods (Maksimović et al. 2009).

As anticipated in the previous section, urban flooding is one of the major and costly environmental hazards, and the urgency on flood prevention and management in the research on GI and ecosystem services is gaining emphasis (Barbedo et al. 2014). Spatial planning is increasingly considering GI and the ecosystem's capacity to regulate water flow as the most promising approaches to increase urban resilience to flooding events (Pappalardo et al. 2017a). In parallel, a substantial cultural change in urban drainage-related disciplines has determined a progressive shift of the focus from the conventional drainage system design, which is mainly single objective and oriented to water quantity control, to a more sustainable and integrated management of the water resource, considering other important aspects such as run-off quality, amenity and recreational values, ecological protection and multiple water uses (Zhou 2014).

Sustainable urban drainage systems (SUDS) are nature-based solutions capable of managing and controlling surface run-off through techniques such as infiltration, detention/attenuation, conveyance and/or rain harvesting (Scholz et al. 2013). Such processes occur naturally within the water cycle, if not altered by urban sprawl (Ahiablame et al. 2012). As a consequence, the deployment of SUDS is intended primarily to mimic the natural hydrological processes through the restoration or preservation of important elements and mechanism of the pre-development run-off processes (Woods Ballard et al. 2015).

For a range of flow conditions, from small to large rainfall events, SUDS offer a sustainable solution to manage surface run-off under the threat of both the climate change-induced hazards and the impacts of urban intensification, also providing a range of significant co-benefits for an overall enhancing of local environmental conditions (Voskamp and Van de Ven 2014).

Differently from conventional subsurface drainage systems, which are basically mono-functional and not capable of providing solutions to manage rainfall events that exceed design conditions, SUDS are multifunctional and deliver the range of benefits typically acknowledged to the implementation of GI. These include physical, emotional and mental health benefits from recreation and aesthetics, improved water availability and quality, enhancement of educational opportunities, thermal comfort, air purification and protection of biodiversity (Mak et al. 2017).

Examples of SUDS include green roofs, trees, permeable surfaces, infiltration trenches, filter drains/strips, swales, shallow drainage channels, detention basins/ponds and wetlands (Fig. 16.1). In order to increase their multiple potential benefits, these measures should be designed and planned as an interconnected system of subsequent components designed to manage, treat and make best use of the water resource (Woods Ballard et al. 2015).

Like other types of GI, SUDS are not fully implemented in urban areas, and their implementation is hindered by a number of different challenges and barriers

Fig. 16.1 Examples of Sustainable Urban Drainage Systems. (**a**) Detention basin in Dun Loghaire (Ireland); (**b**) Permeable pavements in Dublin (Ireland); (**c**) Filter drains/strips in Dublin (Ireland); (**d**) Swale in Amherst (USA); (**e**) Infiltration trenches in Pennsylvania; (**f**) Green roof in Catania (Italy); (**g**) Rain garden in Singapore. (**a–d** and **f**) Photo credit: the authors; (**e**) Photo credit: Montgomery County, under Creative Commons License (CC BY-SA 2.0); (**g**) Photo credit: Roger Soh, under Creative Commons License (CC BY-SA 2.0)

(O'Donnell 2017), among the previous, the design of SUDS schemes according to site-specific conditions (land use, soil type, urban settlement morphology, etc.), the efforts to effectively integrate SUDS design in land use planning processes and the engagement of stakeholders at various levels and from both public and private realms.

16.4 Planning and Policies for SUDS

16.4.1 Methodological Approaches to Inform Planning Decisions on SUDS

Sound planning and policy instruments rely on models for characterizing territorial processes, especially when facing environmental issues and/or aiming at reaching higher levels of urban sustainability. Modelling enriches the spatial planning process in different phases: from knowledge to assessment, from interpretation to decision.

Understanding which type of SUDS can better address specific urban issues is a complex process, as it involves many different aspects and disciplines. The choice of SUDS depends on land uses, hydrologic systems and particular socioeconomic conditions, such as the number and types of social subjects potentially exposed to urban flooding hazard (La Rosa and Pappalardo 2020). Hence, it is important to evaluate and quantify the real benefits associated to different types/scenarios of SUDS with spatially explicit approaches able to locate where and for which urban communities the benefits from SUDS can be applied. The following analytical phases have been proposed in recent research on SUDS modelling to support planning of the most appropriate SUDS.

16.4.1.1 Geographical and Urban Analyses

Land use mapping is the most common way to analyse the use and cover assets of a specific urban context and to identify and distinguish urban and non-urbanized areas, pervious, impervious and other different types of land covers. Land use mapping also represents the base for hydrological/hydraulic analysis, simulation and modelling tools. Particularly, the simulation of hydrologic and hydraulic responses of catchments to rainfall precipitation becomes fundamental in order to identify the most effective strategies for SUDS.

Other types of analyses can include the study of the morphological characters of the urban fabric and of the urban growth process. These analyses can be very helpful to better distinguish the type and age of buildings that may contribute in different ways to water run-off (Barbier and Chaudhry 2014).

16.4.1.2 Hydrological and Hydraulic Analyses

A crucial step in the methodological workflow for SUDS planning is represented by the hydrological/hydraulic analyses (Guo et al. 2010). These analyses simulate the hydrological and hydraulic responses of urban catchments to precipitation events of various duration (i.e. 1, 3 and 6 h). Many types of hydrological, hydraulic or water quality models are available, with different objectives. They can range from simple spreadsheets that predict a single process, such as the run-off from a single storm, to more complex simulations that predict multiple, inter-related processes including the performance of multiple SUDS.

When dealing with storm waters, the Storm Water Management Model (SWMM) developed by the US Environmental Protection Agency (Rossman 2015) is one of the most used by professionals. The model is used for single events or long-term (continuous) simulation and tracks the quantity (and quality) of run-off generated from primarily urban areas within each sub-catchment, the flow rate, the flow depth and the quality of water in each pipe and channel during the simulation period. The run-off component operates on a collection of sub-catchment areas that receive precipitation and generate run-off (and pollutant loads) that are transported along a system of pipes, channels, storage/treatment devices, pumps and regulators (Rossman 2015).

16.4.1.3 Choice of SUDS Scenarios

There are many different SUDS that can be used on a site, but not all types of SUDS can be suitable for all cities, as each site has unique characteristics and specific geomorphological constraints. An example of the criteria that should be considered for the choice of a SUDS scenario is presented in Fig. 16.2. The suitability of a set of five SUDS (swales, rain barrels, permeable pavements, green roofs and rain gardens) is expressed by a semi-quantitative assessment (high, medium, low) of five different design/selection criteria: land use, site geographical characteristics, urban morphology, SUDS performance and urban strategy that can be used to implement the SUDS. Although such a matrix can address the choice towards one SUDS over another, the ideal solution would include many types of SUDS linked together to form a SUDS management train (Pappalardo and La Rosa 2019).

16.4.1.4 Modelling of Scenarios

The simulation of the effects of SUDS in cities depends on the model chosen to represent the SUDS. For example, in the Storm Water Management Model, SUDS can be represented by vertical layers, and their properties are defined on a per-unit-area basis so that they can be placed in any of the sub-catchments at different sizes or numbers. The following types of SUDS can be modelled: bio-retention cells, rain gardens, green roofs, infiltration trenches, continuous porous pavements, rain

SUSTAINABLE URBAN DRAINAGE SYSTEMS SUDs

VEGETATIVE SWALE
RAIN BARREL
PERMEABLE PAVEMENT
GREEN ROOF
RAIN GARDEN

			RG	GR	PP	RB	VS
LAND USE	residential		H	H	H	H	H
	roads/parking		H	/	L/H	L	M
	commercial/service		H	M/H	M	M	M
	industrial		H	M/H	M	M	M
SITE-CARACTERISTICS	soils	permeable	H	H	H	H	H
		impermeable	L				
	slope	< 5%	H	H	H	H	H
		> 5%			L		M
	depth to water table	< 1m	L	H	L	H	L
		> 1m	H		H		H
	area draining	< 2 ha	H	H	H	H	H
		> 2 ha	M	L	H	L	L
SITE-MORPHOLOGY	courtyard bloks		H	L/H	M	M	L
	compact grid		L	L/H	L	L	L
	indipendent bloks		H	L/H	H	H	M
	space availability		H	/	/	/	H
PERFORMANCE	peak flow reduction		M	M	H	M	M
	volume reduction		M	M	H	M	M
	amenity potential		H	H	L	L	M
URBAN DESIGN STRATEGY	retrofit		H	M	H	H	L
	renewal		H	H	H	H	H
	new development		H	H	H	H	H

Fig. 16.2 Design criteria for five different and commonly used SUDS. H (high), M (medium), L (low) represent the suitability degree of the 5 considered SUDS according to the chosen 5 design/selection criteria

barrels and vegetative swales. For these SUDS the surface run-off is simulated as a combination of detention, infiltration and evapotranspiration processes (Rossman 2015).

16.4.1.5 Validation of the Results

Results from the modelling of the SUDS scenario would also require a final step of validation, to link results to the real behaviour of the simulated urban system. However, the availability of field data for this purpose depends on the physical deployment of the chosen SUDS, and this is a condition that can be achieved only for cities that have already implemented SUDS. In all other cases, validation must often rely on existing literature on similar researches (that can vary largely among different cities). For example, databases on SUDS performance and effectiveness for south European regions are not available, and comparisons with other urban contexts where SUDS have been already deployed are not always meaningful (Winker et al. 2019).

16.4.2 Policies for SUDS Implementation

In order to successfully include sustainable storm water management in planning theory and practice, land use regulations should originate from a proper management of a complex of factors. The whole spectrum of decision-making procedures, technical work and interactive learning processes may well be the framework to develop a common share on the future. In fact, once the plan is fully implemented, it is more likely to put into effect a combination of strategies if these are jointly determined by communities and government authorities (Kramer 2014).

Particularly, the building of planning decisions is often a multilevel, multisector and multi-actor governance process, at the end of which every planning activity results in a government action (Rivolin 2008) that becomes crucial for the success of any planning objective in the short and long run. In order to obtain that, planning decisions by public authorities turn into effective, correct and legitimated approaches to the management of storm water; policy statements should inform the entire planning and decision-making process.

In the provision of guidance to local development control decisions, local policies should be consistent with international and national policy statements, among which the promotion of sustainable drainage. Local urban planning and policies on storm water sustainable management provide the opportunity to encourage SUDS adoption and achieve the correspondent multiple benefit (Dickie et al. 2010). The achievement of predefined levels of environmental performance in private domain as well as in public realm depends on the provision of well-structured site-specific frameworks of strategies for regulating land use transformations, acquiring public land, using existing vacant areas and providing incentives for storm water discharge reduction and green infrastructure adoption at the urban scale (Pappalardo and La Rosa 2019). Often policy efforts have focused on suggesting the consideration of GI into site design as mitigation and compensation measures for the increase of surface water run-off due to local urban development.

GI policies could be analysed within the more comprehensive area of environmental policies. The latter are traditionally described by referring to three main approaches. The first approach is to ban, the second is to incentivize, and the third is to educate. Accordingly, the scientific literature identifies command-and-control instruments, incentive-based tools and education and outreach initiatives.

Most commonly, planning objectives have been achieved with the implementation of regulatory instruments (Clinch and O'Neill 2010), which control activities/behaviours by stating what is permitted and what is banned. In this case, uniform standards/targets, which are often classified as technology-based or performance-based, are established by the authority through a *command*. The authority also exerts its *control* on the compliance of the regulation, applying negative sanctions in case of non-observance.

Differently, incentive-based tools are more creative approaches that local governments can use to encourage the use of green infrastructure practices, especially on the private property (EPA 2009). Incentives could be monetary or not, and, in the first case, they rely heavily on market mechanisms and economic variables to influence communities' behaviours. Both categories of price-based and quantity-based market instruments (Whitten et al. 2007; Field and Field 2009) are considered more economically efficient (Nash 2000) and are implemented towards the avoidance of negative environmental externalities, or the incorporation of externality costs of human activities, or the reckoning of the positive externalities of mitigation-adaptation measures (Parikh et al. 2005).

Education and outreach programs are becoming only recently an additional mean to affect individual behaviours even if not as important and widespread as the first two alternatives. Education and outreach take many forms such as brochures/publications, public campaigns, events or demonstrations and pilot projects which give great visibility (Hall 2010).

Similar to other environmental policy areas, the most common approaches for GI aimed at sustainable storm water management are command and control, because spontaneous and autonomous individual *pro-environment* initiatives are rare. Nonetheless, encouraging behaviour change, through market signals rather than through explicit control directives, has proved to be effective in delivering socially desirable outcomes (Stavins 2003) and gives a reason for the emerging increased implementation of incentive-based approaches in various jurisdictions (Field and Field 2009; Clinch and O'Neill 2010).

In the last decades, researches by economists and policymakers in the area of environmental policy have thoroughly informed planning studies due to their potential significance for flood control and sustainable water management through the adoption of GI practices (Pappalardo and La Rosa 2019).

Together with education and outreach, which are mainly acknowledged for their pedagogical effect, regulatory instruments and incentive tools share the basic principle of ascribing the responsibility for causing a negative impact on the surrounding environment to any person who acts with the consequence of generating the damage. Thus, they play a valuable normative role in society, with potential resulting effects on the reduction of negative impacts and the development of more effective technologies for achieving the purpose (Nash 2000).

Indeed, each policy approach presents advantages and disadvantages when applied in terms of economic feasibility (efficiency and cost-effectiveness), social equity (fairness), environmental goal achievement (with improvement of technology and consequent increase in performances of the solutions adopted), local site constraints and enforceability. Most importantly, cultural differences affecting the perception and the reactions to the environmental and urban risk issues represent the key factor on which any successful outcome of policy tools' implementation depend. Once key stakeholders agree on clear, specific, measurable environmental objectives, the development of a feasible environmental policy is mostly based on how to induce change by leveraging on why people behave or, in other words, on how to tailor incentives in order to overcome barriers and constraints to the implementation of desired measure and achievement of the desired change.

16.4.3 Challenges and Opportunities for the Integration of GI in Urban Planning

Despite their importance in cities, the implementation of GI has to face the lack of public open spaces to be set as new green areas.

Land acquisition is directly linked to the economic feasibility of the green space implementation, as direct public acquisitions of land are often economically unsustainable for local administration and can face resistance from private landowners (Bengston et al. 2004). Public acquisition of land represents a traditional approach of public intervention, characterized by the main role of public administrators who act through an articulated set of urban design projects and relevant state funding for covering investment and maintenance costs.

Acquisition of land for GI may be even more problematic when the open spaces that can be part of a GI are located in private residential areas/compound or belong to private landowners. The different property assets therefore put some constraints in the economic feasibility of the new GI (Privitera and La Rosa 2018), especially when the public administrative bodies in charge of planning (i.e. municipalities) do not have the economic resources to buy or acquire new areas for the GI.

However, the recent issues related to climate change require a deep change in planning and implementing urban transformations, which cannot be addressed solely by the public actors through the application of traditional tools. Operating on a public-owned land implies less negotiation with landowners, whereas transformation on private land should be based on market conveniences. Accordingly, compensation and incentive tools should be used to manage transformation of private lands.

Carbon offset fund and transfer of development rights are typical examples. The carbon offset fund allows to reduce the net carbon emissions of new development, retrofitting or regeneration projects by collecting investment from developers and channelling it into a fund that is invested in a range of projects that deliver carbon savings (O'Rourke 2010).

The issue of economic feasibility for managing the provisioning of accessible public open spaces could be addressed through the transfer of development rights and the purchase of development rights or conservation easements (Brabec and Smith 2002). Development rights are the rights to develop land or add more buildings to existing development, subject to some regulations usually included in the urban planning documents or norms. Transfer of development rights programs define the areas to be protected from development and those where development will be allowed. Landowners can transfer the rights from the areas to be protected (sending areas) to those to be developed (receiving areas). As a consequence, the land from which the development rights are being transferred can no longer be developed or be developed only to a limited extent. This land can be used by the public administration as public areas where to set green spaces (i.e. GI) and other public services. As a result, landowners are compensated for regulatory restrictions that reduce their property values (Bengston et al. 2004).

TDR program represents a possible mechanism to increase the amount of public areas to be used as GI and therefore the amount of greenery within urban fabric. It would also effectively reduce the energy demands of building, thanks to climate regulation performed by vegetation. However, any GI involving private space (i.e. planting trees in and around private buildings) should be integrated in a wider strategy aimed at designing larger and accessible public green spaces with other services (pathways, bike lanes, playgrounds, benches), avoiding fragmented or unconnected portions of GI.

The same challenges of practical implementation can be extended to SUDS. The implementation of urban policies for SUDS becomes more challenging with the increase of the number of involved stakeholders. For example, SUDS set up in publicly owned areas (streets, administrative buildings, existing green spaces) can be the first step only in the complex and long process of SUDS implementation in cities, although representing an effective way to showcase the benefits of GI to the general public. Pappalardo et al. (2017a, b) highlighted that for particular urban contexts where public areas are available at a limited extent only, SUDS should be located in private-owned areas, as for the relevant case of green roofs. Urban retrofitting policies should be issued to incentivize private owners to adopt these measures; otherwise it will be much less likely that private owners will invest personal financial resources for green roofs on their buildings. In these cases, it might be necessary to intervene on the behaviour of single citizens, either choosing command-and-control approaches or incentive-based policy instruments, as mentioned in the previous section. In general, experiences and research studies lead to think that a combination of both incentives and regulation may be the most effective policy strategy, which means to search for a proper combination between coercive strengths and a process of induced but voluntary adaptation (Filatova 2014).

16.5 Conclusions

After acknowledging the crucial role of GI to achieve higher levels of sustainability by providing a complete set of ecosystem services, this chapter has discussed the opportunities of spatial planning in implementing GI in contemporary cities. Regulation of climate and water represents the most relevant ecosystem service in cities, and increasing and protecting the ecosystems delivering these services must be one of the priorities for urban planning objectives.

Among different components of the GI, particular emphasis has been put to sustainable urban drainage systems, which are effective solutions towards a more sustainable management of storm water that mimic the natural hydrological processes and functions of water detention, attenuation, conveyance and infiltration.

For some geographical contexts (i.e. southern Europe), GI and SUDS are still lacking a complete and consolidated implementation in cities, and the relative challenges for a full integration in planning were discussed and analysed, with a specific focus on the economic constrains of public bodies when buying land to be used for the GI space implementation.

Various policy tools and planning mechanisms concerning the adoption and the increase of GI – and particularly SUDS – were introduced, such as regulatory instruments, market-based incentives and educational and training programs. For an ultimate implementation of SUDS, a combination of regulatory/control and market-based instruments should work complementary under the supervision of public administrations. This requires a proper combination between top-down regulations/prescriptions and processes of voluntary adaptation and would facilitate public involvement and avoid resistances of urban communities, thus paving the ground to the sustainable development of cities.

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Chapter 17
Soil and Water Bioengineering as Natural-Based Solutions

Paola Sangalli, João Paulo Fernandes, and Guillermo Tardío

Abstract Soil and water bioengineering (SWB) is a discipline that combines technology with biology, making use of native plants and plant communities as construction material for erosion control in degraded environments. The term *engineering* refers to the use of technical and scientific data for constructive, stabilization and erosion control purposes and "bio" because these functions are related to living organisms, mainly native plants with biotechnical characteristics and with the purpose of restoring ecosystems and increasing biodiversity. In this approach, native plant communities' potential is a key factor to achieve the overall objectives of planned interventions. SWB work designs involve both the integration of intrinsic adaptive information processes and legitimate design approaches (i.e. engagement of stakeholders into the project and work strategy). SWB encompass nature-based solutions (NBSs) which offer sustainable solutions in order to mitigate and adapt to climate change and effective restoration approaches suitable for degraded situations. Nowadays there is a rising awareness that nature is a very powerful source of viable solutions that use and deploy the properties of natural ecosystems and services. SWB practice is in accordance with the principles of NBSs "inspired and supported by nature". Nature-based solutions provide sustainable, cost-effective, multipurpose and flexible alternatives for various objectives: technical, ecological, landscape integration and socioeconomics. In this context, SWB techniques offer interesting synergies with urban green and blue infrastructure strategies.

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_17

Keywords Green infrastructure · Blue infrastructure · Biotechnical solutions · Climate change adaptation · Eco-engineering · urban resilience

17.1 Soil and Water Bioengineering in the Context of Global Change

The European Union, aware of the degree of degradation of our ecosystems, has set a strategy aimed at inverting biodiversity loss trends and speeding the transition to a green economy and efficient use of resources by 2050, so that the biodiversity and ecosystem services can be protected, valued and appropriately restored. This approach fights against the deterioration processes and fosters the restoration of degraded areas by introducing a new concept in spatial planning, the so-called green infrastructure. This concept refers to a spatial network of natural and semi-natural areas in order to reduce habitat fragmentation, allowing connections between existing natural areas, improve ecosystem health and resilience, contribute to the conservation of biodiversity and benefit human populations, through the maintenance and improvement of ecosystem services.

Green infrastructure requires projects aiming at maintaining, restoring, improving and connecting areas (either existing or new). Within this framework, restoration is conceived as a recovering process of ecological and social environments as well as the biological potential of the affected areas and the ability to reuse and integrate existing infrastructures and values.

The use of NBSs is urgently needed for restoration and construction processes. NBSs are defined, by the European Commission, as solutions that are inspired and backed by nature, which are profitable and provide environmental, social and economic benefits, and help increase the resilience and/or the adaptive capacity of ecosystems. In this sense, SWB represents a NBS, i.e. an effective tool for environmental improvement and recovery of biodiversity in degraded ecosystems. At the same time, we can also describe it as a *sociocultural-based solution* in the sense that its origins, development and application derive from a strong relation between human societies, the surrounding environment and its processes and components.

17.2 Soil and Water Bioengineering (SWB) as a Discipline

According to the European Federation of Soil and Water Bioengineering (EFIB), soil and water bioengineering (SWB) is a specific discipline of biology-oriented engineering, in which native plants and plant fragments are used as living building material which together with the improvement of soil quality can significantly contribute to human safety and to face all forms of erosion. In other words, bioengineering is a discipline that uses plants as elements of environmental construction and reconstruction.

The term *engineering* refers to the knowledge-based use of technical and scientific techniques and solutions for building, stabilization and erosion control and *bio* because these functions are related to living organisms, mainly native plant species, with appropriate biotechnical characteristics and for the purpose of rebuilding ecosystems and increasing biodiversity. It includes technical functions (e.g. soil protection and slope stabilization), ecological objectives (ecosystem restoration) and landscape objectives (improvement of landscape value and integration) and also takes into account several socioeconomic aspects (efficiency and employability). In this sense, SWB helps to protect land uses and infrastructures, contributes to landscape development and promotes its natural functions through its own systems and functional processes and resources (Hacker and Johannsen 2012; Fernandes and Freitas 2011; Bischetti et al. 2014; Fernandes and Guiomar 2016). In this sense (Studer and Zeh 2014; Rey et al. 2019: 42):

> Soil bioengineering has set itself the aim of designing our environment in a living way by applying construction methods which are close to nature […] based on materials which are found in nature and which are combined with technical building materials.

SWB developed itself on the basis of the rediscovery, reinvention, development and upgrade of traditional building techniques that used predominantly living plants as building materials (e.g. Frossard and Évette 2009), maximizing their functionality through modern technological and conceptual approaches as well as the development of new materials and plant-material combinations, building techniques and innovative fields of application and enlarging its working perspective from the microbiological to the regional and landscape scale (Hacker 2015).

Typically, in SWB techniques, plants and parts of plants are used as living building materials in such a way that, through their development in combination with soil and rock, they ensure a significant contribution to the long-term protection against all forms of erosion. In the initial phase, they often have to be combined with non-living building materials, which may, in some cases, ensure more or less, temporarily, most of the supporting functions. The use of organic materials is preferred, because parallel to the development of the vegetation and its increasing stabilization ability, these materials will rot and be reincorporated in the natural biogeochemical cycles. Therefore, during the SWB work service life, there is a stabilizing function stress transfer process between the employed inert materials and the evolving plant communities. The preferred living materials are native (autochthonous) and site-specific plants, as they promote a biodiversity perfectly suited to the landscape. The planning and construction objectives are the protection and stabilization of land uses and infrastructures as well as the development of landscape elements.

The use of plants in structural and civil engineering is based on the knowledge about their vegetative properties and ecological requirements, a knowledge that often dates back to centuries ago. Thanks to their different properties, plants can respond flexibly to their environment and are therefore employed to perform engineering functions. More in detail, they can:

- Reproduce and grow in different ways – through seeds and/or through vegetative parts
- Regenerate by re-sprouting after disturbance and adverse environmental changes
- Extract water from the soil and release it to the atmosphere (evapotranspiration)
- Connect different materials and structures
- Cover bare surfaces
- Intercept/retain/mobilize solid materials, dissolved substances and water
- Tolerate burying or submersion by developing sprouting roots
- Adapt to changes in local conditions like the variation on the speed of running water flow

All these properties enable the SWB techniques which use native plants to perform complex functions and to fulfil several objectives, which can be roughly divided into four categories: technical, ecological, landscape (aesthetic) and socioeconomic.

(a) Technical objectives: they refer to soil protection and stabilization through the radical system both to reduce surface erosion and to stabilize and consolidate slopes and river banks.
(b) Ecological objectives: bioengineering techniques use pioneer and stress-tolerant native plant species which will, over time, be substituted by more stable and mature plant communities belonging to the vegetation series typical for the intervention site.
(c) Landscape objectives: aimed at integrating structures into the landscape, reducing their visual impact.
(d) Socioeconomic objectives: reduction of construction and energy costs. These are techniques that use local materials and are an important source of employment since they require an intensive manual effort.

Soil and water bioengineering techniques are usually targeted to locations, where their design often needs to be considered at the catchment and landscape scales (Bifulco et al. 2015). For their correct application, a multidisciplinary study must be carried out taking into account the characteristics of the considered territory, be it a basin, a hillside or an urban environment. It is therefore in the territorial dimension that bioengineering techniques acquire their true ecological, technical, social and landscape application.

SWB is projected taking into account the concept of system resilience, i.e. the ability of a system to absorb disturbances without significantly altering its composition, structure and functionality, being able to return to its original state, once disturbance has ceased. For this return to occur, the resilience threshold must not be exceeded. SWB must be projected with the principle of minimal intervention that allows recovering the mentioned threshold.

The result of soil and water bioengineering interventions is living functional systems which develop and maintain their balance by means of natural progressive succession, i.e. through a process of dynamic self-regulation without artificial energy input. The correct choice of living as well as non-living building materials and construction types ensures an exceptionally high level of sustainability whilst normally requiring minimum maintenance. It is important to note, however, that in urban spaces such as towns or cities, which have been subject to major changes and natural processes and are strongly disturbed or even temporarily compromised, these goals require specialized maintenance. Additionally, in urban areas, maintenance actions must be defined in order to prevent the generation of conflicts between land uses and needs with the natural living system evolution activated by the SWB techniques.

The use of these environment-sensitive approaches, acting on natural, near-to-natural or strongly artificial systems, leads to the development of new fields of knowledge and to new ways of planning and design. It also emphasizes the need to conceptualize the global framework of ecologic, sociocultural, economic and technical interactions that occur along the development and functionality of these interventions.

17.3 Main Domains of Application and Fields of Intervention

Soil and water bioengineering techniques have been applied in different contexts such as:

- Slope stabilization (e.g. Stokes et al. 2014; Tardío and Mickovski 2016)
- Wetland restoration and streambank protection (e.g. Evette et al. 2009; Buchanan et al. 2012)
- Coastal defence (Boccalaro 2012)
- Reduction of the negative effects of natural processes (e.g. surface run-off or erosion)
- Prevention of further damages and degradation processes after disturbances such as mining, quarrying and other forms of exploring land resources (Cooke and Johnson 2002; Tischew and Kirmer 2007) or fire (e.g. Robichaud et al. 2008; Aristeidis and Vasiliki 2015)
- Contribution to the recovery of degraded areas, preventing and reversing land degradation processes

Sustainability as well as conservation and promotion of biodiversity and ecological functionality are central aims of this particular type of engineering (e.g. Mickovski and Thomson 2017).

SWB aims at achieving feasible, efficient, long-lasting, self-repairing, resilient, dynamic and ecologically functional engineering structures that, within strict technical and geotechnical limits, fulfil normally with higher efficiency and lower cost than their planned functions (Florineth 2012). SWB perspective must be considered in the context of the plurality of the domains of application of these techniques (Hacker 2015 – EFIB Guidelines) which are:

- Erosion prevention
- Prevention and stabilization of shallow landslides on slopes
- Prevention and correction of gully erosion on slopes and hillsides
- Stabilization and renaturalization of banks and adjacent areas of standing waters
- Protection, stabilization and reinforcement of dykes and dams
- Coastal protection and dune stabilization and restoration
- Protection against wind erosion
- Water regime regulation
- Immediate protection and restoration of areas destroyed by fire
- Avalanche protection

To this list we can add, without being comprehensive:

- Restoration of degraded and disturbed areas
- Global approach to landscape management in terms of avoidance and minimization of disturbance factors
- Improvement of water and soil quality through phytodepuration and phytoremediation
- Climatic mitigation
- Noise protection and mitigation

These manifold application domains build an integrated landscape management framework that goes way beyond a simple set of construction techniques. In fact, NBSs are informed to an integrated approach based on both technical and ecological grounds. This approach offers powerful synergies with green infrastructure development strategies.

However, it is important to refer that SWB faces also limitations, all connected with the characteristics and properties of vegetation. The first is that not all available plants in a given habitat have the needed technical characteristics (Stokes et al. 2014; Fernandes and Guiomar 2016).

Second, plants, as living beings, do not behave in a standardized way, limiting the ability to precisely calculate many structures and interventions (Hubble et al. 2010; Preti 2013). Finally, plants have limited ability in terms of root growth, hindering their capacity to stabilize soils to depths larger than 1.5–2 m (Ghestem et al. 2014). Also important, but quickly reducing through newly research efforts, is the lack of a systematized knowledge on the physical behaviour of plants and particularly their roots, when exposed to external forces (e.g. de Baets et al. 2008; Mao et al. 2014) allowing the application of standardized calculation methods. Limitations associated with local adverse conditions have stimulated the growth of a particular segment of the industry related with complementary materials (e.g. organic geotextiles and biological and chemical adjuvants) aimed at reducing the impact of water and soil erosion in the early stages of the interventions and at finding complementary construction solutions (e.g. Giménez-Morera et al. 2010; Guerra et al. 2010). In order to stabilize the intervention area from the very onset of the SWB work service life, it might be necessary to use inert materials providing the needed stability of the first interventions. Ensuring a successful stress transfer process between the different materials utilized in a SWB work is a keystone of the overall work strategy and at the same time is essential for achieving an effective and well-performing SWB intervention.

The main technical functions of SWB are related with soil support, cover and consolidation functions and regulation of the factors affecting soil surface, i.e. gravity, hydrology, hydraulics or wind regime (Hacker and Johannsen 2012). Such support should be viewed in terms of creating or fostering the development of structures able to stabilize slopes or riverbanks affected either by an increase of slope angle or by an increase of the external or internal acting forces or disturbances (e.g. Gray and Sotir 1996; Fernandes and Guiomar 2016). SWB may be applied for a wide spectrum of purposes like the following ones:

- Cover functions: mainly related with the protection against wind and water erosion (Zuazo and Pleguezuelo 2008) as well as trampling. On this purpose, soil and water bioengineering may represent the only solution for particular situations, such as areas above the timberline or sky tracks (e.g. Barni et al. 2007; Zuazo and Pleguezuelo 2008).
- Consolidation functions: aiming at soil protection, structuring and reinforcing (Gray and Sotir 1996) as well as soil anchoring, aggregating, draining and buttressing (Coppin and Richards 1990).
- Regulation functions: for example, as regards the mitigation and control of hydrologic processes such as interception, infiltration, evapotranspiration and run-off.
- Ecological functions: in general, through the creation of new plant communities and the recovery of the degraded ones.

All these fields of application demand strong and reliable engineering approaches based on a replicable knowledge of the way each plant, organism or complementary construction material behaves in each particular soil, geologic, climatic, biological and cultural context (Fernandes and Guiomar 2018). Presently it is no more acceptable to rely exclusively on the peer experience and the "feeling" of the planner or designer; instead, one must ensure that behind each project there is a reliable and multidisciplinary knowledge basis, as well as replicable calculations.

This is exactly the domain where increasing research efforts are being addressed worldwide during the last years, focusing on the structural and dynamic behaviour and the biotechnical characteristics of plants in general and on their root systems in particular (e.g. de Baets et al. 2008; Ali et al. 2017; Boldrin et al. 2017). Modelling and calculation, either in slope stabilization (e.g. Mao et al. 2014; Tardío and Mickovski 2015, 2016; González-Ollauri and Mickovski 2017) or riverbank protection (e.g. Woolsey et al. 2007; Bariteau et al. 2013), are also domains where intensive research is being conducted (Fernandes and Guiomar 2016). Developing and assessing the complementary action of inert materials and structures used in combination with plants in particular circumstances (e.g. von der Thannen et al. 2017; Sanyal 2017) are also a relevant domain with important implications in terms of the development of specific industrial solutions.

These research efforts led already to important results that change consolidated paradigms in fields such as the hydraulic behaviour of plants (e.g. Sutili et al. 2012; Weissteiner et al. 2015).

Nevertheless, recent scientific and technical advancements also point out the need for further innovative approaches to use vegetation as key tool to master natural processes such as the retention of surface run-off, the hydraulic regulation of water courses, the prevention of erosion and, more in general, the provision of the correspondent hydrologic and environmental services.

17.4 Recent Progress in Soil and Water Bioengineering. Some Examples in Urban and Suburban Contexts

As indicated, SWB in addition to the technical and landscape objective meets ecological goals of ecosystem regeneration.

SWB although well planned, from an ecological point of view:

- Allows the development of more stable plant communities belonging to the vegetation series typical for the site. When native species are used, the recovery processes leading to the most complex and mature communities are accelerated.
- Improves the water balance by increasing interception, soil water retention capacity, soil permeability and water consumption by the plants.
- Increases protection against emissions, wind and noise.
- Improves local microclimatic and edaphic patterns.

By means of all the above-mentioned actions, an integrated approach to improve and recover the ecosystem resilience is developed.

From this point of view, these techniques can be used both for the regeneration of degraded areas as well as for new construction approaches, replacing or in combination with traditional engineering techniques.

In order to illustrate the evolution and possibilities of bioengineering, five projects executed in the urban and peri-urban contexts of several European countries have been selected as examples highlighting the NBS character of the SWB interventions. These case studies also show interventions where a successful work service life evolution was achieved. In all presented cases, new ecosystem services were provided to the citizenship.

17.4.1 River Birse, Soyhières, Switzerland

Water bioengineering: River Birse, Soyhières, Switzerland
Project author: Bernard Lachat-BIOTEC
Year of execution: 1984

Fig. 17.1 Evolution of the work carried out on Byrse River: comparison of images from 1984 to 2007. (Photo credit: B. Lachat)

Technique used: organic and inorganic geotextiles and dormant cuttings, tree and shrub plantations

During the construction of a new highway passing through the town of Soyhières, the Birse River had to be diverted by building a new channel of about 850 m in length. In order to carry out the new channel design, a hydrological and hydraulic study was carried out, establishing the design flow values allowing the ecosystem recovery all along the channel and the riverbanks. In this case, although a traditional engineering solution was chosen, the use of an innovative construction system allowed the total recovery, over the years, of the riparian vegetation both in terms of quality and diversity (Fig. 17.1).

17.4.2 River Fella, Malborghetto, Udine, Italy

Water bioengineering: River Fella, Malborghetto, Udine, Italy
Project author: Giuliano Sauli
Year of execution: 1994
Techniques used: green walls, vegetated log cribwall, brush buttressing

Living material used in 1994: 14 different woody plant species were used in the SWB intervention, i.e. *Pinus mugo* Turra, *Pinus nigra* Arnold subsp. *austriaca* (Höss.) Novak, *Pinus sylvestris* L., *Fagus sylvatica* L., *Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Tilia platyphyllos* Scop., *Alnus incana* (L.) Moench, *Crataegus monogyna* Jacq., *Ligustrum vulgare* L., *Salix caprea* L., *Salix purpurea* L., *Salix eleagnos* Scop. and *Salix appendiculata* Vill.

Thanks to the high effectiveness of the intervention, 250 different plant species were recorded in a survey carried out from 2010 and 2011. These species could be referred to the following habitat types:

- Wetlands: 23.41%
- Sub-mesophilic forests: 8.29%
- Forest fringes: 7.80%
- Meadows: 18.05%
- Anthropogenic communities: 18.54%

As a compensatory measure to the construction of the Pontebbana railway line, the Fella River renaturalization in the immediate proximity of the new railway station was carried out. The elimination of the concrete channel, the fluvial space extension and the riverbank reconstruction with SWB techniques, chosen according to the hydrological and hydraulic conditions and the proximity of the railway, were included as essential actions. Along with the floristic and biodiversity improvement, there has also been a morphological and sedimentological improvement. Therefore, both the self-regulating natural hydrodynamic processes and the functioning of riverine ecosystems were reactivated (Fig. 17.2).

17.4.3 Artía Channel, Irun, Spain

Water bioengineering: Artía Channel, Irún, Spain
Project author: Basque Government
Year of execution: 2003–2004
Technique used: brush mattress, vegetated log cribwall, flat gabions, rhizome transplantation of halophyte species

Given that the Artía watercourse was completely channelized, the total lack of connection of the stream with the surrounding lands as well as the absence of natural hydrodynamic processes made necessary both the elimination of the concrete barriers and the reactivation of the river natural processes. Before the Artía channel construction, there was a natural creek called Ibarla. This stream had a very different development and dynamics since it flowed into the Bidasoa River a few hundred meters downstream from the point where it currently flows. Therefore, the problem to be solved with the SWB intervention was to recover the natural behaviour and dynamics of previous water flow (Fig. 17.3).

Fig. 17.2 Evolution of the work carried out on Fella River (Italy): comparison of images from 1994 to 2016. (Photo credit: G. Sauli)

The main lines of the intervention were:

- The demolition of concrete walls and floor (bed)
- The increase of the hydraulic capacity of riverbed by reshaping the slopes
- The renaturalization of Artía channel by increasing its sinuosity
- The protection of the riverbanks by means of SWB techniques
- The recovery of the riparian soils
- The connection with the local human community through a new recreational and walking area

17.4.4 Slope Stabilization, Mazères, France

Soil bioengineering: Hill stabilization in urban area, Mazères, France
Project author: Klaus Peklo
Year of execution: 2000
Technique used: vegetated log cribwall, brush and hedge layers

The main objective of this project was to guarantee the safety of an existing detachment next to a residential area. After a topographic and geotechnical study,

Fig. 17.3 Evolution of the work carried out on Artía Channel (Spain): comparison of images from 2002 to 2019 (i.e. after 17 years of service life). (Photo credit: P. Sangalli)

the protection of the fluvial slope toe was achieved by the use of a Krainer double log cribwalls. Besides, the slopes were stabilized with brush layers. The fluvial slope was 10 m high and 35 m long with a slope of 100%. The intervention allowed to recover and stabilize the slope and to create a good connection of the watercourse with the adjacent forest (Fig. 17.4). Originally, the civil engineering proposal for solving the problem included micropiling and a breakwater deflector installation at the slope base but without recovering the ecological connection with the adjacent forest area. One of the main challenges of the SWB intervention alternative was to convince the neighbourhood about the effectiveness and safety of this solution. Because of the lack of knowledge and familiarity of the local populations with SWB techniques, the idea of using plants to stabilize the landslide did not find a strong support at the beginning. Fortunately, after checking the performance and the effectiveness of the NBS actions, this situation changed as well as citizens' attitude.

17.4.5 Stabilization N1, Etxegarate, Guipúzcoa, Spain

Soil bioengineering: slope stabilization in the Road N1, Etxegarate, Guipúzcoa, Spain
Project author: Paola Sangalli, Paolo Cornelini SCIA SL

Fig. 17.4 Evolution of the work carried out at Mazères (France): comparison of images from 2000 to 2015. (Photo credit: K. Peklo)

Year of execution: 2010
Technique used: simple cribwalls, loricata walls, living drainage fascines, brush layers

After some extremely intense rain events, a landslide took place affecting a 13–20-m-wide and 40-m-long surface. This landslide was triggered by soil saturation and the consequent loss of soil cohesion. Due to local slope and soil characteristics, the likelihood for new mass wasting was rather high. The SWB intervention was proposed as an alternative to a traditional engineering proposal through micro-piling. Given the importance of the road whose slopes had to be stabilized, there was a strict and short time to complete this intervention. In spite of this, SWB was proved to be not only effective but also environment-friendly (Fig. 17.5).

17.5 Conclusions

Soil and water bioengineering is a discipline that allows the regeneration and restoration of ecosystems, whilst offering a new way of building with a sound environmental-sensitive approach. SWB is an effective NBS, an effective tool for

Fig. 17.5 Evolution of the work carried out on Road N1 (Guipúzcoa, Spain): comparison of images from 2011 to 2013. (Photo credit: P. Sangalli and P. Cornelini)

implementing green infrastructure, and besides, it is able to offer a large amount of direct employment opportunities during both project and construction phases.

The effectiveness in the implementation of green infrastructure plans and projects improves the ecological functioning of natural systems and provides essential ecosystem services. The success of interventions strongly depends on having a sound technical and scientific knowledge as well as on social and political commitment. It is, therefore, necessary to highlight the need for adopting legitimate design approaches involving citizen participation and engaging local populations in the maintenance and conservation of the restored or improved areas.

In recent years, SWB has been shown to be an effective and advantageous proposal replacing or complementing traditional engineering in many different situations. In order to move towards their support, an increasingly effective implementation of SWB techniques is necessary to overcome the distrust from citizenship and practitioners. This situation requires further research in the design methodologies providing a quick assessment for the validity of the bioengineering solutions and their dynamic response. In this process, the knowledge of the behaviour of utilized living material and its biotechnical capabilities is essential.

The potential of SBW and NBSs provides very powerful tools, synergies and opportunities for the development, generation and implementation of green infrastructure strategies and actions in natural, rural and urban environments.

Acknowledgements The authors expressly thank Klaus Peklo, Giuliano Sauli (in memoriam), Bernard Lachat and Paolo Cornelini for the information and the images provided to illustrate this chapter.

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Chapter 18
Guided by Water: Green Infrastructure Planning and Design Adapted to Climate Change

Camila Gomes Sant'Anna, Ian Mell, and Luciana Bongiovanni Martins Schenk

Abstract Green infrastructure (GI) has made important contributions to the process of landscape planning, helping to embed ecosystem services and biodiversity thinking into land use and urban design. The inclusion and adoption of water-sensitive green structures have been a starting point for many planners and landscape architects in this process. Traditionally the promotion of sustainable water management in urban planning has taken the form of catchment approaches. Landscape architects, though, argue that water is the best indicator of natural processes because it is a transboundary element that integrates different environmental and sociocultural values simultaneously and is related to decision-making in most urban areas. However, place-based strategies do not always succeed in mapping, promoting and protecting the ecosystem service of green and blue spaces, and can fail to respond to contemporary climate adaptation pressures. This chapter identifies the main methodological approaches used in the planning and of designing green infrastructure strategies. Water issues are presented as a proxy evaluating how design valorises ecosystem services and connects ecological resources with other urban infrastructures to promote resilience. Based on the analysis of a series of city and site examples from the UK, we identify the methodological approaches used in planning and designing multiscale GI strategies that guarantee the delivery of climate adapted landscapes.

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_18

Keywords Green infrastructure · Water landscape · Planning · Project · England

18.1 Introduction

Within their 2019 special report, the Intergovernmental Panel on Climate Change (IPCC) argues the importance of seeking, however difficult it may be, to limit global warming to 1.5 °C to minimize the effects of climate change (IPCC 2019). Climate change has significant effects on ecological and socio-economic life and will be exacerbated by the growing urban population predicted to be approximately 70% of global population by 2030. However, with population growth comes a corresponding increase in instances of urban heat islands (UHI), low hydrological performance, and ecological degradation. The impacts of which on natural and social processes include landscape fragmenting and raise questions regarding what the best use of the landscape in its widest sense is to promote quality of life of its inhabitants (Grundmann 2016).

Experience from across the world highlights the increasing breadth of evidence of global climate change and our reactions to it. Within these debates, water resources are considered one of the most impacted upon natural elements, as changes in water cycles and increased climatic variation change the frequency and severity of floods and drought; rising sea levels have also been reported. This is amplified due to the lack of attention given to the role of water in the definition of the landscape of cities, which:

> […] has substantial impacts on the availability and quality of water within the internal and external limits of cities, including overexploitation of water resources, lower water safety, the greater possibility of floods and impacts on health related to water. (Giner 2013: 153)

Hydrological cycles are, however, important elements in the construction of the landscape, and according to McHarg (1964: 8–9) "water, as the agent of erosion and sedimentation, is causal to geological evolution, the realities of physiography". McHarg's *pioneer theory* and practice on design with nature developed an integrated and multiscale strategy for landscape planning and strategy, based on water and its social, ecological, and economic contributions to the built environment.

Nowadays we face the challenge of rethinking McHarg's theory and practice to support a contemporary landscape planning and practice. Locating water as a starting point for the renaturing of cities places green infrastructure (GI) in a central position not only for the construction of sustainable cities but can also go promote the quality of life for an urban population in the face of climate change (Andreucci 2017; Firehock 2012; Mell 2010; Benedict and McMahon 2006; McHarg 1971).

Green infrastructure is a contemporary, holistic, and multidisciplinary approach to landscape planning, design, and management (Mell 2016; Rouse and Bunster-Ossa 2013; Firehock 2010; Ahern 2007), which integrates sociocultural interests with assessments of natural and economic factors. From this fundamental articulation, green infrastructure utilizes the ecological network concept popularized by

McHarg, which is characterized by green and blue systems and composed of links, nodes or sites, and hubs, in an ongoing dialogue with grey infrastructure and its supporters.

Within this chapter, we draw on recent research reflecting on the methodological strategies for the planning and design of the landscape utilizing green infrastructure drawing on examples of water-centric case studies from the UK. This is supported by a novel policy/practice framework that provides valuable and transferable learning for planners, designers, and managers to aid their promotion of multifunctional and sustainable landscape planning that is adaptive to climatic as well as demographic and economic change.

18.2 Building Green Infrastructure and Design with Water

The contribution of water, and networks of water resources, in green infrastructure thinking emerged as a paradigm reversing the direction of traditional planning. By contemplating water from an integrated perspective, and not through the separation of different parts of an urban area, such as housing, in a strict sense (Sant'Anna 2020), green infrastructure planning concentrates on the system and its relationships with housing, infrastructure, production, and social networks. This contemporary approach places its emphasis on their ecological and cultural value, as part of the design and functionality of how the landscape works.

Water or *blue infrastructure* networks could be considered as the primary resource integrating landscape into planning, as planning for water affects and is affected by most other sectors of physical urban development, including land use, transportation, infrastructure, open space, waste processing, and energy generation and transmission (Ahern 2010: 137). Green infrastructure practice can therefore be framed from a water network perspective, which is associated, when not substituting other grey infrastructures (obsolete or not), guiding and articulating itself with the plans that aim to deliver social production of a territory, notably those related to housing and mobility (Sant'Anna 2020). This strategy of association between infrastructures is being used to guide new thinking of landscape planning and adopt design principles to reflect more directly on climate change.

However, it is not just a question of creating technical answers to ecological and social infrastructure demands but also one that requires an engagement with the values of art and culture of a given location, which are capable of guaranteeing social inclusion, promoting quality of life and the right to landscape.

18.3 Planning and Designing Green Infrastructure Strategies: Key Methodological Approaches

Starting from the analysis of the watershed, the strategies for planning and designing the landscape from a green infrastructure perspective are organized in the following but not necessarily linear steps: *scoping*, *mapping*, *construction of possible scenarios*, *synthesis of the proposal*, *implementation*, and *monitoring* (Fig. 18.1).

This methodological process introduces the importance of aligning technical, political, and practice-based thinking together with the ecological and sociocultural perspective proposed in the development of green infrastructure strategies and the possible outcomes or products of this new way of planning and designing with the landscape at a number of scales (Sant'Anna 2020). From a reading of green infrastructure elements and its conditions to evaluate the strategies proposed, water is considered from the watershed plan to sustainable drainage system. Figure 18.1 outlines this process in more detail.

The scoping stage: in this stage, the relevant existing material is collected and organized, serving as the basis for the study. Its methodological steps are developed through a mapping of the multifunctional characteristics of the territory, having the regional watershed plan as a starting point, an action that is elaborated in an interdisciplinary way, considering the natural and human processes present. User participation and perceptions are very important in this process.

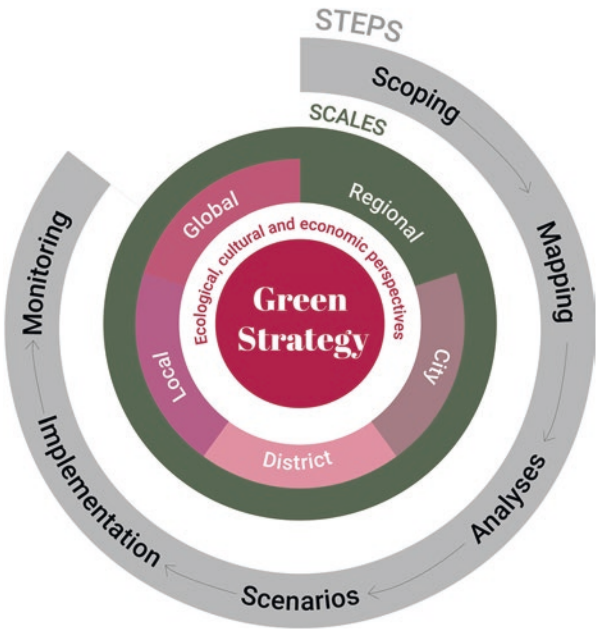

Fig. 18.1 The steps of the methodological process from the global to the local scale. (Credit: Camila Gomes Sant' Anna, designed by Bárbara Gomes)

In the mapping stage, thematic readings are carried out with the production of complementary cartographies and other forms of representation (sections, visuals, and models), which would assist in the construction of an approach discussing the multiple scales of a territory and that is also interdisciplinary. Thematic readings define the current condition of the multifunctional values of the territory's landscape infrastructure in view of the objectives established by the landscape planning and design stakeholders, taking into account the potential for integration. These mappings incorporate local issues (challenges, risks, and needs) raised with the participation of the community.

Building possible scenarios stage, is used to identify adaptive solutions to climate changes, as well as other established goals and/or opportunities for GI. This results in an overlaying of opportunity maps, necessities and challenges of existing green infrastructure and its multifunctional performance (urban form and functionality), and the integration with existing infrastructures.

These analyses are built from the technical and cultural repertoires of the researchers involved, by overlapping the thematic readings giving rise to the synergistic readings, composed of cartographies, complemented with other forms of representation, photographs, drawings, and filming, covering the territory multiscale and discussed with the community and the main actors.

The visions then begin to be translated into drawings in order to structure the proposal development process, having water courses as guiding elements. Drawing, as a representation of a possible scenario, is considered a fundamental tool, because it allows users to simulate the proposed place experience; otherwise, the inclusion of the population in the process is compromised.

These stages are followed by activities to raise public awareness and involve stakeholders through public consultations; technical teams (architects, engineers, biologists, planners, geographers, and land management specialists) define the green infrastructure proposals that could be adopted at different scales of the territory and consider their implementation in the short, medium, and long term).

It is not just about zoning but finding land use and occupation that allows the best sociocultural and ecological performance of a space or suite of spaces. Technical teams define and plan the actions and strategies for the promotion and protection of ecosystem services and the integration with the built infrastructure, utilizing green infrastructure as a base for their consideration.

In the implementation stage, the ideas are translated in the form of both plans (milestones, goals, and planning programmes) and executive and public policy projects, within the constellation of views that builds the proposal. The aim is to structure its implementation from the regional scale to the local context, taking into account their interrelationships and reflecting on their influence on the global scale.

In the monitoring stage, assessments of the performance of a green infrastructure plan (or set of plans) and designs are made and the *Green Landscape Infrastructure Observatory* is created, where the performance of natural and human processes and the relationship between the different urban infrastructures at different scales and deadlines are comprehensively analysed, with the help of the technical staff and the population.

The majority of these steps are visible globally in green infrastructure practice; however, they are most frequently used to structure investment in North America and the UK. Within the later location scoping, scenario building, consultation, and subsequent action are aligned with the policy structures of the country and have been used to support investment in green infrastructure for over a decade (Mell 2016).

A number of British practitioners have incorporated green infrastructure as a way of updating local plans and to support landscape-focused projects in face of the contemporary urgencies, i.e. climate change and extensive flooding. As a consequence, they are considered as best-practice examples of the successful translation of policy into practice, being guided by sustainable planning for water. The main premise underpinning this analysis is to better understand how the methodological discussions of planning and landscape design utilizing green infrastructure were incorporated and to appreciate which of these values have been consolidated in the UK (and potentially at a wider European scale) using an analysis of the experiences of the planning of sociocultural and ecological networks in Greater London.

18.4 Landscape Planning and Design with Green Infrastructure: The City-Region National Park of London

If you were to look down at London from the stratosphere, you would be struck by how green it is, with a plethora of green and open spaces, formal and informal, large and small, helping to define and shape the form of the city. Down here on the ground, we look to these spaces for all that they add to the quality of the particular places we live in, work in or visit. What we aim to do is look at them in a joined-up way, making sure the contribution they make to the quality of life, to the environment and to the economy are maximized. The term "green infrastructure" may sound odd, but given the scale and range of benefits these spaces give our city and its neighbourhoods, it is vital we see them as being as integral to the capital's metabolism as its roads, rail lines and water pipes. (Greater London Authority 2015: 4)

The debate on landscape planning and design for the city-region of London was historically opened by the proposals situated within the Greater London Plan of 1944, coordinated by Sir Patrick Abercrombie (1879–1957) with contributions from John Henry Forshaw (1895–1973). Since that time, the plan has been updated and deepened in order to both predict and respond to the expansion of the city, preserving and promoting its system of open spaces, especially its rich set of preserved green areas since the nineteenth century, based on water (Fig. 18.2).

From 2010 onwards, the guidelines for the *smart* development of the territory (smart cities) have turned to the promotion of London as the first city to brand itself the first *national park city* in the world (Greater London Authority 2015). In 2012, the planning and design of the landscape of London engaged in the promotion of strategies that utilized green infrastructure (which represents 47% of its territory),

Fig. 18.2 London system of open spaces and water bodies. (Credit: Mateus Rosada)

to frame urban infrastructure from a *greener* perspective helping to shape the development of London's expansion and its supply of housing, work, and mobility, as is clear in the following excerpt:

> […] the network of green spaces (as well as features such as street trees and green roofs) that is planned, designed and managed to deliver a range of benefits, including: healthy living; mitigating flooding; improving air and water quality; cooling the urban environment; encouraging walking and cycling; and enhancing biodiversity and ecological resilience. (Greater London Authority 2015, p. 2)

Within this context, the methodological strategy entitled the *All London Green Grid* (ALGG) was defined, which, through a reading of the physical, economic, and sociocultural layers that build the spatial form of London, aims to define and articulate green and blue system as key pieces for its development, summarized in a synthetic way:

London's existing river and other key landscape corridors, including the Thames; established open spaces and identified opportunities for creating new parks, such as the Wandle Valley Regional Park; existing and proposed green connections and corridors, such as the proposed London Riverside Link; and, the designated and protected landscapes that are generally located at the boundary of London and flow across administrative boundaries to neighbouring areas and often include areas of degraded urban fringe (Mayor of London 2012, p. 12).

In response to this and with the use of GIS systems, the GLA created thematic maps that identified the multiple layers of the landscape – the existing free spaces – and aligned this analysis with the scaled approach to green infrastructure at the regional, metropolitan, neighbourhood, and site scale. Therefore, mapping deficiencies in water resources result in updated material to support the Green Grid synthesis map. The GLA also mapped access to nature, ecological zones, different connections, productive landscape areas, green belt and urban fringe areas, as well as the area of operation along the River Thames.

As a result, the strategy supports the delivery of a sociocultural and ecological network, characterized by multifunctional green and open spaces, as London aims to house an additional 1.2 million inhabitants by 2031 and adapt the city to the urgencies of climate change. We can also observe the protagonist role of London's water network in the definition of the main corridors and connections in the plan, visualised via blue schematic arrows.

The methodological steps undertaken by the GLA and Mayor of London's Office were provided in the 11 strategic areas of defined green infrastructure networks. Named *Green Grid Areas* (GGAs), their objective was to promote greater alignment between their urban policy, planning and design, and the expansion of six areas established by the East London Green Grid (ELGG) of 2006 to connect the Thames with the main areas of work and housing.

For each area, the objective is to deepen contact with multiscalarity, identifying potentialities and weaknesses and defining how established strategies can be translated into urban design. To better understand these methodological steps, which were established at a regional scale, we will analyse area 09, i.e. the Arcadian Thames, as an example. This area was chosen as it presents an opportunity to understand multiscalarity of green infrastructure, that is, how the same approach defined at the regional level is subsequently developed in local terms via project implementation. The first is consolidated as an area of great urban development of state of the art planning, while the second emerges as an area of great importance – protection and patrimonial valorization. However, both aim to promote the integration of urban/rural areas of Greater London.

18.5 The Arcadian Thames: Landscape and Water

The Arcadian Thames region has significant historical importance for the city, as it concentrates cultural assets such as gardens and historical game parks, the most visited being those of Royal Gardens (Kew) and Hampton Court. The existing landscape architecture was influenced by the eighteenth-century English Landscape Architecture movement, which has as its exponents Alexander Pope (1688–1744), Lancelot Brown known as *Capability* Brown (1716–1783), Horace Walpole (1717–1797), and J.W.M. Turner (1775–1851). A striking feature is the archaism that was constructed from visuals in which the territory as a whole was seized and through its parts, which referred to bucolic, pastoral themes and the appeal to the elements of nature. This strand was greatly influenced by artists such as Nicholas Poussin (1594–1665), Claude Lorrain (1600–1682), and William Turner

(1775–1851). Thus, a great challenge for any proposal in this area was to intervene in a landscape that had a historical significance and in an area of world heritage value, i.e. the listed areas of Richmond that was inspiration for Turner's paintings.

In addition to this artistic interpretation of the landscape, the area is one of London's few productive landscapes with an important river system, characterized by the presence of the River Thames, which connects to the Hogsmill, Grand Union Canal, and River Crane, establishing a physical and visual relationship between the historical buildings and their banks.

The deepening of the layered reading of the All London Green Grid, a study that developed 11 of the Green Grid Areas, subdivided the study area into 3 subareas according to the physiographic characteristics of the London landscape structure defined by Natural England in 2009:

> The above landscape character zones are interlinked by a network of linear ecological corridors alongside the River Thames and its tributaries as well as a patchwork of parklands and commons, and the network of historical avenues. (Mayor of London 2012: 10)

Concerning these studies, the Mayor of London's Office based its analysis of the watershed on the following themes, which were considered to be problematic in the area: (i) the accessibility to open spaces; (ii) the management of events related to climate change (floods and drainage); (iii) the deficiency of open spaces at the local, neighbourhood, metropolitan, and regional level; (iv) the access to nature and areas of ecological importance; and (v) the anthropized landscape associated with connection and mobility facilities.

The subsequent analysis used thematic-mapping followed by the construction of synthesis maps (made up of overlapping images) to identify potential clusters in order to insert an economic dimension into the area's proposals. Another aspect that emerges from the synthesis map is the definition of the main historical landmarks, since the area contains a set of important landscape visuals associated with buildings, many of them classified as listed England heritage official documents or World Heritage Site.

This analysis leads to the proposition of strategic axes of development in the localities of (1) banks of the River Thames and its tributaries, (2) leisure areas on the banks of the River Thames, (3) Hogsmill River Valley, and (4) Brook River Valley. In these areas the strategy would be to intervene with actions such as (i) fostering biodiversity and developing nature-based solutions (NBS) and the connection between pedestrian flows, (ii) promoting the connection of pedestrian flow and river crossings, (iii) integration of the urban landscape with the landscape of the surrounding territory, (iv) valorization of the cultural landscape characteristics of the Arcadian Thames, (v) creation of sports centres of excellence, and (vi) the promotion of the productive landscape.

Concerning green infrastructure solutions, interventions are connected by the waterbodies and set up in different orders: cross-sectional strategic green corridors, strategic green connections, green trails and bicycle paths, and the relationship with the different types of parks and open spaces. In the proposal, all the in-depth strategic axes related to the proposed green infrastructure network are defined with its numbered open space projects and green connection elements.

One of these projects is in the second subarea of the Arcadian Thames and is one of London's most visited gardens, the Royal Botanical Gardens, known as Riverside Gardens – Royal Botanic Gardens Kew. The main goal of Kew Gardens' green infrastructure strategy is to valorise the multifunctional green infrastructure relation with the river system. One of the strategy's actions is to adapt the flooding area to climate change impact.

18.6 The Landscape of the Royal Botanic Gardens

Declared a World Heritage Site in 2004, the Royal Botanic Gardens boasts one of the largest and most diverse collections of living plants in the UK. The creation of the botanical garden in 1840 had already been considered in its area of the viewshed, which was recognized by UNESCO in 1995.

The methodological strategy of the project started from an understanding of the area today and its relationship with the river system, especially the buffer of protection of areas of environmental interest. The analysis of the area was carried out in layers from historical perspectives and included an analysis of the evolution of landscape design since the creation of the botanical garden. The main buildings and their historical framework were also identified.

An analysis of the watershed was also performed in order to identify the characteristics of the blue infrastructure system, in particular periodic floods area, and the landscape units in the area: (1) entrance area, (2) river zone, (3) northeast zone, (4) Palm House area, (5) visual axis zone of Pagoda, (6) southwest zone, (7) Syon view area, and (8) west zone.

These analyses were complemented by the survey of plant species (the first such process since the last cataloguing in 2010) and the main visual axes present in the park. All these analyses were overlaid and gave rise to a project with three strategic areas:

- The area of the River Thames frontage rethinks the relationship between the area and the Thames proposing a flood mitigation structure with nature-based solutions of infiltration and storage.
- In the Victoria Gateway area, the design of the botanical garden stands as a landmark change. Located at the main entrance of the garden, its goal is to connect with the main transports, with the new reception centre for people and plants, presenting a new circuit of sponge gardens.
- The Breathing Planet Walk area is a circuit of gardens with meadows, forests, lakes, valleys, and floodplains with plants of different biomes. It connects with the new X-Strada Tree Top Walking, Sackler Crossing, and Lost World Display projects with Riverside Wetland, Habitat Gardens, and Polar House.

The proposal includes wetland construction, initiatives for rainwater gathering, and the promotion of ecological resilience through the use of sustainable drainage solutions (SUDS). It is important to remark that the quality of representations brought to the public is of a high quality, thus supporting a more refined approach to consultation that helped to consolidate the project's proposals and approach in practice.

18.7 Conclusion: Implications for the Landscape Planning and Design

The construction of a landscape planning and design process with green infrastructure, utilizing a water perspective, is essential to protect and promote existing ecosystem services and biodiversity, seeking to foster a balance between humans (and their actions) and nature to ensure that sociocultural needs are met in the face of climatic emergencies.

When reviewing these practices, when or if green infrastructure is thought of as a fundamental part of urban infrastructure, we can articulate the different dimensions of investment and management, i.e. economic, cultural, social, ecological, and aesthetic, that correspond to our understanding of the landscape of cities more effectively. From this perspective, green infrastructure has a strategic position in building sustainable urbanization, including improvement to risk management and the promotion of resilience to climate change. However, its contributions overpass these actions, promoting gains of various orders related to the landscape for which it is planned and projected in the expansion of biodiversity, in public health and in the aesthetic quality of cultural experiences of the territories.

The contemporary reduction of the productive landscapes and the understanding of rural areas as places of food production also need to be reconsidered in these discussions. In addition, London's green infrastructure has been framed by the introduction and retention of the Metropolitan Green Belt as a form of landscape protection from the 1930s onwards. Even though Green Belts are not located in all English cities, they hold an important place in how water and green infrastructure strategies are developed. The strategies developed in London have been structured to incorporate the green corridors that accompany the bodies of water, within a planned and projected network, establishing layers with constitutive dimensions of the landscape, uniting agrarian zones of high ecological value and historical and artistic significance.

Within these discussions, water emerges as an element that will guide the development of strategies, assisting in responding to contemporary emergencies, such as climate change, and guaranteeing the right of a climate adapted landscape.

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Chapter 19
Abandoned Lands on Lower Danube's Urban Front as Opportunity to Enhance the River Corridor and the Urban Green Infrastructure

Angelica-Ionela Stan and Mihaela Hărmănescu

Abstract In the logic of the forced industrial growth, followed by the 1990s' decline, small and medium-sized cities located on the banks of the Lower Danube, in Romania, Bulgaria, and Serbia, now have the chance to redefine their spatial and social identity within the Danube corridor, capitalizing on the former/abandoned industrial lands. Changes of economic profile and political environment have brought to these cities serious socio-demographic phenomena of shrinking and decline. Paradoxically, the natural values related to the presence of the Danube – the waterfront vegetation, oysters, lakes, islands, and beaches – together with the ruins of the former industries re-covered by the vegetation, are spatial elements that outline the premises of a *green redefinition* of the entire Danube's corridor. In order to improve the spatial development discrepancies, existing along Danube between the recognizable *civilized* west segment and the *wild* south-east, it is necessary to drive attention to cities and villages on Lower Danube that can be harmonized in a coherent and diverse system, planned for a sustainable development. This chapter explores the ways in which the landscape values of the Lower Danube small and medium-sized cities can be used for improving the river green and blue infrastructure and its ecosystem services.

Keywords Lower Danube · Blue infrastructure · Urban landscape · Small and medium-sized cities · Abandoned urban land

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_19

19.1 Introduction

In many cities on the Lower Danube, in countries as Romania, Bulgaria, and Serbia, the forced industrialization of the communist years, followed by the decline of these industries after 1990, has decisively marked the urban space and landscape, leaving visible large abandoned areas. These places, mainly located on the riverbank, are an ignored resource for the local development, and they have the chance to reactivate through a complex, systemic capitalization of green infrastructure. Although the small and medium-sizes cities (or towns) are considered to play an important role in Europe's polycentric urban structure, preserving the uniqueness of urban life (Servillo et al. 2017) and with an important role in tourism, these places have largely been ignored by academic research and policymakers at national, regional, and European level.

The change of economic profile has brought serious socio-demographic phenomena of shrinking – population decline, ageing, unemployment, and the general decrease of the living standard in these cities. Despite that these abandoned lands have been intimate part of the cities' evolution, now, their presence is almost neglected, and they are not seen as part of the local development. Waterfront vegetation, oysters, lakes, islands, and beaches, together with the ruins of the former industries or harbour zones, partially or entirely re-covered by the vegetation, are spatial elements that outline the premises of a possible (re)definition of a real urban green infrastructure (UGI), providing important connections between communities and nature and numerous ecosystem services, contributing to improvement in mental health and socialization, and helping cities to increase their resilience to climate change, improving their attractiveness by offering a cleaner and healthier environment (de Sousa Silva et al. 2018). The small and medium-sized cities have now the chance to affirm themselves as part of the green infrastructure of Danube's corridor, in order to improve the discrepancies between the recognizable *civilized* west segment (from the spring to Vukovar, in Croatia) and the *wild* south-east (from Vukovar to Danube Delta), parts of the same river.

This book chapter approaches the problems of abandoned urban lands existing in different positions relative to Lower Danube cities' structure: inside it, at the limit/periphery, or outside the city. Considering important to verify the axiom of *thinking big about thinking small*, we tried to figure out the macro-landscape scale of the Danube through the micro-landscape of small and medium-sized cities situated there. The objective was to help in eliminating the "invisibility" of small and medium-sized cities and affirm them as important elements of Danube's landscape development, driving the attention not only to the extraordinary natural Danube's sceneries but also to urban-scale problems and potential. The aim of this chapter is, thus, to show a methodological typology of abandoned lands located in these cities, in order to capitalize on their landscape, helping to shape the systemic coherence necessary for a green urban infrastructure on the scale of the Lower Danube.

19.2 Context and Premises

The context of economic development of South and Lower Danube segment cannot bypass an important historical issue, known as *the dispute Saligny* vs. *Antipa*, two different conceptual models for the use of the Danube floodplain. The first mode was proposed, in 1910, by the polymath biologist and ecologist Grigore Antipa in favour of preserving the natural flood regime and floodplain features to develop fish farms and animal husbandry (Constantinescu et al. 2015), thus protecting the initial Danube's landscape. During the same period, at the proposal of Romanian Ministry of Agriculture and Domains, the famous engineer Anghel Saligny was appointed, in 1910, as General Director of the first Land Improvement Service in Romania, with the mission of valorizing the large lands in the Danube floodplain and flood protection of adjacent areas. In the period that followed (1910–1913), there were numerous discussions between the representatives of the two models: one of non-submersible damming, proposed by Anghel Saligny, and the other one of submersible damming, supported by Grigore Antipa.

Due to personal prestige and technical-scientific arguments of Saligny, his point of view prevailed. The Balkan War of 1912–1913 and the European War of 1914–1918 did not allowed the State to be able to make the necessary loans to start the works, so that Anghel Saligny could not see his efforts fulfilled. The project has been implemented after 1960, by the communist regime creating the Lower Danube landscape as we can see now. The Saligny's model was implemented through extensive embankments and drainage works along lower Danube (Bondar 2008), and as a result, over the next two decades, the natural hydrologic and geomorphic regime was largely changed. Despite their economic benefits, embankments along the river resulted in a narrowing of the channel bed with a direct impact on the hydrologic regime. After 1990, most of the floodplain returned to private ownership, renewing the debate of how to develop the Danube floodplain and which type of landscape it might support. The conservative model promoted the ongoing agricultural activities, taking in consideration the structural switch of passing from centralized and intensive agriculture, typical to communist era, to one decentralized and dispersed, much less intensive, after 1990. The alternative ecological model advocates a return to the natural hydro-geomorphic regime through the removal of engineering structures (Constantinescu et al. 2015).

In the range of negative effects that have resulted from the application of the Saligny's model, collateral effects are added for the existing settlements in this area, as part of the same vision. The identity and development of the small and medium-sized cities of this region were altered in the name of the socialist economy. Their natural relationship with Danube was truncated: politically, ideologically and socially, and also physically, by occupying and destroying the land and the landscapes situated on the river shores. After 1990, these industrial activities ceased, and discussion on how to develop this part of Danube could be resumed this time from the premises of sustainability and more ethical development.

In 1967, Lászlóffy sectioned the Danube River into four general units (Upper, Middle, and Lower Danube and the Danube Delta) based on geomorphological and hydrological features (Lászlóffy 1967). The Lower Danube section stretches over 885 river kilometres from the point where the Danube breaks through the Carpathian mountains and passes through the Walachia lowlands. Its major tributaries in that section include the Siret and the Prut rivers. The last section is represented by the arms of the Danube Delta. An important division of Danube have been done in 1986, as a result of regional cooperation between the Danube countries. The Danube basin was divided into the three major sections, and the Lower Danube section is defined by the Romanian and Bulgarian lowlands including the catchments of the Prut and Siret rivers and their surrounding mountains (ICPDR 2010).

Another relevant aspect is the actual tendency of restudying the river restoration preconditions in terms of ecological functions, considering Danube as a dynamic system, formed by the natural characteristics of the drainage basin-like climate, geology, tectonic, vegetation, and land use.

> The geometric features of the river channel, e.g. longitudinal and cross sections, and the substrate in the river channel are depending on the conditions in the watershed area. River and floodplain are a unit (Binder 2008:7).

River restoration projects along the Danube are mostly designed and implemented locally. Usually, national river engineering administrations constitute the highest level of planning. Moreover, cultural diversity and political and language barriers hinder the exchange of experiences regarding the design and implementation of river restoration strategies (DDNRI 2010). We can mention here the notable river restoration projects, as the Integrated River Engineering Project for the free-flowing Danube in the Austrian Alluvial Zone National Park, within the 50 km stretch from Vienna to Bratislava (Alluvial Zone National Park), aiming to (Reckendorfer et al. 2005) (1) stop river-bed degradation, (2) improve navigation and (3) fluvial dynamics within the inshore zones, (4) enhance the lateral connectivity between the river and its floodplain, and (5) reduce high water levels at flood periods.

19.3 Methodology and Tools

This chapter transversally addresses a hidden issue contained in several fields: a) in those related to polycentricity in current urban and territorial planning theories and of the importance that small and medium-sized cities/towns have in shaping the necessary spatial and functional balance; b) in the literature of the UGI and ecosystem services needed to be rebuilt in post-industrial cities and regions, such as the Danube; and c) in the Danube's harmonious and equitable regional development between the Western and Lower Danube. For achieving all these points, the methodology we present in this book chapter aimed at delimiting the following aspects:

1. Defining and characterizing the small and medium-sized cities (SMSCs) situated on Lower Danube in the European context.
2. Identifying the potential of abandoned urban lands (AULs) found in above-described SMSCs.
3. Revealing a spatial typology of AUL related to the potential of building a local UGI.
4. Revealing the connectivity of the local UGI based on the AUL development, to a coherent GI at the level of Danube corridor.

The tools used were mainly the empirical observations, tools like the open street maps, the literature associated with the central topics of the research, as well as the results of recent or ongoing European projects, such as DANUrB, *a regional network building through tourism and education to strengthen the Danube cultural identity and solidarity* (2017–2019); DANUBEPARKSCONNECTED, *Bridging the Danube Protected Areas towards a Danube Habitat Corridor* (2017–2019); and DANUBIAN_SMCS, *Creative Danube: innovative teaching for inclusive development in small and medium-sized Danubian cities* (2019–2022).

According to the DANUrB Strategy (Interreg Danube 2017a), the green infrastructure of the whole Danube Corridor – including the area under investigation – needs to be treated in a unitary way, especially considering its cross-system connectivity (Interreg Danube 2017a).

The proposed methodology details the method developed by DANUBEPARKSCONNECTED and adopts several standard criterions of revitalization for Danube river, such as (a) Danube river's restoration and rehabilitation through lateral connectivity, (b) Danube river's restoration and rehabilitation through longitudinal continuity, (c) capture community opportunities, and d) create value. Our work details on points (c) and (d) of these criteria through which it identifies and highlights the urban potential of the abandoned lands, for the restoration and sustainable development of the Danube landscape and creation of an appropriate green infrastructure (Box 19.1).

Box 19.1 Selected EU projects on the Danube region and/or related to the SMCs

1. DANUrB – a regional network for tourism and education aiming to strengthen the Danube cultural identity and solidarity (2017–2019) by INTERREG.
2. DANUBEPARKSCONNECTED – Bridging the Danube Protected Areas towards a Danube Habitat Corridor (2017–2019) by INTERREG.
3. ESPON-TOWN – Small and Medium-Sized Towns (2012–2014) by ESPON.
4. DANUBIAN_SMCS – Creative Danube: innovative teaching for inclusive development in small and medium-sized Danubian cities (2019–2022) by ERASMUS+.

19.4 Defining and Characterizing the Lower Danube Small and Medium-Sized Cities

19.4.1 European Territorial Framework of SMSCs

As regard the European cohesion policy, SMSCs are important units playing the role of mediators: between the centres and the peripheries, between the urban and the rural, and between the local and the global. At the local level, important aspects are highlighted: the territorial position, densities, and accessibility of SMSCs (Selada et al. 2012). In the EU, a large proportion of the population lives in small and medium-sized urban centres: approximately 40% live in small urban areas (from 10,000 to 50,000 inhabitants) and 20% in medium-sized cities (between 50,000 and 250,000 inhabitants). In the European spatial system, there are nearly 1000 urban centres with above 50,000 inhabitants and about 5000 towns that have between 5000 and 50,000 inhabitants (EEA 2006).

Despite everyone having a feeling of what constitutes (small and medium-sized) towns in terms of their physical characteristics, spatial identity, daily routines, and lifestyle:

> the term does not immediately constitute a coherent category or object of study, as it covers a diversity of situations across Europe (Servillo et al. 2017:12).

According to the ESPON-TOWN applied research project (2013–2014), small and medium-sized towns (SMSTs) in their functional territorial context are considered places with populations between 5000 and 50,000 inhabitants across Europe (DG Regio) with a density of population between 300 and 1500 inhabitants/sq.km) (Servillo et al. 2014). The conclusion of ESPON-TOWN project covering 31 case studies across Europe (Fig. 19.1) is that industrial activities are declining in SMSTs due to international competition, delocalization, and concentration toward main urban areas, and this constitutes a major potential threat for many SMSTs (Servillo et al. 2014).

At the same time, other studies conducted in Europe by ECOVAST (2013) have discovered that at national level, the upper size limit defining *small towns* is not uniform. Their survey study received 12 different answers from the 22 European countries, and the majority of responses were that the average size for the upper limit is 25,000 inhabitants but 3 countries, e.g. Austria, suggested that 50,000 inhabitants are the upper limit for a small town. However, the two aspects of SMSCs – function and size – defined them along with their distinctiveness and contribution to local development. The SMSCs' identity has developed due to production capacities located on Danube, such as fishing ports, naval ports, and transport industrial equipment, activities that attracted labour and population growth.

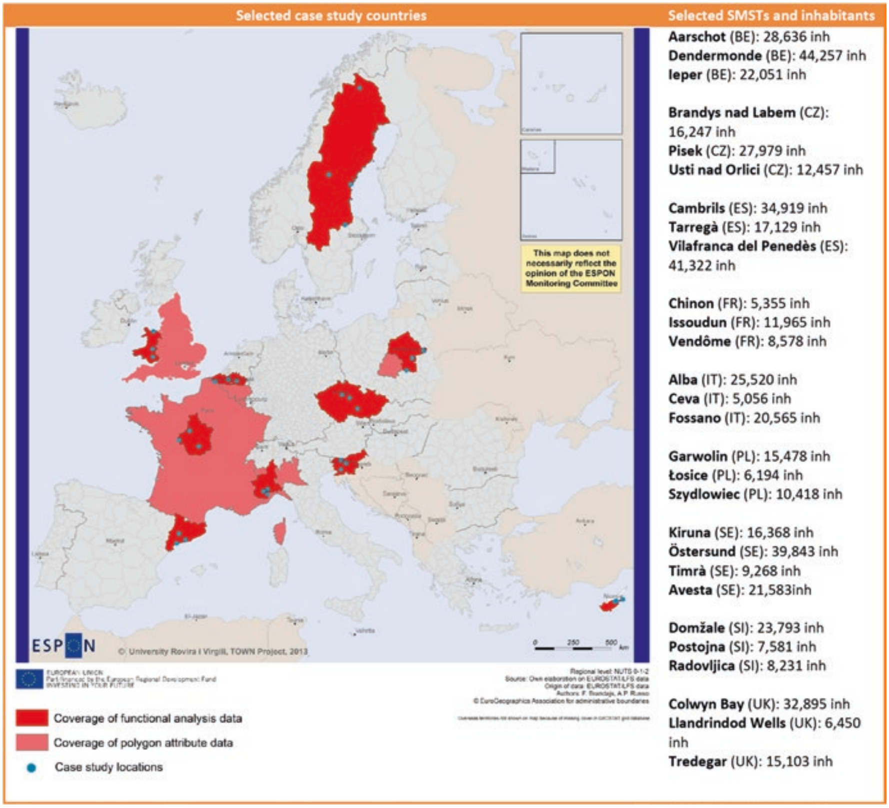

Fig. 19.1 Case study countries and SMSTs covered by ESPON- TOWN. (Source: https://www.espon.eu/programme/projects/espon-2013/applied-research/town-%E2%80%93-small-and-medium-sized-towns, accessed on 8 December 2019)

19.4.2 Identification and Analysis of the Lower Danube's Small and Medium-Sized Cities

Taking in consideration the current studies at European level; the current various academic definitions of SMSCs; the national definition comprised in development plans and strategies in Romania, Bulgaria, and Serbia; and the current situation of densities in all urban settlement in this region, we have a primary cut of small and medium-sized cities following the current population (inhabitants) and the density (inhabitants/ sq.km) (Fig. 19.2) Thus, small cities are cities between 3000 and 50,000 inhabitants with a density below 500 inhabitants/ sq.km, while medium cities are cities between 51,000 and 100,000 inhabitants, in constant demographic decline since 1990, with a density below 1500 inhabitants/sq.km. Other important criteria of defining the SMSCs on Lower Danube region are territorial autonomy, cross-border connections, and demographic dynamics.

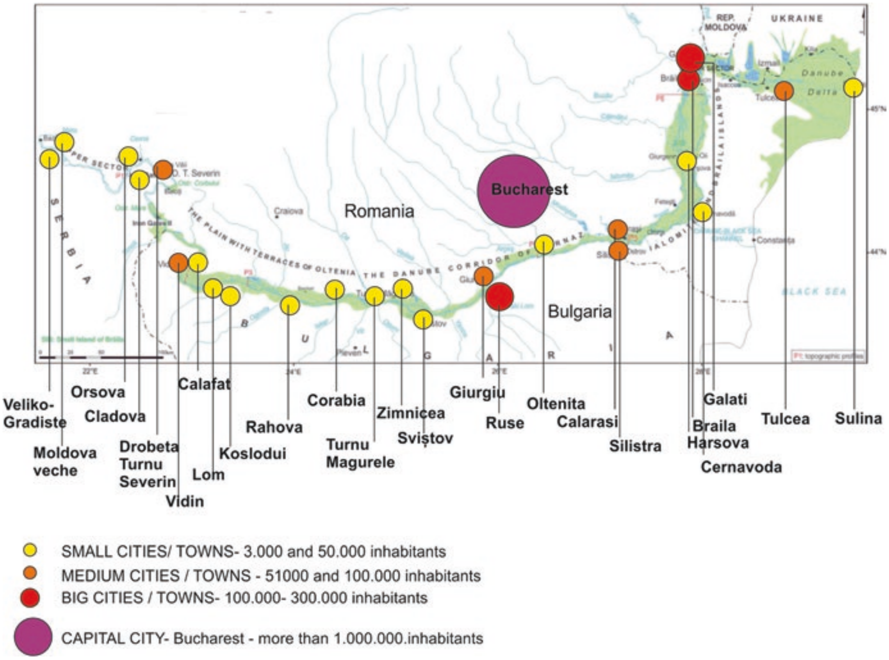

Fig. 19.2 Lower Danube SMSC – across Romania, Serbia, Bulgaria, Ukraine and rep. Moldova

According to ESPON (Öir et al. 2006), SMSCs in their functional territorial contexts are variable in function to the bigger city or settlement network to which it belongs or has relationship. So, there are *autonomous* cities – isolate, self-standing towns, usually found in peripheral rural regions (*autonomous*: A); agglomerated towns that are integral parts of polynucleated *metropolitan* areas and conurbations dominated by large cities/major metropolises (*metropolitan*: M); and cities taking part of a *polycentric* networks of towns (*polycentric*: P).

Since the presence or absence of the connection across the Danube between the studied cities – either this bridge (road/rail) or water transport is a feature associated with their profile (industrial, service, or agricultural) – it is obvious the importance for their development as criterion in defining the SMSC typology. It is not a coincidence; in fact, the cities connected by bridges or ferries and that have been developed together across Danube (also named Twin Cities) (Dumreicher et al. 2019) are among the largest ones: Giurgiu and Ruse, Vidin and Calafat, and Călărasi and Silistra.

Demographic dynamics over the last 30 years is also a criterion of analysing these cities, as the shrinkage phenomenon came together with the decline of the industrial activity. Most of them are in demographic decline which generates numerous co-lateral negative effects, such as the lack of jobs, the migration of working class, the population ageing, the loss of public money, and as consequences, the decline of investments in public equipment loss of spatial identity. According to their current demographic status expressed by last census (EC 2011), the cities analysed are in different situations: of light growth since last census (+), stagnation (0), or in decline (−) (Table 19.1).

Following these criteria, we identify a number of 23 SMSCs located on the banks of the Lower Danube in Romania, Bulgaria, and Serbia, from which 17 are into the small category (Veliko-Gradiște, Moldova Veche, Orșova, Cladova, Lom, Calafat, Koslodui, Rahova, Corabia, Turnu Măgurele, Zimnicea, Sviștov, Oltenița, Cernavodă, Fetești, Hîrșova, and Sulina) and 6 are into the medium category (Drobeta Turnu Severin, Vidin, Giurgiu, Călărași, Silistra, and Tulcea) (Figs. 19.3a, b). Among them, three cities fall out the SMSCs category, having a larger population and densities: Ruse (Bulgaria), Galați, and Brăila (Romania).

Table 19.1 Criteria for SMCS situated on Southern and Lower Danube's urban fronts. Small cities = 3000–50,000 inhabitants; medium cities = 51,000–250,000 inhabitants. Territorial autonomy (A), parts of metropolitan areas (M), part of a polycentric networks of towns (P)

	Town/city	Population (n. in.)	Density (in../inhabitants/km^2)	Territorial autonomy	Cross-border connection	Demographic dynamics
Small cities	Veliko-Gradiște	17,610	Very low	A		−
	Moldova Veche	8545	Very low	A		−
	Orșova	10,441	Very low	A		−
	Cladova	23,000	Very low	A		−
	Lom	24,300	Very low	P		+
	Calafat	18,858	Low	P	x	+
	Koslodui	14,630	Low	P		−
	Rahova	5031	Very low	A		−
	Corabia	16,441	Very low	A		−
	Turnu Măgurele	24,772	Medium	P		−
	Zimnicea	14,058	Very low	P	x	0
	Sviștov	30,591	Medium	P	x	0
	Oltenița	24,822	Very low	P		0
	Cernavodă	17,022	Low	P	x	−
	Fetești	30,217	Low	P	x	−
	Hîrșova	9642	Very low	A		0
	Sulina	3663	Very low	A		−
Medium cities	Drobeta Turnu Severin	92,617	Very high	P	x	+
	Vidin	48,071	High	P	x	−
	Giurgiu	61,353	Very low	M	x	+
	Călărași	65,181	High	M	x	+
	Silistra	42,153	Low	A	x	−
	Tulcea	91,875	High	A	x	+

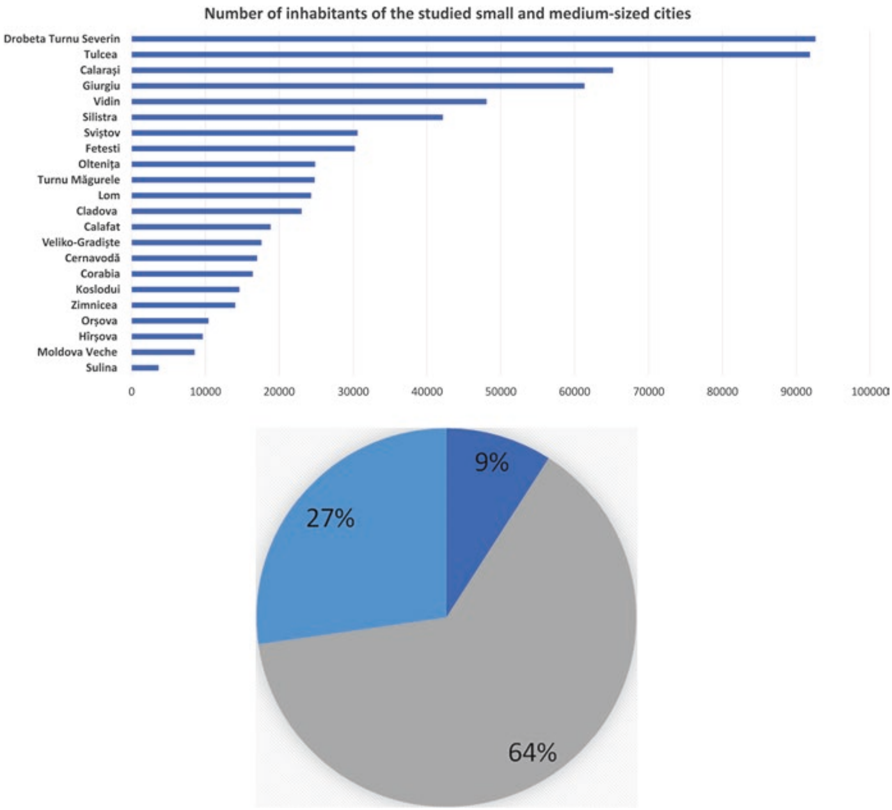

Fig. 19.3 (**a**) Above, number of inhabitants of the studied small and medium-sized cities; (**b**) below, number (in %) of analysed small and medium-sized cities by countries

From the total of the 23 cities identified as having the characteristics set out in Table 19.3, a first typological group reveals that there are four types characterized by all these criteria taken together, namely, type 1, small cities (under 10,000 in.), with low density, without cross-border connection, autonomous at territorial level and in demographic decline; type 2, small cities (under 30,000 in.), with low or very low density, without cross-border connection, polycentric or autonomous, in decline or stagnation (the most dominant type); type 3, small and medium-sized cities (under 60,000 in.), with low to medium density, with cross-border connection, autonomous or polycentric at territorial level, in various dynamics; and type 4, medium cities (under 100,000 in.), with dominant high density, with cross-border connection, polycentric or included in metropolitan areas, in various dynamics, most of them in growth (Fig. 19.4).

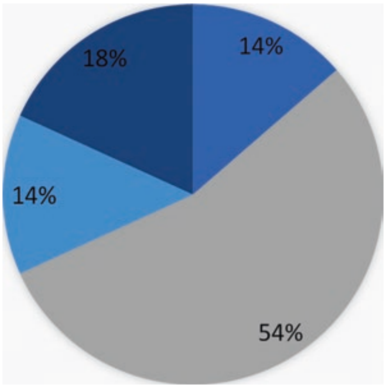

Fig. 19.4 Number of small and medium-sized cities studied per typological group

19.5 Defining and Revealing the Green Potential of the Abandoned Urban Land (AUL) Within the Danube-Specific Green Context

19.5.1 The Danube Green Infrastructure Context and Visions

The Danube's context outlines certain considerations that influence the conception of green infrastructure in this region. The configuration of the river corridor, the way in which the banks were regulated, the types of agriculture practised formerly and at present, and the current natural protection areas – Natura 2000 and of the Danube Delta Natural Reservation – are the essential substrate elements of this issue. At the same time, the territorial system of human settlements, their cross-border connections and the post-industrial status of their functional and demographic profiles, and the types of habitat fragmentation due to road and rail transport corridors are also important elements which influence the vision on the Lower Danube green infrastructure. Recent projects such as the TRANSGREEN (Integrated Transport and Green Infrastructure Planning in the Danube-Carpathian Region for the Benefit of People and Nature) (Interreg Danube 2017c) and GREEN DANUBE (Integrated Transnational Policies and Practical Solutions for an Environmentally-Friendly Inland Water Transport System in the Danube Region) (Interreg Danube 2017b) define and delimit different objectives related to the desire of a nuanced and balanced strategy on the Danube development but also on its ecosystem preservation.

For this region, it's relevant that the goals of:

> identifying, promoting and preserving a strategically planned green infrastructure network can provide ecological, economic and social benefits, […] becoming a priority for the planning and decision-making process in sectors such as conservation, (land) resource efficiency, agriculture, forestry or urban development. (Liquete et al. 2015: 6)

Thus, Danube green infrastructure is set out in the spirit of the European Commission communication which envisioned in 2013 the ground for a tool that aims to provide ecological, economic, and social benefits through natural solutions. This vision integrates the notions of "ecological connectivity, conservation and multi-functionality of ecosystems" (Mubareka et al. 2013: 16) which are in fact basic elements of a specific methodology that can be used to identify and map GI elements at landscape level and that can be used at different spatial scales for research, planning, or policy implementation (Liquete et al. 2015). According to other authors, the degree of landscape fragmentation is correlated especially with the population of cities and its density, reclaiming planning measures aimed at controlling the densification processes (sprawl, gentrification, location of specific activities, etc.) (Petrişor et al., 2016).

After more than a century, the strategy envisioned by Grigore Antipa (1895, 1907, 1910) still remains the only forward-looking solution for the economic exploitation of the Danube floodplain and also allows a better preservation of the fluvial ecosystem. The Danube River Basin District Management Plan (DRBM plan), adopted in 2009, analyses the disconnection of floodplains from the river as one of the main problems, and it assesses that the reconnection and restorations of different areas are necessary to ensure the river corridor's biodiversity (ICPDR 2002).

Considering these aspects as contextual elements, the authors have developed a synthetic methodology, comprising the definition and methodological framework of the GI at the EU level as significant contribution in the areas of regional development (EC 2013a, b), the territorial national attributes of planning and natural protection inputs, and the results of several topic-related EU by INTERREG-funded projects.

19.5.2 Identifying the AUL Spatial Typology and GI Integration

Generically, AULs are defined as fragments of urban or peripheral territories former related to industrial activities (production, storage, port, military, etc.) or agricultural land not currently exploited. More specifically, for the case of SMSCs, AULs are situated on the Danube banks, and this condition imposes a primary morphological differentiation (Table 19.2):

1. As compact elements, strongly delimited by infrastructural or natural elements, tributary of the shapes, and configuration of former industrial or other activities (Type-A).
2. As linear, connective elements accompanying the banks of the Danube (Type-B).
3. As fragmented elements, dispersed in the proximity of the peripheral urban tissue and being tributary of its structure (Type-C).

Combining the criteria of defining a general GI with the specific of SMSCs on this Danube region, it is possible to create a list of main attributes necessary to assess the AUL potential role in the UGI: (1) locations within the city, (2) morphological features, (3) size category, (4) exposure to riverbanks, (5) ecological connectivity, (6) presence of vegetation, (7) presence of wetlands, and (8) natural protected area.

Table 19.2 Abandoned urban land (AUL) spatial typologies. Type-A: compact sites, strongly delimited by infrastructural or natural elements, tributary of the shapes and configuration of former industrial activities. Type-B: linear (connective elements accompanying the banks of the Danube). Type-C: fragmented elements, dispersed in the proximity of the peripheral urban tissue and being tributary of its structure. Each type is represented by an example from the list of the 23 studied SMCs

City and morpholgical type of identified AUL	City map	Characteristic image
Moldova Veche, type-A: Compact		
Corabia, type-B: Linear		
Sulina, type-C: Fragmented		

Table 19.3 Abandoned urban land matrix potential for building a urban green infrastructure in studied SMSCs

	Criteria for defining typology of abandoned urban land (AUL) on Lower Danube shores								Score
SMSC	Locations within the city	Morphological features	Size category	Exposure to riverbanks	Ecological connectivity	Presence of vegetation	Presence of wetlands	Protected area	
	0 – Central	0 – Fragmented	0 < 50 ha	0 – No exposure	0 – Small	0 – Small	0 – No	0 – No	
	1 – Periferic	1 – Compact	1 – 50–200 ha	1 – Small exposure	1 – Medium	1 – Medium	1 – Small	1 – Partially	
	2 – Outside	2 – Linear	2 > 200 ha	2 – Large exposure	2 – Big	2 – Big	2 – Consistent	2 – Full	
Moldova Veche	1	2	1	2	2	1	1	1	11
Corabia	0	1	2	2	1	2	1	1	10
Zimnicea	2	0	1	1	0	0	0	0	4
Calafat	1	0	1	2	1	0	0	0	5
Turnu Măgurele	2	2	1	0	1	0	0	1	7
Oltenița	2	2	1	1	1	1	1	1	10
Cernavodă	1	2	2	2	2	2	1	1	13
Hîrșova	1	1	2	1	0	0	0	0	5
Sulina	1	1	2	2	2	2	2	2	14
Fetesti	1	0	2	1	2	0	0	0	6
Lom	1	2	1	2	2	1	1	0	10
Koslodui	1	2	0	1	1	1	0	0	6
Calarași	0	2	2	2	2	1	1	0	10
Drobeta Turnu Severin		2	0	2	2	0		0	6
Giurgiu	1	2	2	2	2	2	2	1	14
Tulcea	1	1		1	2	1	1	1	8
Vidin	2	1	1	0	0	0	0	0	4
Silistra	2	2	1	2	1	0	1	0	9

In order to evaluate the AUL potential of taking part of a UGI, indices-values are associated to these criteria (Table 19.3).

The score of the AUL identifies a series of qualities and potential to urban environments and landscape where the UGI with the specific of SMSCs on this Danube Region is associated with a high potential in delivering multiple benefits that are supporting general health and well-being. According to this evaluation, the authors estimate the spatial potential for connecting the AUL identified in SMSCs to the Danube green infrastructure. The most suitable type of AUL is the compact type (A), tangential to the Danube shores, situated in the periphery or inside the city. This type has an area of 50–200 ha, a cross-border connection, good connectivity and continuity in the urban green spaces system, and an important presence of vegetation and/or wetlands.

The presence of natural protected areas is also an important characteristic to define the most suitable type for these AULs. None of identified examples among the 23 studied cities summarize all the necessary features described above, but some of them have reached the level of possibility of, using specific means to integrate at various spatial scales of landscape planning, reaching the goal of providing ecosystem services.

As Mell (2012) noticed:

> by thinking innovatively, and in some cases more holistically, about the form Green Infrastructure investment takes planners and developers can encourage greater social and spatial interaction with green investments, which in time will promote a better understanding of ecological resources and decrease the competition between grey and green development. Mell (2012: 8)

The term "grey infrastructure" refers to large-scale transport systems which can be integrated with green infrastructure principles.

The efficiency and the methods available for identifying green infrastructure approaches are similar for the grey infrastructure, from which most of the AULs studied in this paper are part. The integration depends on the site character location, connectivity, and resource base but also governance structure, property regime, and strategic vision of development.

The reality in countries like Romania, Bulgaria, and Serbia is that in the last 30 years after falling the communist regime, a huge (and yet not estimated) amount of potentially green territories have been lost (or are in danger to be lost) because they have been used for other economic developments or are abandoned, being deeply polluted. Recent journalistic investigations in Romania showed how counties as Giurgiu, Teleorman, Olt, Brăila, or Galați, despite the official local development strategies – which have been formally completed after 2006 in the terms of UE requests – do not tackle the issue of abandoned urban lands. In these cases, the private interests have been involved in local development projects using natural resources for personal purpose, thus reducing the chances of the AULs to become healthy, clean and to be integrated into a truly green infrastructure. The most emblematic and scandalous case is the *Belina Island* on Danube, Teleorman county (Romania), which became private land by a local council political decision.

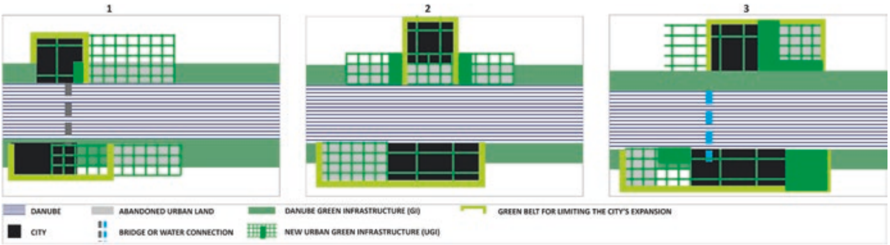

Fig. 19.5 AUL and GI matrix connection
1- peripheral, tangent position on the shore, linear form, twin-cities with bridge connection
2- inside, tangent position on the shore, fragmented form, cities without bridge or water connection
3- outside, semi-tangent position on the shore, compact form, cities with water connection

The way in which strategic plans are put into action affects ecosystems and human health, urban comfort, and culture. According to several authors (Huang et al. 2010; Pincetl 2012; Farr 2008), considering urban habitats as green infrastructure is justified by the ecosystem services provision and the potential benefits and uses offered by urban open spaces. Their transformation should be carried out according to specific investigation of local needs and aiming at enhancing their natural characters and social ecological values.

Under the category of AUL, various uses and functions can be listed that are possible to be integrated into a green infrastructure, by restoring them at actual ecological standards. The vision is to transform these AULs into true centres of ecosystem restoration of the city and its neighbourhoods, precisely building on their traumatic history, which *kidnapped* them from the Danube natural basin, industrializing and polluting them during socialist era, cutting them from the system of natural and human-made habitats (Fig. 19.5). The most frequent uses of AUL and their possible intervention to integrate them into the Danube UGI are reported in Table 19.4.

19.6 Planning in Small and Medium-Sized Cities for Building an Urban Green Infrastructure

Considering urban green infrastructure as a smart solution for today's needs of cities, it can be seen that a single area of land can offer multiple benefits, providing ecosystems and a stream of valuable, economically important goods and services such as clean water and air, carbon storage, pollination, etc. and also:

> playing a central role in fighting climate change impacts by protecting cities against floods and other environmental disasters and being a highly valuable policy tool to promote sustainable development and smart growth. (Andreucci 2013: 8)

But the healthy condition of our small and medium cities on Lower Danube is far more complicated to be achieved and cannot be reached only by good strategic discourse and academic inputs. In societies with a fable eco-friendly education, it is

Table 19.4 The most frequent uses of AUL and their possible intervention to integrate them into the Danube UGI

Type or former AUL function	Valued eco-services and GI integration method	New uses and functions able to provide GI maintenance and support
Peripheral brownfields, industrial activities, warehouse	Decontamination, soil formation, phytoremediation, climate regulation, storm-water retention, natural hazard mitigation, urban resilience, biodiversity enhancement, environmental culture	Unitary urban waterfront conception for the main Danube channel – With a coherent spatial vision to be implemented, offering walkable public open space in order to value the historic relationship between the settlement and the river; promoting the local and regional identity; developing local/specific tourism opportunities
Cities' shores related to Danube navigation and harbours; industrial railway infrastructure related	Decontamination, soil formation, phytoremediation, climate regulation, storm-water retention, natural hazard mitigation, urban resilience, biodiversity enhancement, environmental culture	
Abandoned intensive agriculture fields on southern and lower Danube basin	Storm-water retention, decontamination of polluted environments, soil formation, carbon sequestration, biodiversity enhancement	Creating an ecological infrastructure using the basic three elements: 1) the green corridors by using the street alignments of local tree species and linear protection of various infrastructure implants or cemeteries, b) the matrix composed by scattered green entities composed by all urban green public areas (gardens, parks, squares), and c) the patches which connect major habitats through dedicated structures, with special ecological amenities (as urban parks, new natural protected areas, waste and storm-water biotreatment sites, etc.)
Commercial or other abandoned urban amenities, including ex-railway facilities, infrastructure, and unused plants	Storm-water retention, soil formation, carbon sequestration, biodiversity, healthy lifestyle, environmental culture	
Swampy floodplains and spontaneous forests, islands with temporary existence due to the Danube flow, temporary beaches, reef areas and Ostrov areas in the proximity of urban/rural settlements	Biodiversity protection (flora species, protected fauna), carbon sequestration, climatic regulation, landscape amenities, shoreline erosion control, pollution buffering	

very important to start with the beginning in order to make all different sectors of the society to deeply understand that:

> if these natural powerhouses are damaged, it is not just our biodiversity that suffers but society as a whole. (EU 2013: 12)

Even if all these considerations are well known in the large part of Europe, the local administration on SMSCs of Danube shores is not so aware of the benefits of green infrastructure. The role of urban and landscape planners should include also the spreading of the main discourse of urban green infrastructure positive impact on urban and rural environment and identifying possible development scenarios that enhance the spatial potential within the project focusing on smaller towns along the Danube (Joklová et al. 2019). Among the huge range of benefits – environmental, climate change adaptation and mitigation, social, economic, and cultural – we mention those which are especially related to AUL in these territories:

- (Re)creating a healthy provision of urban clean water
- Removal of pollutants from air and water.
- Protection against soil erosion.
- Flood alleviation.
- Rainwater retention.
- Improvement of land quality.
- Mitigation of land takes and soil sealing.
- Strengthening ecosystem resilience.
- Carbon storage and sequestration.
- Mitigation of urban heat island effect.
- Disaster prevention (e.g., storms, forest fires, landslides).
- Improved habitats for wildlife.
- Landscape permeability.
- Better health and human well-being.
- New job opportunities.
- Diversification of local economy.
- Greener cities, more attractive, especially for young people.
- Higher property values and local distinctiveness.
- More integrated transport and energy solutions.
- Enhanced tourism and recreation opportunities.

Following this general picture of potential benefits, we can also design a targeted framework of the main structural components of urban green infrastructure, Lower Danube's shores. The framework presented below contains elements from the most natural ecological services potentially provided by various types of AUL (a) to the most artificial ones (f):

(a) Danube natural protected areas (included/to be included in Natura 2000 sites or other natural protected areas) with high biodiversity and high level of ecosystem services.
(b) Outside protected zones containing large healthy functioning ecosystems, with natural features acting as wildlife corridors, like small watercourses, islands, ponds, hedgerows, and woodland strips.
(c) Restored habitats on previous polluted areas (such as industrial settling lakes, tailing dumps, garbage pits) that help reconnect or enhance existing natural areas.
(d) Artificial urban or peri-urban lands with features that enhance ecosystem services or assist wildlife movement such as eco-ducts or eco-bridges, peri-urban parks and green recreational facilities, urban green belts, fish ladders, or green roofs.

(e) Buffer zones that are managed sustainably and help improve the general ecological quality and permeability of the landscape to biodiversity, e.g. wildlife-friendly farming, fish ladders, urban agriculture, and community gardens.
(f) Multifunctional zones inside or tangent to urban territories where compatible land uses can join forces to create land management combinations that support multiple land uses in the same spatial area, e.g. food production and recreation, cultural tourism activities, and ecological education centres (Lazăr-Bâra 2012).

19.7 Conclusions

Starting from planning policies, AULs can be reintegrated both to the city and to the natural system through intelligent and consistent interventions and through policies and measures that pursue the purpose of producing healthy ecological services within the Danube green infrastructure. These interventions, however, may be expensive in the first instance, but on the one hand politicians should understand that such interventions are healthy and long-term beneficial, thus economically and socially advantageous, and on the other, the population must be educated in order to respect and maintain them.

Spatial planning practices – e.g. strategies, development, green systems, and action plans – should enable interactions between different land uses to be investigated over a large geographical area. Strategic level of spatial planning at the scale of the small and medium cities situated on the shores of Lower Danube can especially help to:

- Locate the best places for habitat enhancement projects by using AUL identification (e.g. involving restoration or recreation of habitats) to help reconnect healthy ecosystems, improve landscape permeability. or improve connectivity between protected areas.
- Guide infrastructure developments away from particularly sensitive nature areas and instead towards more robust areas where they might additionally contribute to restoring or recreating GI features as part of the development proposal.
- Use the linear AUL spatial type for creating connected zones on the Danube's shores, creating recreational public facilities related to both the city's urban front and to the natural river ecosystems.
- Identify multifunctional zones where compatible land uses that support healthy ecosystems are favoured over other more destructive single-focus developments.

Using a strategic approach to building green infrastructure ensures there is a clear focus for individual initiatives and local-scale projects so that these can be scaled up to the point where, collectively, they will make a real difference (URBACT 2011). In this way, green infrastructure becomes much more than the mere sum of its parts. It is also a means of bringing different sectors together in order that they may decide together on local land use priorities in a transparent, integrated, and cooperative way.

A very important aspect of GI building is that it should not be understood as a top-down planning tool but as being essentially based on the involvement of the population and on the individual and local community initiative. Any of these plans will be successful and be pursued in time to reach the level of expected ecosystem services, if it is not accepted by the population and internalized within the local community. In small and medium-sized cities, this may seem easier to achieve than in large cities, given the ability of smaller population and of different sectors of societal life to join a cause. But, to be realistic, looking especially at the Romanian cities on the Lower Danube, we can say that it is not very easy to implement such projects. Besides the financial aspect, the financing of such projects, considered in relation to the reduced local budgetary capacity, is the aspect of assuming them as priority and to start to build not only in the physical plane but especially and more importantly, in the social plane, in education of citizens to accept and value such interventions.

One of the less obvious values of these AULs from the small and medium-sized cities situated on the Danube's shores, in Romania, as well as in Serbia or Bulgaria, is related to the memory of the place, a socio-psychological character related to a past, but still present history, through testimonies, written or oral narratives, images, literature, art, and not least the people themselves who directly participated in its realization and whose descendants are still living (or could decide to come back) in these cities. A tragic and traumatic era in its essence has left its mark on both the earth and the mind of a generation, and the trauma is transmitted to children and grandchildren in the sense of an obligation to re-cover what has been lost, a gesture of respect for nature and remembrance of past history. The emotional burden of these places that were the workspaces of the previous generation could lead the current generation of political decision-makers and spatial planners to act for its intelligent and resilient restoration.

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Chapter 20
The Collserola Special Protection Plan (PEPNat): A Bid for Co-responsibility in Agricultural and Forest Management

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Abstract The Collserola mountain range is a unique natural area covering over 8000 ha at the heart of a complex metropolitan realm. It thus presents great potential in terms of providing ecosystem services on a metropolitan and regional level yet has little ecological continuity with other nearby open spaces. As a result of the creation of Collserola Natural Park in 2010, a new special protection plan, the PEPNat, is currently being approved. This plan aims to preserve biodiversity and increase ecosystem services under dynamic and adaptive management. This contribution highlights the proposal for public-private management in relation to the preservation of ecological values and the valorization of natural resources and built heritage. Two important aspects are the structure of the property – the Park is over 60% privately owned – and the poor condition of the built heritage. The PEPNat establishes a link between the development of permitted uses in existing traditional buildings and a way of managing the property that promotes the silvo-agricultural mosaic and improves the functionality of interconnected spaces and habitat conservation among other things. The discussion focuses, on the one hand, on the ecological, social, and economic benefits on various levels and, on the other, on the main difficulties of its implementation.

Keywords Agroforestry mosaic · Barcelona metropolitan green infrastructure · Public-private forest management · Planning for ecosystem services

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_20

20.1 The Agroforestry Mosaic Within the Metropolitan Green Infrastructure Programme

Barcelona Metropolitan Area (AMB) covers an area of 636 km^2, comprising 36 municipalities with 3.2 million inhabitants, and it provides 1.5 million jobs. Although it is a densely populated area with complex metropolitan dynamics, it is worth noting that open spaces occupy 54.6% of the territory, the vast majority of which are protected (more than 90%) (PDU 2019b: 7). In addition, inside the set of natural and semi-natural spaces, according to "Habitats" 92/43 EU Directive, 30 habitats of European Community interest (HCI), 5 of which are priority habitats, have been identified, which occupy 28.4% of the metropolitan territory (PDU 2019a: 192). Therefore, despite strong anthropogenic pressure, the metropolitan area of Barcelona still maintains a high rate of open spaces and a remarkable biodiversity (Farrero 2014). Many of these open spaces coincide with important landmarks (rivers, beaches, and the coastal range) to which the urban settlement has been adapting gradually.

As a result, the orography, which has shaped land occupation, also made it possible to preserve spaces of high ecosystem services value such as the Collserola range, the natural areas surrounding the Llobregat delta, the Garraf Massif, the Ordal mountains, and the Marina mountain range. These spaces are all protected, and most of them conserve their forest coverage and are a key feature of the so-called metropolitan green infrastructure (Fig. 20.1). At the same time, forest areas combine with farming activities, thus forming the agroforestry mosaic.

The surface covered by this agroforestry patchwork has diminished throughout recent decades, due to the abandonment of the countryside and rural areas, which gave way to forests. Two of the consequences of this situation are the occupation of open spaces with marginal and/or peri-urban uses and the accumulation of

Fig. 20.1 Serra de Collserola Natural Park and the Metropolitan green infrastructure

flammable materials that fuel wildfires (Terradas and Rodà 2004). Conversely, forestry policy has mainly addressed publicly owned forests, and, as regards private woodland, there is an obvious lack of cooperation, participation, and association between the stakeholders; issues arise as a result of property fragmentation and the market's lack of transparency and productive orientation (Farrero and Baiges Zapater 2009).

The promotion of the agroforestry mosaic (or the agrosilvopastoral mosaic that includes elements and benefits obtained from agriculture, forestry, and pastoral activities) creates areas of transition (ecotones) between natural habitats and farmland. Such ecotones can enhance the function, the biodiversity, and the permeability of entire ecosystems while maximizing their regulation services and supporting wildfire prevention, among other features. Therefore, an active policy to improve agroforestry mosaics could make the territory increasingly resilient and biodiverse. To do that, it is necessary to search for imaginative formulas that aim to achieve this balance of interests, conserving the territory's values and boosting ecosystem services.

Within this context, in accordance with the principles of landscape stewardship (Bieling and Plieninger 2017), the Collserola Special Protection Plan (PEPNat), designed to protect the environment and landscape of the Serra de Collserola Natural Park (PNSC), contemplates a comprehensive public-private management model. This model aims to encourage synergies between the activities of the primary sector and the conservation of the biological values currently occurring in the Park while promoting recovery and highlighting the remarkable value of the extant cultural heritage.

20.2 Serra de Collserola Natural Park

Serra de Collserola Natural Park was protected by different legal instruments until it obtained natural park status on 19 October 2010. It is a unique area of over 8000 ha, with significant ecological value, located in the heart of a complex metropolitan realm. Its relief, more abrupt than the surrounding flatter spaces, has preserved it from indistinct urban sprawl; today, in the middle of a densely populated and congested area, we find a well-preserved biodiverse territory of farmland and forests, which could play a key role in the environmental and ecosystem balance of the metropolitan area (AMB 2019c: 3). Nevertheless, the metropolitan context of the Park suffers from isolation from the surrounding natural areas (Fig. 20.1), which could jeopardize the conservation of ecological values and biodiversity (Barcelona Regional 2013; Mayor and Belmonte 2003).

It is essential to maintain ecological processes for conserving the biodiversity and functionality of the Collserola range. Therefore, it is of uppermost importance to improve the external and internal ecological connection in order to overcome the current isolation pattern (Mayor and Belmonte 2003). At the same time, a key factor for maintaining the integrity and quality of the space is the balance between disruptions coming from social use and Park's activities and the conservation of the ecological and cultural values (AMB 2019c).

In the following paragraphs, we provide an analysis of the Park's most relevant features, bearing in mind the role played by the area of Collserola at a metropolitan level, which has led to considering the need for comprehensive management and a bid for co-responsibility in agriculture and forestry. These features are specifically related with the need to conserve biodiversity and to boost ecosystem services and, with the promotion of the agroforestry mosaic, the maintenance of traditional buildings and estates and the governance model.

20.2.1 Biodiversity and Ecosystem Services

We cope with a complex and ever-changing ecological framework that is difficult to govern and manage with strict and static rules. The Park's integrity is based on preserving biodiversity, maintaining and actively managing ecological processes, and controlling disturbances. As a result, besides a general regulatory framework, managers require dynamic tools to be able to appropriately assess the projects that may directly or indirectly impact this space (AMB 2019c: 163).

As regards biodiversity conservation, Collserola has a wealth of both habitats and species that require proper management. As much as 13 HCIs have been detected, of which 4 are priority habitat types of European Community interest, and other ones host several key or threatened species. In fact, 66% of the Park's territory consists of habitats of European Community interest, and 2.27% consists of priority habitats. In relation to traditional land uses and to the occurrence of ecotones in a complex agroforestry mosaic, it is important to point at the priority HCI 6220* *Pseudo-steppe with grasses and annuals (Thero-Brachypodietalia)*. Other noteworthy habitats are the priority habitats associated with wetlands, such as HCI 91E0* *Alluvial forests (Alno-Padion)* and, to a lesser extent, HCI 3170* *Mediterranean temporary ponds* (AMB 2019c; Pérez-Haase and Carreras 2012).

On the other hand, the presence of allochthonous species with colonizing potential is growing, and this process may threaten the Park's biodiversity. At the same time, both natural and anthropogenic hazards must be taken into account as vectors that could influence the conservation of biodiversity. For example, there is a significant risk of fire in Collserola, with highly flammable plant communities throughout its surface (AMB 2019c: 163).

Likewise, there are numerous and noteworthy services to local population and the whole territory granted by the Natural Park. Collserola is a social-ecological system or social ecosystem (Depietri et al. 2016): in other words, a system where ecological and social vectors have always interacted throughout history and where they still interact today, in an intense and continuous manner. The array of services provided by the Park comprises multiple environmental functions – such as the scupper effect of vegetation, conservation of the water cycle or air quality – as well as economic and social functions (both of tangible and intangible nature) (Gabinet d'Estudis Econòmics 2018).

Consequently, it is necessary to guarantee the conservation of the Park's natural values and environmental functions in balance with the services it offers the inhabitants of the metropolis. If the ecosystems and biodiversity are conserved, this will guarantee at least a part of most of the environmental services that Collserola is able to provide the territory.

20.2.2 Promoting the Agroforestry Mosaic

Throughout recent years, land cover has changed in Collserola according to society's demands, a fact that has modified the landscape, mainly in terms of agricultural abandonment, afforestation, deforestation, and urban sprawl. Nevertheless, while afforestation and agricultural abandonment mostly occurred in the periphery, deforestation and urban development show a more irregular pattern. At present, the Park consists of two large areas with a higher degree of wilderness (where woodland and shrubland prevail) and a narrow irregular strip mostly made of crop fields and grassland (Mayor and Belmonte 2003).

As regards public forestry activity, concession agreements have been set in motion to grant public land owned by different entities to the Natural Park Consortium (CPNSC), so as to perform unitary management, centred on preventing fires and increasing the resilience of forest cover against different types of disturbances. The purpose of these agreements is to achieve economies of scale that can valorize products and minimize management costs. It is worth noting the results obtained from the implementation of low combustibility strips and the forest recovery actions performed after episodes of gales and snow where, thanks to the energy produced from the products, the restoration work costed practically nothing. On private land, efforts have been made to devise technical plans for forest management and improvement and create forest owner associations (AMB 2019c: 165). In this regard, in 2017 the association *Collserola Iniciatives* was formed, which groups together the owners and entities in charge of private activities on the rural estates of the Collserola range. Conversely, agricultural production in the Park is currently in great trouble. The few producing farms that are still active within the Park (about 20, counting both crops and livestock) are generally small in size and their viability is uncertain (CPNSC 2013). Furthermore, as regards climate change, fertility is expected to drop and soil erosion to increase. Unless this trend is not properly faced, it will lead to an even greater reduction in the Park's agricultural land and, therefore, a further loss of the agroforestry mosaics, which are vital for the conservation of the Park's areas of transition. Consequently, it will be necessary to apply efficient protection and monitoring measures, ensuring that they have an adaptive capacity in view of the uncertainty of future scenarios (AMB 2019c: 163). In order to respond to these challenges, in December 2013 the Collserola Farming and Livestock Plan (Pla Agropecuari PNSC) was approved, thus establishing criteria for managing these activities and, among other aspects, encouraging the production of locally grown food and creation of quality brands with the Collserola stamp (CPNSC 2013).

20.2.3 The State of Traditional Buildings

People have lived in the Collserola range for thousands of years. Since the days of the Neolithic until today, different cultures have lived there and they continue to leave a remarkable footprint made of a wide variety of artefacts, mostly related to primary activities (AMB 2019c: 100). Local agricultural heritage (farmhouses, drystone walls, shepherds' huts, etc.) is really huge: according to the latest census, around 125 *masies* (traditional Catalan farmhouses) still exist in the Park, which were originally associated to extensive crop fields, livestock farming, and/or forestry production (Mangrana Arquitectes 2015).

This architectural heritage is not in good condition. It has gradually devaluated, subsequently reducing the Park's vitality and leading to a deterioration of the estates. In the 1990s, as part of the work for the Inventory Catalogue of the Architectural Heritage of Collserola Park, the Barcelona Provincial Council estimated that half the architectural heritage was in an unsatisfactory or deficient condition (SPAL 1995). This situation has not improved in recent years (AMB 2019c).

With the purpose of guaranteeing the maintenance of this heritage within the context of limited public budgets comes the need to widen the range of uses admitted in traditional buildings, such as *masies* (AMB 2019c: 166). But these uses must not only be compatible with the fact that they are located inside a protected space, but they must also provide added value. The reuse of traditional buildings should have a positive impact on the cultural and ecological assets of the Park as well (AMB 2019b: 345, 353). In this sense, since the local cultural built heritage is particularly related to primary activities, its reuse can play an important role in the revival of agrosilvopastoral activities, thus enhancing the biodiversity and resilience of the Park.

20.2.4 The Governance Model and the Need for a Co-responsibility Formula

The basic features of the governance model are the predominance of private estates, which cover a greater area than that of public land (Fig. 20.2); the existence of a permanent management body with a budget; and a special programme drawn up with the participation of all the players involved, with which the space can be planned and managed.

This management model issues from the participation of all members of a consortium of the different public authorities whose activities and interests may impact

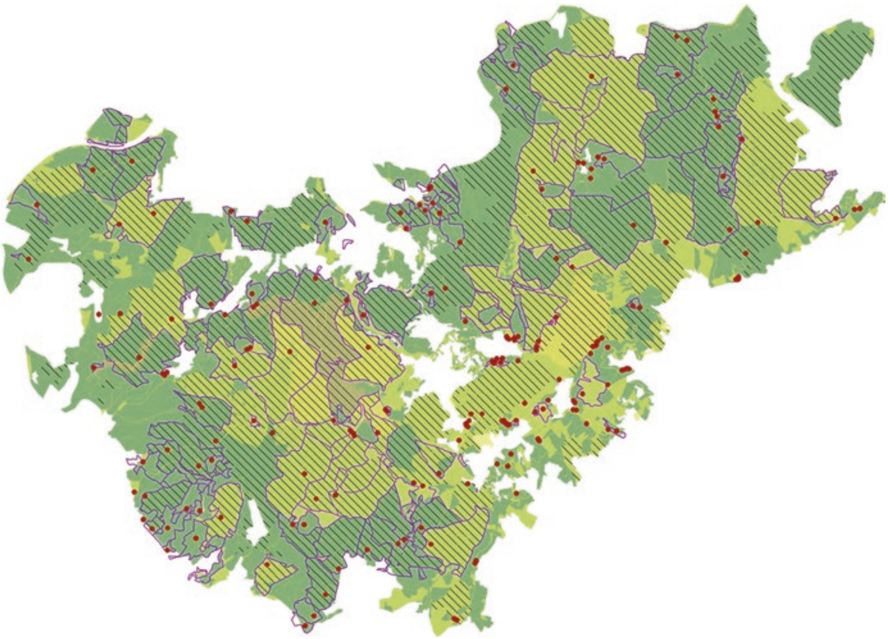

Fig. 20.2 Predominance of private estates within the Park; private estates (*green*), public estates (*yellow*), estates over 15 Ha (*linear hatch*), and traditional constructions (*red dots*)

the territory: the Government of Catalonia, Barcelona Provincial Council, Barcelona Metropolitan Area, and the totality of local councils. Furthermore, unlike other natural spaces of AMB, this one has its own management body. For over three decades, the existence of the CPNSC has been one of the strength as regards conserving and improving biodiversity and boosting ecosystem services. However, the very high number of stakeholders involved in the Consortium requires cohesion (Batlle et al. 2019: 55).

With regard to co-responsibility in land management, since its foundation the CPNSC has cooperated with different sectors and organizations to meet the goals of the declaration of the Natural Park. In relation to the agricultural and forestry management, for instance, the project of bringing farmers together and the dialogue with the already mentioned association *Collserola Iniciatives* stand out. The first project aims at providing farmers with a meeting space and at facilitating dynamics that might help them to function collectively. On the other hand, one of the central axes of *Collserola Iniciatives* is the development of an active, integral, and sustainable management of the estates, as well as to develop agrosilvopastoral activities that add value to the territory and help to preserve its ecological and cultural values.

However, to meet environmental and landscape protection goals, it is necessary to find formulas for a more comprehensive estate management. Given the structure of the property and budgetary restrictions, management agreements based on public-private collaboration models are needed. This management requires to be able to facilitate the conservation and improvement of this natural heritage in a densely populated area (AMB 2019c: 275).

20.3 The New Collserola Range Protection Plan (PEPNat)

From both the urban and environmental perspectives, the concern over protecting the Collserola range has been present in all the plans developed in this regard. The most relevant urban documents are the Barcelona County Plan (1953), the General Metropolitan Plan (1976), and the Collserola Range Protection Plan (PEPCo) (1987), the latter two still in force today (Patronat Metropolità Parc de Collserola 1990). Subsequently, the Territorial Plan of the Barcelona Metropolitan Region (PTPRMB) (2010) establishes a system of open spaces of special protection, among which the Collserola range figures in a noticeable position.

From the perspective of environmental legislation, in 1985 the Natural Spaces Act was approved, which was developed in 1992 with the Plan for Sites of Natural Interest that includes the Collserola range. In 2006, Collserola was included in the Natura 2000 network, and, finally, in 2010, with Decree 146/2010 of 19 October, the Serra de Collserola Natural Park and the nature reserves of Font Groga and Rierada-Can Balasc were established. The Natural Park comprises an area of over 8156 ha and includes the two nature reserves. These reserves have been classified as partial nature reserves, since certain uses and activities that might contribute to the preservation of their values are admitted, albeit in a limited and strictly regulated manner.

As a result of the creation of the Natural Park, a new special plan is currently being processed, the PEPNat. This Plan was approved provisionally by the Metropolitan Council on 30 April 2019. Once it has been definitely approved by the Government of Catalonia, it will replace the PEPCo, the plan in force since 1987.

The PEPNat is a hybrid plan that combines environmental and urban planning aspects. The main goals are to conserve biodiversity and boost ecosystem services within the framework of a dynamic and adaptive management. The Plan is based on the ecological strategy as a cross-cutting axis and backbone of the Park model and is structured in six areas (Fig. 20.3). This document highlights the area dedicated to the valorization of natural resources and built heritage, especially in regard to co-responsibility in the comprehensive management of the estates.

An important aspect of the Plan is the environmental zoning. Thus, apart from the partial nature reserves, defined at the time by Decree 146/2010, and other equally critical elements that are difficult to delimit, such as paths and field boundaries, the PEPNat defines four areas that play a key role in the preservation of biodiversity and the enhancement of ecosystem services: patches of connectivity interest, areas of special importance, islands of tranquillity, and priority areas for agriculture. These areas are based on certain processes or functions of the Park and play a key role in management plans (see Sect. 20.4.2).

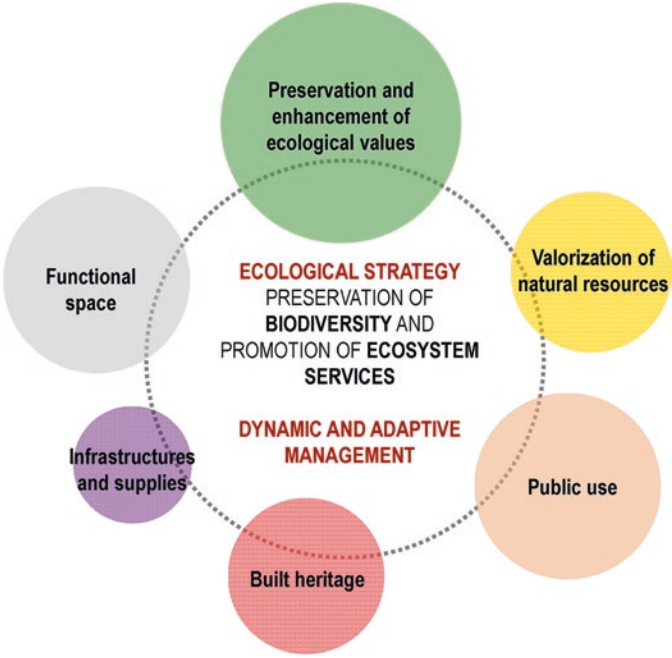

Fig. 20.3 The ecological strategy as a cross-cutting axis and backbone of the Park model. The different size of the circles depends on the weight this topic has in the Plan, the most relevant being - as it is a protected area - the preservation and improvement of ecological values

20.3.1 The Natural Resources Valorization Model

Forestry, agriculture, and livestock stand out among the primary activities. Unlike the current Plan, the PEPNat admits these activities, albeit with strong restrictions in the most sensitive areas, in the whole Park. Regarding forestry uses and activities, management guidelines for all estates with forest exploitation have been established, and there is an obligation to have forest management plans. In addition, in relation to agricultural uses and activities, the aim is to facilitate their implementation in spaces with the most suitable conditions that are defined as priority areas for agriculture, thus optimizing resources (see Sect. 20.4.2).

One of the Plan's main goals is the increase and restoration of agricultural land uses, given that the amount of cropland has dropped considerably during last decades. Nevertheless, in recent years, an increase has been detected in the local demand of quality products and in the number of people willing to become farmers (Associació Arran de Terra 2017). Therefore, this aim is in accordance with the current interest of farmers in Collserola to increase production. This is also compatible with the goals to promote the agroforestry mosaic and the proper management of habitats and species mentioned in Sect. 20.2.1.

Fig. 20.4 Diagnosis and main objectives established by PEPNat in relation to the natural resources valorisation model

Figure 20.4 shows the main points of the diagnosis related to the objectives of the Plan. The former have to do with the primary sector itself and with the characteristics of the territory. The latter are aligned with the Farming and Livestock Plan and take into account as well the loss of biodiversity and possible scenarios arising from climate change.

20.3.2 The Model in Relation to Cultural Heritage

The proposals related to cultural heritage and traditional manufacts can be divided into two key points: to recover and highlight the value of local remaining cultural heritage and to forbid new constructions (with a few exceptions related to primary activities and the management of the Park). These two strategies respond to the diagnosis and goals identified by the PEPNat (Fig. 20.5). The main concern is the impact of existing and new manufacts within the Park. In order to achieve these goals, a series of constructions have been listed in the Catalogue of *masies*, rural homes, and other constructions (199 manufacts in total). These constructions issue from the traditional and sustainable colonization of the territory and respect the traits of local agricultural and natural landscape (AMB 2019b: 352).

The aim of the Catalogue is to regulate – in a way that is beneficial for the Park – the maintenance of the architectural, historical, and cultural heritage and the uses allowed in it. The intention is to introduce uses that strengthen the protection of the ecological and cultural values of Collserola. The admitted uses are family homes, artistic and professional activities, rural tourism, restaurants, and public facilities (AMB 2019a).

One key aspect is the link between the reuse of buildings and estate management. In this way, private owners might contribute to the preservation of the ecological assets of the Park through a public-private estate management formula. However, besides supporting the safekeeping and custody of the surrounding agricultural and

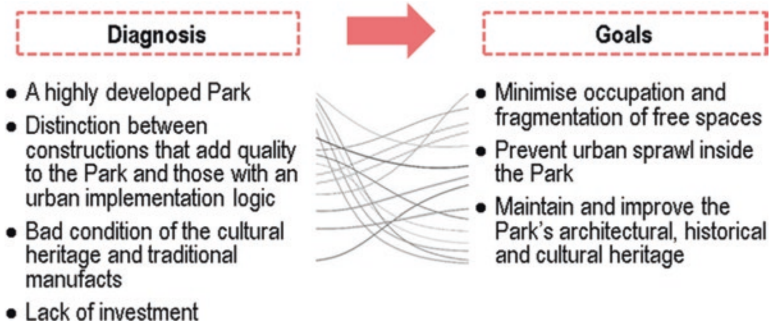

Fig. 20.5 Diagnosis and main objectives established by PEPNat in relation to the cultural heritage model

forestry areas, these uses might have other effects. They should help fix a population with strong ties with the Park, revert on a well-kept heritage, and stimulate the revitalization of the territory by offering related complementary activities. From a citizen perspective, they might as well help to disseminate the Park's values and to re-establish the connections between the metropolitan population and nature.

Regarding their impact, the uses allowed vary for each construction and depend on their proximity to sensitive natural sites, among other factors, such as gross floor area and accessibility. Moreover, compensation and mitigation measures are established when restoring or transforming a building in order to protect and improve the ecological values and the biodiversity and the ecosystem services of the habitats nearby. For example, the dismantlement and the reuse of the manufacts must be respectful and integrated with the surrounding landscape, and any intervention must take into account the costs to restore stripped land, estate management, path maintenance, etc. However, the measures that might have the strongest positive impact are the ones related to estate management, in particular those linked to the places and elements of ecological interest and the environmental zoning areas (see Sect. 20.4.2).

20.4 The PEPNat and Co-responsibility in Agricultural and Forest Management

As it already argued in Sect. 20.2.4, the management of the Park belongs to the CPNSC, a public consortium. However, despite some one-off agreements with other public bodies, the percentage of land managed directly by this consortium is low. This fact hinders the integral management of the Park and has a negative impact on the improvement of biodiversity and the promotion of ecosystem services in general and, more specifically, on the promotion of the agroforestry mosaic.

The previous urban planning regulation was centred on protecting and stopping forest transformation/degradation. Without abandoning this idea, flexible formulas need to be found to manage these spaces. To do this, changes are required in the approach, in the goals, and in the involvement of all local stakeholders, hence moving from a position of public control to one of cooperation, actually enabling dynamic and adaptive management.

Given this context, the PEPNat encourages the establishment of synergies between the management body and the owners of agroforestry estates. More specifically, it facilitates sustainable agricultural activities and it establishes a link between the admitted uses of existing traditional buildings and a specific estate management. This management should also foster the agroforestry mosaic, ensuring the role played by patches as steppingstones improving habitat surface, quality, and connectivity, among other aspects. In this way, the PEPNat aims at promoting primary sector activities from an ecological perspective, as well as recovering and highlighting the extant cultural heritage. The instrument to accomplish this co-responsibility formula is the Technical Estate Management Plan.

20.4.1 The Obligation to Draw Up and Process a Technical Estate Management Plan

The special Plan establishes the obligation to design and have an estate management plan approved in order to develop new uses in existing constructions listed in the Catalogue of *masies*. The only exceptions are family homes, as they have less impact on open spaces, and public facilities related to the Park, as their very nature already adds verifiable value to the protected space. The licence applications to implement any other use require the approval of an estate management plan. Management commitments of agroforestry estates will be coordinated with the management body and will be proportional to the characteristics of the estate and particularities of the uses to be developed. In this regard, local councils may request an economic-financial survey that demonstrates the real possibilities of executing and maintaining the proposed action.

20.4.2 Mitigation and Compensation Measures Connected with Estate Management Plans

The aspects and measures that need to be included in the management plans are of a different nature. On the one hand, in general terms the PEPNat establishes a series of prescriptions and recommendations that will have to be considered, especially in regard to crops in priority areas for agriculture and the maintenance of paths and field boundaries, as well as the particular features of the environmental zoning areas (nature reserves, patches of connectivity interest, areas of special importance, islands of tranquillity, and priority areas for agriculture).

On the other hand, the Catalogue of *masies* states the conditions of use and intervention for each traditional construction in terms of protecting and improving ecological values, biodiversity, and ecosystem services. These conditions refer both to the environmental zoning and other elements and spaces of interest. The prescriptions specify whether it is necessary to consider the development of admitted uses in regard to the presence of priority habitat types of European Community interest according to "Habitats" 92/43 EU Directive and/or the building is inside a patch of connectivity interest, a nature reserve, and their zone of influence or near the water network. In this way, the most generic determinations of the special Plan are strengthened by the corresponding information sheet of the Catalogue of *masies*. These mitigation and compensation measures complement the specific proposals and strategic projects to be developed by the management body in the environmental zones and other key sites in the Park.

In the following paragraphs, we list the different environmental zoning areas and other key spaces of interest explaining which function they perform in the Park, their extension, and how they should be addressed in management plans.

Nature Reserves

As already argued in Sect. 20.3, these areas comprise the sites declared and delimited as a partial nature reserve according to Decree 146/2010. Their purpose is to strictly conserve and, where applicable, restore natural systems, biological diversity, and the landscape. They are divided into two areas: the partial nature reserves of Rierada-Can Balasc (383 ha) and Font Groga (117 ha). The admitted uses and activities are strictly regulated and limited in these spaces, most of which consist of scientific and handling work, organic farming, livestock breeding and forestry uses associated to the management activities of the habitats, species of flora and fauna being protected, as well as activities aimed towards disseminating their values, either organized by the Natural Park management body or with its authorization. Management plans need to be consistent with this regulation.

Patches of Connectivity Interest

The purpose of these patches is to generally guarantee territorial permeability, from the perspective of ecological connectivity, both within the Natural Park and between the Park and the surrounding territory, namely, with all the other open spaces in the metropolitan region. The Plan identifies two categories of patches of connectivity interest based on their functionality: functional connective patches and water network of connective interest, which combined cover a surface of 2662 ha. Intervention criteria are established for patches of connectivity interest, in order to ensure that the natural ecological processes and flows that characterize them are maintained. It is also obligatory to avoid land fragmentation and disturbances must be minimized, thus preventing the increase of spatial land use fragmentation.

Areas of Special Importance

Permanent water points and stone pits are considered areas that require a differentiated strategy. The Plan identifies 3 water bodies of remarkable importance (Vallvidrera reservoir, Can Borrell reservoir, and the large pond of Can Coll) and 12 stone pits. For all of them three basic strategies have been identified: (1) to combine the restoration of forest areas and open spaces, (2) to not intervene and leave the ecosystems evolve naturally, and (3) to not intervene in stone pits already integrated in the urban fabric. Management plans need to be consistent with the specific strategy set for each area to promote their values individually. The main goal is to prioritize the conservation of environmental values and restrict and/or regulate public access in a way that is compatible with their potential as interpretation and knowledge sites.

Islands of Tranquillity

They issue from the identification of the least disturbed areas, mainly in relation with the social use of the Park and any other element or activity that creates disturbances in ecosystems and their functionality. Five islands have been identified, i.e. la Salut, Turó d'en Xai, Can Balasc, Sant Medir, and Can Catà. Their total surface covers an area of 2494 ha. These spaces require favourable conditions for flora and fauna and are areas that receive differentiated treatment. As a result, access and crossing is expected to be more restricted in these islands, and there are specific conditions as regards possible disturbances.

Priority Areas for Agriculture

The recovery of the traditional field structure, corresponding to an occupation consistent with the territory's physical and morphological characteristics, is key for maintaining the agroforestry mosaic. These areas cover a surface of 434 ha corresponding to both cropland currently in use and abandoned fields that can easily be recovered. Although in principle farming is admitted throughout the entire Park, to conserve and improve the Park's values, this activity is especially suited to these priority areas. It will be necessary to include provisions for these areas in the pertinent management plans and specify how the agricultural activity will be carried out.

Paths and Field Boundaries

Besides marking the edges of properties and plots, path and field boundaries play a fundamental role in the conservation and improvement of the Park's biodiversity. On the one hand, the aim is to increase the surface of cultivated land and, on the other, recover the traditional field structure by recreating field boundaries. Due to their importance as biodiversity refuges, care will be taken to maintain the vegetation, trees, and drystone walls that make up these borders. If they are affected by agricultural needs, they will be restored in the same way nearby. Their treatment should be respectful of the fauna inhabiting them.

Water Network

The water network is made up of a vast network of streams and brooks (with an extension of around 400 km), springs (around 200), permanent and temporary ponds, and 3 artificial water bodies. This network is fundamental in habitat diversity and connectivity. The management plans need to consider different aspects according to each typology of natural wet sites, all directed towards guaranteeing the conservation and maintenance of the water network and its functionality.

Priority HCI

In the Natural Park, 13 HCIs have been detected, of which 4 are priority habitat types of European Community interest (3170*, 5230*, 6220*, and 91E0*). The estate management plan will have to provide measures aimed towards their conservation.

Furthermore, it is necessary to keep in mind other spaces and elements of environmental interest included in the inventories of the PEPNat, as well as all those identified in the future by the management body.

20.4.3 Can Capellans as an Example of the Aspects to Consider in the Management Plan

Can Capellans farmhouse is a traditional private construction in poor condition. It is located in the municipal district of Molins de Rei, in an estate of over 36 hectares that borders with an industrial area outside the Park. The building dates back to the thirteenth century and has undergone successive transformations (Fig. 20.6 on the right). At present it occupies an area of over 1000 m^2 of floor area (Bosch and Caballé 2020; AMB 2019a). In accordance with the PEPNat, to develop its use as a restaurant, it will be necessary to draw up and process an estate management plan, with a 15-year timeframe, which provides for farmland management and forestry maintenance.

According to the PEPNat, a total of 22 buildings (11% of the buildings included in the Catalogue of *masies* and rural homes) can be used as restaurants, whether it is new use (11) or the maintenance of a previously existing restaurant (11). Using a traditional building as a restaurant is one of the uses that could potentially generate a higher influx of visitors and environmental impact. In addition, it is a use admitted in the current plan (PEPCo) by which the PEPNat establishes more restrictive new conditions, especially regarding access by motor vehicles, location, and the obligation to have an estate management plan.

The general aspects requiring consideration in the management plan are especially due to the fact that the site has two priority areas for agriculture, with a combined extension of 2.6 ha, and also hosts an ecological connector of high importance (the connector of the Can Miano stream) to the south-east (Fig. 20.6, left). This connector links the Park with the Llobregat river. Consequently, this area would be especially suitable for applying measures to improve habitats and their ecological permeability. It will thus be necessary to keep in mind the environmental protection measures established in the PEPNat, particularly in relation to the loss of ecological permeability and degradation of patches of connectivity interest.

As regards the information sheet of the Catalogue of *masies*, it will be necessary to consider the presence of priority habitat types of European Community interest, as well as other features of the estate, such as the pond, the drystone walls, etc.

Fig. 20.6 Can Capellans estate on the left: priority areas of agriculture (*red line hatch*), habitats of European Community interest (*orange grid hatch*), patches of connectivity interest (*green linear hatch*), and relevant items (*dots*). Pictures of the manufact on the right

particularly those included in the inventory as annexes of the special Plan, like the pond of Can Capellans. Therefore, this pond, recognized as a site of special interest for the amphibians and reptiles in the Park, will have to be restored and its functionality in this regard will have to be strengthened. Additionally, the spaces around the edge of the pond will require biodiversity improvement measures, such as planting species of trees and bushes in order to attract vertebrate fauna (mainly amphibians and reptiles). Care will be taken to favour the pond's connection with the habitats of the ecological connector of the Can Miano stream. In respect of habitats of European Community interest (HCI), the estate contains two different sites of habitat 6220*, corresponding to perennial grasslands and mentioned as being specifically related to the occurrence of ecotones in agroforestry mosaics (besides several non-priority HCIs). These sites will require specific conservation measures, and, in all cases, they will need to be protected from new uses associated to the restaurant activity (AMB 2019a).

Furthermore, other spaces and elements of environmental interest included in the annexes forming part of the PEPNat will have to be considered, as well as all those identified in the future by the management body. For example, the present study case, apart from the pond, pointed out the impact of the 500-m buffer on the nesting site of the Eurasian hobby (*Falco subbuteo* Linnaeus, 1758), being the slopes of Can Canaris at the same time a site of interest for cliff-nesting birds and a site with high richness of amphibians.

20.5 Final Considerations

The co-responsibility formula in the Park's agroforestry management offers a series of benefits, but there are also a number of difficulties and challenges, especially in the future. The former are related to the pursued goals: in the first place, improvement of biodiversity, provision of ecosystem services, and maintenance of agricultural surface and the remaining built heritage and, secondly, the mitigation and adaptation to the effects of climate change, prevention of natural hazards, and the provision of locally produced food. On the other hand, the difficulties are related to the lack of similar cases to use as a reference and the particular features of the estates that make up the Park, while the challenges consist of opportunities and changes that need to be made in order to ensure the success of the proposal, its replicability, and implementation at metropolitan level.

20.5.1 Ecological, Social, and Financial Benefits of Co-responsibility

There are multiple benefits and they belong to different scales. The proposal improves the landscape and environment of the protected space and is financially beneficial, for both governmental and private entities.

At an estate level, it is appropriate to underline the possibility of populating traditional manufacts, create direct ties between owners and the natural Park's values, and strengthen the settlement of possible disputes with proximity and at a local scale. As regards matters concerning the Park, it enables more efficient integrated management of the natural space. More specifically, it facilitates the implementation of a coordinated policy to maintain the Park's values, as well as promote the agroforestry mosaic and improve biodiversity, while guaranteeing the development of the Farming and Livestock Plan (Pla Agropecuari PNSC) and the conservation of built heritage. On the other hand, by incrementing the Park's surface managed according to the criteria established by the management body, it will be possible to better manage natural hazards and increase the territory's resilience against the effects of climate change. In this regard, the action that needs to be taken by private owners in compliance with the technical estate management complements the specific proposals and strategic projects to be developed by the management body in the environmental zoning areas and other key sites in the Park. Therefore, the co-responsibility formula makes it feasible to achieve the goals of the declaration of the natural Park in a coherent manner, in accordance with current budgetary resources. A third level would be the metropolitan scale where, if this model is successful, the proposal could be extrapolated in order to strengthen the functionality and services offered by green and blue infrastructure.

20.5.2 Main Difficulties

The most significant difficulties can be sorted in two groups: on the one hand, difficulties deriving from the change of paradigm entailed by the proposal and, on the other, the low profitability and wide range of specific cases, in terms of both the estates and traditional constructions in the Park, and possible future scenarios that could derive from admitting new uses.

Although there is certain agreement in relation to the good faith of the co-responsibility approach, as shown by relatively recent initiatives, it is still an innovative approach that not only has to dispel the doubts of reluctant legislators but also has to convince owners that are largely uninformed. For example, both the preliminary document of the metropolitan master Plan and the draft bill of the new planning Catalan law include the need to find formulas for the co-management of open spaces. The first especially focuses on agroforestry land with the purpose of encouraging agricultural activity and forestry management. One of its main goals is to ensure ecological functionality and to obtain benefits from own resources using the logic of a green and circular economy (PDU 2019a). In addition, the latter proposes in general terms that the use of existing buildings and custody of affected estates are compulsory conditions for authorizing uses and works in open spaces (DGOTU 2017). Nevertheless, the current legislative framework for urban development matters does not explicitly provide for this possibility.

On the other hand, of the 199 constructions included in the Catalogue of *masies*, only 55 have an estate of over 15 Ha and could therefore benefit from the measure. It must also be borne in mind that the authorization of uses with the greatest impact, which are usually the most profitable, depends on numerous variables. Alternative formulas need to be devised for estates that do not contain patrimonial constructions that could be used as restaurants, rural accommodation, or facilities, whether it is because they do not contain any constructions building (8), they are not large enough (32), or the construction does not match with the established criteria.

Likewise, there is a wide disparity of sizes and situations. The gross floor area of constructions included in the Catalogue ranges between 100 and 7000 m^2, with 40% of the construction with a floor area of less than 500 m^2 (AMB 2019a). This implies numerous variations in terms of profits from the possible admitted uses. However, there are also significant differences in the size of the estates and extent of the aspects to consider, a fact that requires care when it comes to assessing estate management plans.

Besides the wide range of specific cases of estates and their associated constructions, it should be remembered that, depending on the uses that will be implemented in the Park, there will be multiple future scenarios of a very different nature. As a result, taking into account that Collserola is a complex territory – due to both its location and vocation – it will be important to monitor the effect of the adopted strategies to be able to continuously assess their development and meet the set goals. Finally, it must also be taken into account that the function of the Collserola range is not isolated, but it interacts with the metropolitan context and it is also prone to climate change.

20.5.3 Future Challenges

The future challenges identified during the writing stage of the PEPNat are especially related to the change of paradigm, particularly connected to the need to create trust, to obtain the full involvement of owners and Park managers, and to regularly assess the effects of the plan on the natural heritage of the Park. In this regard, throughout the participation process, special emphasis has been placed on two concerns that received numerous enquiries and contributions: an approach towards agrosilvopastoral activities that enhance the biodiversity and resilience of the Park and a new policy based on a public-private ownership (AMB 2019c: 173). To do that, it would be necessary to strengthen the synergies between the management body and private owners in order to reactivate the sector. Involving the owners in the different approaches and management stages is a key factor. This line of work should be studied further to obtain the participation of the owners and citizens in general.

In relation to regular impact assessment, it is important not to lose sight of the overall view and take into account the possible cumulative effects of the admitted uses in the *masies*. Therefore, special attention needs to be paid to the number, quality, and achievement of approved management plans. Thus, to orchestrate dynamic and adaptive management, capable of responding to the Park's changing reality, the Plan includes a set of indicators to monitor the status of the protected space. These indicators have been set at the Park and the estate scale. In terms of the proposal concerning this chapter, the indicator that refers to the proportion of cropland/open spaces, scrubland and forest areas, and the indicator that assesses the changes of use in traditional constructions should be highlighted. These indicators need to be monitored to give a suitable response in accordance with the established goals.

Agreeing to an estate management plan makes it possible to create a fully managed territory, making it more resilient and functional, with a high level of quality in terms of biodiversity and the capacity to regulate natural cycles. At a second stage or scale, the replicability of the proposal and its performance in a larger context should be considered in order to extend it to other key open spaces of the metropolitan green infrastructure. Thus, after confirming that the proposal functions properly in the Park and corroborating its benefits, it should be tested in other forest areas with different characteristics, such as the Marina mountain range or the Ordal mountains. In all these areas, their particular features should be considered as well as the possible benefits of the territory's biodiversity and the provision of ecosystem services, without forgetting the potential undesired disturbances. The final challenge would be adopting equivalent formulas at a metropolitan level for the agroforestry mosaic as a whole.

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Part III
Nature-Based Solutions and Innovative Design Approaches

Chapter 21
Exploring Regenerative Co-benefits of Biophilic Design for People and the Environment

Maria Beatrice Andreucci, Angela Loder, Beth McGee, Jelena Brajković, and Martin Brown

Abstract There is an increasing awareness of the role that buildings, districts, and neighborhoods play on health in the wake of the Covid-19 pandemic that coincides with pressing climate concerns. This has renewed attention to the benefits of nature for both human and climate health. Buildings, cities, and regions are attempting to align regenerative design principles with human health goals but often lack the tools and knowledge to do so. This is partly rooted in a failure to understand how to apply research and policy for different contexts as well as at different scales. It is also still uncertain exactly what types of nature can lead to which types of benefit, and for whom, despite long-standing research within the environmental psychology, sustainability, and design fields. This chapter outlines key research paradigms that influence the way we understand the benefits of nature, where biophilic design theory sits in this field, and how it can be and has been applied at different scales through two case studies at the building and city scale. This chapter ends with the proposal of new directions for integrating biophilic design into regenerative design and policy.

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_21

Keywords Biophilia · Health and well-being · Research paradigms · Restorative environmental design · Urban policy · Regenerative design

21.1 Introduction

Integrating nature into our cities, and more recently, our buildings, has long been associated with improved environmental and health outcomes. The recent Covid-19 pandemic has also thrown into sharp relief the role that buildings, districts, and neighbourhoods play in human health: both from location – those living in areas with worse air pollution have been shown to have a higher death rate from Covid-19 (Wu et al. 2020) – and from amenities. For example, the role of urban parks in stress reduction and socialization has renewed attention on the benefits of nature, both in and outside buildings (Surico 2020). However, despite long-standing research on the benefit of access to nature for human and climate health, there is still uncertainty in the sustainability and design fields on exactly what types of nature can lead to which types of benefit, and for whom. Uncertainty is partly rooted in a failure to understand how to understand and apply research on nature and health to different design and policy interventions at different scales. Issues arise also from a disconnection between biophilic design principles and specific health outcomes, as well as from a lack of integration between different fields. This is particularly true as buildings, cities, and regions attempt to align regenerative design goals with human health ones but often lack the tools and knowledge to do so.

This chapter outlines key research paradigms that influence the way we understand the benefits of nature for different sectors, including the workplace, neighbourhood, and city, and explains where biophilic design theory sits in this field. A brief explanation of the key driving beliefs and goals of the most influential research on health and nature, key known outcomes, and how and where they can be used to support the integration of nature into buildings, communities, and cities to support human and ecological health is provided. This is followed by a discussion about how this research aligns, or does not align, with architectural and urban design. Through case studies at the building and city scale, this chapter then examines how biophilic design can be applied and highlights lessons learned, synergies, and trade-offs when implementing nature for both human and ecological health. The contribution ends with key policy and design lessons learned around regenerative design and biophilia, as well as with the indication of new directions for action, particularly with regard to climate change and infectious disease.

21.2 Key Research Paradigms on Benefits from Access to Nature and Health

The last 30 years have provided vast amounts of empirical data to support the now well-established observation that access to nature has benefits for human health and well-being. This has captured the interest of health practitioners who are prescribing time in nature to their patients. It has also been of interest to designers who include access to nature for its diverse benefits, such as in the workplace, and city planners who are interested in the sociocultural benefits of green infrastructure for human health and well-being (Millennium Ecosystem Assessment 2005). Despite this evidence, there remains a disconnect between this vast body of research and the kind of evidence that convinces stakeholders that adding nature will reap real, measurable benefits for their particular project. This is partly due to the types of research – and the paradigms that support them – that lie behind the vast majority of findings that have gotten the attention of policymakers and building owners and that does not always align with the more holistic approach of designers using a *biophilic* framework (Wilson 1984).

There is a wide variety of measures and types of research on health and nature which can complicate comparison and make the establishment of robust results difficult. The most influential research programs in the last 30 years have been based on adaptive or utility paradigms. The adaptive paradigm is grounded in the assumption that biological survival (or evolution) motivates psychological and physiological responses to the environment and that certain environments are better suited to human health and well-being than others. The most common research programs that have come out of the adaptive paradigm have focused either on so-called restorative environments that help to improve cognition or the restoration of attention, notably Stephen and Rachel Kaplan's attention restoration theory (ART) (Kaplan and Kaplan 2005; Kaplan 1995), or on the ability of those restorative environments to support stress recovery and positive mood, notably Roger Ulrich's psychophysiological stress reduction theory (PSR) (Ulrich 1993).

Research testing the ART argues that nature possesses four attributes necessary to hold our attention involuntarily and be experienced as restorative: fascination, mystery, coherence, and the feeling of *being away* (Hartig et al. 1991). A large subset of this research has looked at aesthetic preferences for different types of nature, arguing that some types of nature are more conducive to restoration than others and that nature is more restorative than urban environments (Kaplan and Kaplan 2005). Research testing the PSR theory also uses an evolutionary biology theory, which states that, because we evolved in *nature*, we need to feel connected with natural stimuli; this attitude is called *biophilia* (translated as a love of nature) (Ulrich 1993).

The utility paradigm, though related, focuses on the role that nature plays as a quality of an environment to satisfy current personal or interpersonal needs, often measured by levels of physical activity, restorative experiences, or social cohesion, interaction, and safety.

Though there is qualitative research that has been done in the adaptive and utility paradigms, the vast majority of this research follows a psychometric research approach, which aims to generalize human relationships with nature through quantifiable measures (Zufferey and King 2016). Research also tends to follow, or support, a linear, individualistic, and reductionist approach to understanding how and why nature supports health, focusing on the mechanism between the phenomena (here nature) and the response in the individual (Herzog et al. 2002; Patterson and Williams 2005). This approach that aligns well with green building paradigm has created a vast amount of data on the benefits of access to nature (outlined below), has been very influential in public policy, and has provided much of the support for adding nature into buildings, neighbourhoods, and cities to date. However, this type of linear and somewhat mechanistic approach to nature and health does not always align well with the more holistic, design-thinking approach seen in biophilic design and green infrastructure work to support human health, as will be explained further. This approach also tends to miss some of the collective lived experience of place aimed at in biophilic design.

Critics have argued that studies following the adaptive paradigm tend not to address the larger context of place including economic, social, and political forces that structure environmental conditions and distributions of power that influence access and regulate these conditions within society. For example, some people may be threatened by *messy* ecological urban greening projects despite their good intentions and environmental value. Similarly, the utilitarian paradigm has been criticized for its limited understanding of the socio-economic and sociocultural factors influencing access to nature, the reduction of environmental values to utility, and the general disregard for the symbolic meaning of nature for humans. This can be problematic when designing biophilic interventions for specific populations or disadvantaged communities, when aiming to create a positive sense of place, or even when trying to compare biophilic interventions with complex outcomes such as workplace productivity. Thus, while the adaptive and utility research has provided strong evidence to support the health goals of biophilic design, biophilia's focus on sense of place, lived experience, and holistic design-thinking may be more aligned with some of the relational and sense of place work on the human relationship to nature that rarely gets cited. Why is this important? By understanding the strengths and limitations of research being used to support nature interventions for health at different scales, designers, engineers, and building owners can be better equipped to draw upon the right research for the right context. This in turn can build trust and better align design goals with the specific context and outcomes desired. Below are some examples of what kind of research can be applied to which context, followed by its application in case studies.

21.2.1 Physiological and Mental Health and Well-Being

As indicated above, the adaptive and utility paradigms have created a vast amount of research linking access to nature and improved physiological and mental health and well-being. Some researchers have theorized these relationships as a series of pathways: (1) stress reduction, (2) physical activity, (3) social cohesion, and (4) air quality (Hartig et al. 2014).

The first pathway – following the adaptive paradigm – has traditionally received the most empirical and theoretical attention and focuses on the restoration theories outlined above: (a) the evolutionary-based positive affective responses to nature (Stress Reduction Theory: Ulrich et al. 1991) and (b) the cognitive recovery and resource replenishment after viewing natural settings (Attention Restoration Theory: Kaplan 1995). These two theories mainly rely on aesthetic and visual qualities of the natural environments and are related to presumed intrinsic characteristics of nature-based on evolutionary theory and the related biophilia (or *biophobia* – fear of nature) (Kellert and Wilson 1993; Ulrich 1993). Studies following this paradigm have been done at multiple scales and with various types of nature – ranging from lab studies to wilderness excursions. This variety speaks to the strength of the research, though their application at a building scale has been harder to evaluate, given the high number of factors involved. Importantly, the underlying evolutionary paradigm – i.e., that love of nature is innate – can seemingly hide cultural, socio-economic, and power differences that influence the success of different urban greening interventions and equitable access to nature for all.

The second pathway, physical activity, follows the utility paradigm and is recently gaining attention. Outdoor physical activity (as opposed to sedentary behaviour) has demonstrated positive effects on mental health. Experimental studies have pointed at added benefits of physical activity in green areas as opposed to indoor or artificial urban areas (Barton et al. 2012). However, cross-sectional and/or epidemiological studies at the neighbourhood scale show unclear results (van den Berg et al. 2019). This is partly due to the difficulty of applying lab-based studies to real-world situations, where other explanatory variables may be influencing outcomes, and the need to take into account other factors such as green space characteristics, location, and other influences on behaviour or preferences. For example, factors other than green space availability may facilitate or hinder physical activity. A study in Denmark found that it was not necessarily the amount of green space in the proximity of participants' homes to be appreciated but the availability of specific green space characteristics such as walking routes, wooded areas, a water area, or a pleasant view (Schipperijn et al. 2013).

Improvement in social interactions (at the individual level) and social cohesion (at the neighbourhood level) is a third proposed pathway linking nature exposure with mental health. Research in this pathway often varies in its research paradigm or approach. For example, the design of urban parks have been found to influence the relationship between green space and social cohesion (Peters et al. 2010). Research like this often falls under a utility paradigm, i.e., what characteristics of nature influence desired uses or behaviours. Conversely, the link between social interaction and mental health has been firmly established (Holt-Lunstad et al. 2010) although the link between social interactions and social cohesion and green space has received less research attention than the first two pathways. This type of research sometimes follows a public health socioecological approach (which looks at complex factors influencing health outcomes) that enables it to be adopted by public policy (Jennings et al. 2016).

Air pollutants, the fourth pathway, have also received less attention. Air pollution does have pronounced negative effects not only on physical health and mortality (Sun and Zhu 2019) but also on mental health (Klompmaker et al. 2019) and cognitive performance (Calderón-Garcidueñas et al. 2014). Besides a direct link between air pollution and mental health, it has also been proposed that air pollution, together with traffic-related sounds, can put a constraint on the restorative potential of an environment (von Lindern et al. 2016). Trees and plants do not reduce all pollutants; some, for instance, also release pollen which may aggravate allergies (Cariñanos et al. 2019; Hartig et al. 2014), thus taking into account ecosystem disservice is equally important. This last pathway can be one of the most easily integrated into regional-level planning and regenerative policies and can be a good way to balance synergies and trade-offs at this scale (Fig. 21.1). However, the benefits of nature

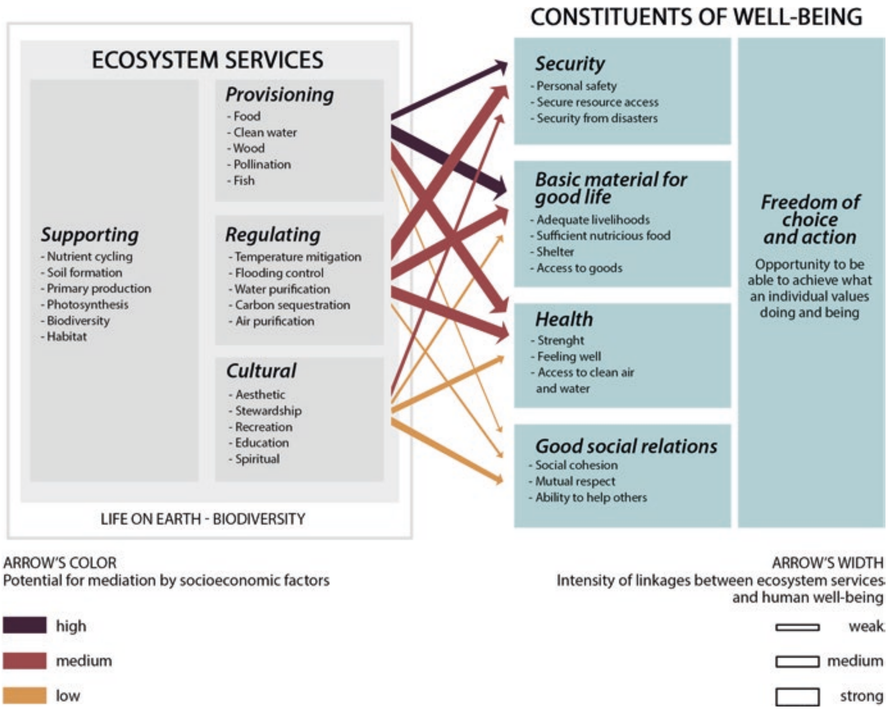

Fig. 21.1 Services and constituents of wellbeing. (Adapted from Millennium Ecosystem Assessment 2005)

explored in typical city or regional-level analyses and policies often lack the specific detail on health outcomes seen in the other three pathways, leaving building-level owners feeling a sense of disconnection between project-level nature-health outcomes and regional goals.

21.2.2 Cognitive Function and Performance

To assess cognitive function and performance, research about the benefits of nature in the workplace can be critically examined in order to guide design interventions. For example, multiple studies have shown improved task performance from access to nature – measured often through cognitive tests and proxies for productivity. These studies have been criticized for not replicating the actual day-to-day tasks of office workers, and there have been very few studies done in situ for office workers.

The benefits of improved task performance from better concentration are supported by multiple studies in nature (Choudry et al. 2015; Li et al. 2018). These proxies should not be used alone to prove increased performance; however, if combined with other measures at an individual and organizational level, they can provide a reasonable indication of cognitive function and performance in the workplace. This means that biophilic designers can confidently argue that access to nature can support better concentration and performance for those nearby (Loder 2020).

21.2.3 Biophilic Design Attributes and Troubles of Implementation

E.O. Wilson (1984) originally proposed the *biophilia hypothesis* which prompted the modern biophilic design movement. He defined *biophilia* as the "innately emotional affiliation of human beings to other living organisms. Innate means hereditary and hence part of ultimate human nature" (Wilson 1984: 31).

Wilson proposed that people have an innate need to connect with nature and natural processes. S.R. Kellert and E.O. Wilson then applied this concept to the built environment (1993). The idea went beyond just working with a green and plant-like environment. It was initially operationalized in Kellert's proposed attributes for *biophilic design* (2008), where he introduced key dimensions, elements, and attributes of biophilic design. As two main dimensions, the author identified organic/naturalistic and place-based/vernacular. Organic dimension refers to "shapes and forms in the built environment that directly, indirectly, or symbolically reflect the inherent human affinity for nature" (Kellert 2008: 5). Vernacular dimension refers to "buildings and landscapes that connect to the culture and ecology of a locality or geographic area" (Kellert 2008: 6).

As Kellert points out, this latter dimension includes a sense or a spirit of place. Further classification goes to 6 main elements, which then break out into more than 70 biophilic design attributes. These attributes are as simple and straight forward as presence of water, air, sunlight, plants, and animals, but also, there are more complex ones – sensory variability, information richness, exploration and discovery, or geographic, historic, ecological, and cultural connection to place. Importantly, biophilic designers need to understand that the environment can be an atmosphere, a process, or an experience. If architecture is not atmospheric and does not generate a *sense of place*, then it is *lifeless.* Recognition of atmospheres, ambiances, energies, mediation, experiences are considerations of biophilic design and are important if we want biophilic design to be meaningful and a feel-good lived experience.

> The ambiance or atmosphere of a room or an urban space is the overall feeling and tuning of the experience. It is a non-material or peripheral experience that tunes our minds in a specific way. We feel atmospheres immediately and without being conscious of the process. The final target of the design is not the physical building but its impact as a lived experience. (Pallasmaa 2018: 2, 3)

Within Kellert's theory, defined elements and attributes are open to revision, while others are improvable over time. There have been some further revisions to Kellert's work, an example of which is Terrapin Bright Green's *14 Patterns of Biophilic Design – Improving Health and Well-Being in the Built Environment*. This report defines 14 patterns of biophilic design organized into Nature in the Space, Natural Analogues, and Nature of the Space Patterns. Another is the Biophilic Interior Design Matrix which adopts and adapts Kellert's work to operationalize it for interior environments (McGee et al. 2019) in order to provide tangible and clearer guidance for designers.

Kellert (2008) also pointed out some of the difficulties with biophilic design that designers experience in practice, especially when translating conceptual and abstract attributes into design. Biophilic design is not always straightforward in its guidelines, and many people want clear rules that they can apply to design or that can be added into modelling software. The patterns and attributes of biophilic design are almost philosophical and require a holistic approach and profound understanding of both human and non-human environmental factors and components – their purpose and relationship that generates the overall atmosphere. Examples include their sense of place and the *lived experience*, which is the ultimate goal of architecture. Good biophilic designers must have highly developed both rational and irrational skills in designing space. They must understand all dimensions of space and human experience – mental, sensory, temporal, natural, cultural, traditional, etc., as well as a sense of playfulness. This kind of approach to the benefits of nature does not always align well with health-nature scientific evidence that uses a psychometric research paradigm, which can lead to a disconnection, which in turn can be expressed as a lack of knowledge about existing health-nature research and/or as a difficulty translating biophilic attributes into design goals that can be measured and quantified.

21.3 Applying Research to Practice

Biophilic design is illustrated below at two different levels of implementation: buildings and city scale. This emphasizes the value of biophilic design principles for people and the interior environment, followed by its application at a regional scale for regenerative design and resilience.

21.3.1 The Biophilic Interior Design Matrix

How can we apply biophilia at a building scale and codify the principles for designers? Since people spend most of the day inside, it is necessary to further address how to support biophilic design and its related benefits at the building scale. The Biophilic Interior Design Matrix was recently developed attempting to operationalize biophilic design to give guidance for interior environments without being prescriptive (McGee et al. 2019). This includes looking at a variety of experiential considerations like sensory comfort, psychological feeling, and spiritual experience. It was tested with interior design practitioners using evidence-based design, to develop the language to be user-friendly and offer specific examples for clarity. The Matrix has six elements offering connections to nature originally based on Kellert's (2008) work. The categories are as follows: (1) actual natural features (what we usually think of when we talk about biophilia, bringing actual nature inside), (2) natural shapes and forms (representations of nature), (3) natural patterns and processes (natural features that change over time like weathered leather), (4) colour and light (design considerations like pools of light), (5) place-based relationships (historical connections like old portraits), and (6) and human-nature relationships (things that when paired represent nature-like order and complexity, when used together there is harmony). These 6 elements include 54 interior design attributes that provide a great variety of design features.

The Matrix can be used as a post-occupancy assessment tool, and it also has been useful during the design process as a conceptual aid and creativity boost. The Matrix also helps designers feel more confident and knowledgeable about biophilic design after using it. Aiming at overcoming the elusiveness of the biophilia concept, a growing body of research is more recently linking specific biophilic attributes with evidence-based design. When one seizes to deeply understand the core concepts of biophilia, respect its values, and constantly rediscover them, one practises biophilic design with ease and playfulness. The Matrix supports this and aids users to better understand the concepts of biophilic design, specifically biophilic interior design (see Fig. 21.2 for full attribute list).

Fig. 21.2 Biophilic Interior Design Matrix. (Source: Beth McGee et al. 2019)

21.3.2 Case Study: The University of Florida Clinical and Translational Research Building

With the growing research and interest focused on biophilic design, it is interesting to look at a building specifically designed and constructed as a model to highlight the biophilic indoor attributes. The University of Florida Clinical and Translational Research Building was built in 2013 by a well-known architecture firm, and it was inspired by biophilia (University of Florida Clinical and Translational Research Building 2014). The concept "emerged from the desire to provide sustainable healing, working and educational environments" (University of Florida Clinical and Translational Research Building 2014: online). The approach the firm took to site the building aligns with biophilia in understanding the existing environment and surrounding context, including both the geography and man-made structures. It also integrates sustainable design features like solar panels and recycled building materials. The LEED Platinum certification represents the University's sustainability mission and commitment which is "protecting the environment, health, and well-being of our employees, customers and the global communities where we operate", according to the plaque in the lobby. This further connects to the long term of goal of biophilia to be restorative in all manners (Derr and Kellert 2013).

This facility is 120,000-square-feet with two joined wings at a central atrium. This layout is an example of the attribute *linked series and chains*. Looking only at the atrium, there is a prominent staircase that encourages moving and fitness that also represents the attribute *exploration/discovery*. The west-facing two-storey curtain wall provides ample *natural light* and *spaciousness*. It has a view to the outside wetland (*views and vistas*) and Cairn, a sculpture by Adam Frezza and Terri Chiao. There is also a nice play of light from the artificial linear recessed downlights and the sunlight reflecting off the flooring (*reflected light*). The two-tone flooring continues to the outside and creates a nice continuity that represents *inside-outside*. These are a few of the attributes included (Fig. 21.3).

This space has a variety of biophilic attributes that are supported by a thoughtful application of features. During testing of the recent Matrix revision, this space did receive comments from experienced design practitioners that the space seemed very cold and not optimally biophilic. It appears that although a design may do a great job in adding direct visual connection with nature and a few strong nature-based features, this may not fulfil all the experiential components required for biophilia. Using a higher variety of design attributes may be more successful in eliciting connections to nature, which aligns with the idea that our innate need to connect with nature would require variety similar to natural environments that are rich with sensory feedback. Looking at the six main elements and seeing how one can use features from each element to further deliver more variety can be a stronger biophilic strategy for designers in eliciting preference as greater variety appears to support increased preference for a space. The wider variety of items used in the interior, when also thoughtfully applied, theoretically make the interior feel more like a nature-based environment. This seems to fit the biophilia hypothesis. Given the fluid

Element	Site Image	Attributes
Actual Natural Features		Views and Vistas* Habitats*
Natural Shapes & Forms		Botanical Motifs* Animal* Shells & spirals* Fluid forms Abstraction of nature Inside-Outside*
Natural Patterns & Processes		Sensory richness Age, change & the patina of time Area of emphasis Patterned wholes Bounded spaces Linked series & chains Integration of parts to wholes Complementary contrasts Dynamic balance & tension Natural ratios & scales
Color and Light		Composition Communication Preference Pragmatics Natural light* Filtered light Reflected light* Light as shape & form Spaciousness* Spatial variety Space as shape & form Spatial harmony
Place Based Relationships		Geographic connection to place Ecological connection to place Cultural connection to place Integration of culture and ecology
Human Nature Relationships		Order AND complexity Curiosity AND enticement Attraction AND attachment

Fig. 21.3 Elements and attributes of biophilic interior design included in lobby, based on the Biophilic Interior Design Matrix. Starred items are strongly present. (Images shown help illustrate the overall context. Photos by Beth McGee et al. 2019)

nature of biophilic design, this codification can help link the more abstract elements of biophilia with design guidelines. Combined with data on the benefits of access to nature outlined above, this example provides a hybrid approach to translate research to practise effectively.

21.3.3 Oslo, Norway. The Blue-Green City: A Conscious Choice

Looking next to the city scale, the translation of biophilic design interventions for human health and well-being is found in the City of Oslo. The City of Oslo, in Norway, spans 454 km^2 and consists of 32% built-up areas, 60% forests, 2% agricultural land, and 6% freshwater. The city is situated at the end of the Oslo Fjord and is surrounded by water and islands to the south and forests to the north and east. Ten main rivers run through the urban areas (Oslo Kommune 2019).

Since the end of the nineteenth century, the City of Oslo has invested in its blue-green infrastructure, acquiring several forests and islands surrounding the city in order to provide its citizens with recreational areas and to secure potable water. As a result, large tracts of forests surround two-thirds of the urban areas, and drinking water is sourced from lakes within the city's borders.

Ninety-four per cent of the Oslo inhabitants live within 300 m of a blue-green area. Biophilic planning and design principles (Box 21.1) – following Oslo official plans – led to the construction of parks and gardens, as well as of 220 km of greenways and footpaths that contribute to easy access to nature, and sustainable transportation in the city while providing ecological corridors for plants and animals.

Box 21.1: Attributes of Biophilic Design

Direct experience of nature

- Light
- Water
- Vegetation
- Animals
- Weather conditions
- Natural landscape and ecosystems
- Fire

Indirect experience of nature

- Images of nature
- Natural Materials
- Natural Colours
- Simulated natural light and air
- Naturalistic shapes and forms
- Evoking nature
- Information richness
- Age, change, and patina of time
- Natural geometries
- Biomimicry

Experience of space and place

Prospect and refuge
Organized complexity
Integration of parts to wholes
Transitional spaces
Mobility and wayfinding
Cultural and ecological attachment to place

(Adapted from Kellert and Calabrese 2015)

The *iceberg*, i.e., the Oslo Opera House, conveys concepts of togetherness, joint ownership, and easy and open access for all. The Harbour Promenade, opened in 2015, is one of Oslo's newest paths and stretches for 9 km along the waterfront. Parks adjacent to waterways play a central role in Oslo's action plan for stormwater management by functioning as retention basins during extreme weather events. In order to accommodate its growing population, sites along the waterfront, in the city's Fjord City project – areas like Tjuvholmen, Aker Brygge, Barcode, and Sørenga – have been more recently transformed from shipyards and dry docks into compact densely populated eco-neighbourhoods that combine 9000 new dwellings, 45,000 new workplaces next to shops and restaurants, and more than 50 ha of parks and *biophilic* public spaces. The bathing water quality is now either good or excellent, and two outdoor public sea baths were opened in 2013 and 2015 (Oslo Kommune 2019) (Fig. 21.4a. b).

Worldwide, edible city projects have demonstrated that cultivated urban spaces (e.g., allotment gardens, edible forest gardens, edible urban forests) can improve social cohesion, healthy ageing, and well-being (Andreucci et al. 2019). Oslo's horticultural therapy project of Losæter *Garden of Senses* evolved from grassroots movements and stands out as a biophilic success. Located in Sørenga near the Oslo Fjord the project has emerged through an organic process that was started by the artist group Futurefarmers in 2011. The project belongs to the *Sprouting Oslo* programme, an outstanding example of the 2019 Green Capital's commitment to productive, inclusive, and *healing* urban landscapes (Andreucci et al. 2019) (Fig. 21.4a, b).

As the European Green Capital 2019, Oslo has taken on an important task, i.e., to be a role model to other cities. Oslo is small enough to test innovative biophilic solutions. However, Oslo is also big enough for those solutions to be scaled up to larger cities.

Oslo's population is expected to increase 35% by 2040. Population growth demands densification near transport nodes and regeneration of underused areas. In these areas, Oslo is therefore currently implementing biophilic planning guidelines in order to encourage the establishment of new green areas and meet the demand from all residents.

		Environmental Features	Natural Shapes and Forms	Natural Patterns and Processes
SCALE **Building** PLACE **Opera House**		Color, Water, Air Sunlight Natural Materials Views, Vistas Landscape Habitats, Ecosystems	Simulation of Natural Features Biomorphy, Geomorphology, Biomimicry	Sensory Variability Information Richness Central Focal Point Bounded Spaces and Transitional Spaces Dynamic Balance and Tensions
SCALE **Urban Park** PLACE **Bee Sanctuary**		Color, Water, Air Sunlight Plants, Animals Natural Materials Landscape Habitats, Ecosystems	Botanical and Animal Motifs Simulation of Natural Features	Sensory Variability Information Richness Patterned Wholes Linked Series and Chains
SCALE **District** PLACE **Akerselva**		Color, Water, Air Sunlight Plants, Animals Natural Materials Views, Vistas Greewalls Geology, Landscape Habitats, Ecosystems	Botanical and Animal Motifs Simulation of Natural Features Trees and Columnar Support Biomorphy, Geomorphology, Biomimicry	Sensory Variability Information Richness Age, Change and Patina of Time Bounded Spaces and Transitional Spaces Integration of Parts to Wholes
SCALE **Neighborhood** PLACE **Sørenga**		Color, Water, Air Sunlight Plants, Animals Natural Materials Views, Vistas Geology, Landscape Habitats, Ecosystems	Botanical and Animal Motifs Simulation of Natural Features Biomorphy, Geomorphology, Biomimicry	Sensory Variability Information Richness Age, Change and Patina of Time Bounded Spaces and Transitional Spaces Integration of Parts to Wholes Dynamic Balance and Tensions
SCALE **Community** PLACE **Losæter**		Color, Water, Air Sunlight Plants, Animals Natural Materials Views, Vistas Green Walls Geology, Landscape Habitats, Ecosystems	Botanical and Animal Motifs Trees and Columnar Support Shapes Resisting Straight Lines and Right Angles	Sensory Variability Information Richness Age, Change and Patina of Time Growth and Efflorence Patterned Wholes Bounded Spaces and Transitional Spaces

Fig. 21.4 (**a**, **b**) Elements and attributes of biophilic design in Oslo. (Adapted from Kellert 2008. Photos by Maria Beatrice Andreucci)

21.4 Biophilia and Connection to Nature: A Missing Link for Sustainable Behaviour and Climate Change?

Climate change has been described as:

> […] the most serious threat to global economic, social and environmental stability in recorded history […] with many […] prevalent human diseases linked to climate fluctuations. (Africa et al. 2019: 2)

Some have argued that it is our destruction of natural habitats that helped the current Covid-19 pandemic and that we can expect more zoonotic-originated diseases in the future:

> There is a single species that is responsible for the Covid-19 pandemic - us. As with the climate and biodiversity crises, recent pandemics are a direct consequence of human activity. (Settele et al. 2020: 1)

Light and Space	Place Based Relationships	Evolved Human Nature Relationships	
Natural Light and Shadow Filtered and Diffused Light, Reflected Light Spaciousness, Space as Shape and Form Spirit of Place and Avoid Placelessness	Historic, Geographical, Cultural, Ecological Connection to Place Landscape Features that Define Built Form Spirit of Place and Avoid Placelessness	Order and Complexity Curiosity and Enticement Attraction and Beauty	SCALE **Building** PLACE **Opera House**
Natural Light and Shadow Filtered and Diffused Light, Reflected Light Spatial Variability and Harmony	Historic, Geographical, Cultural, Ecological Connection to Place Indigenous Materials Landscape Orientation and Ecology	Information and Cognition Curiosity and Enticement Exploration and Discovery Affection and Attachment	SCALE **Urban Park** PLACE **Bee Sanctuary**
Natural Light and Shadow Filtered and Diffused Light, Reflected Light Spatiousness, Space as Shape and Form Spatial Variability and Harmony	Historic, Geographical, Cultural, Ecological Connection to Place Landscape Orientation and Ecology Spririt of Place and Avoid Placelessness	Exploration and Discovery Affection and Attachment Security and Protection Attraction and Beauty	SCALE **District** PLACE **Akerselva**
Natural Light and Shadow Filtered and Diffused Light, Reflected Light Spatiousness, Space as Shape and Form Spatial Variability and Harmony	Historic, Geographical, Cultural, Ecological Connection to Place Indigenous Materials Landscape Features that Define Built Form	Curiosity and Enticement Exploration and Discovery Security and Protection Attraction and Beauty	SCALE **Neighborhood** PLACE **Sørenga**
Natural Light and Shadow Spatiousness, Space as Shape and Form Spatial Variability and Harmony Inside-Outside Spaces	Indigenous Materials Landscape Orientation and Ecology Landscape Features that Define built Form Spirit of Place and Avoid Placelessness	Prospect and Refuge Security and Protection Curiosity and Enticement Attraction and Beauty Affection and Attachment	SCALE **Community** PLACE **Losæter**

Fig. 21.4 (continued)

In figuring out how to address future global emergencies like Covid-19, our connectedness and relationship with nature, and in particular biophilic design, may be key for improving sustainable behaviour and our well-being. Rather than relying on abstract universal ideas of *nature* to encourage sustainable behaviour, using design and policy at a building, neighbourhood, and city scale to connect our daily lives with nature may encourage connection and make action feel more meaningful. Improving sustainable behaviour might then help address the current climate and disease crisis. For example, while inaction and business as usual has plagued climate change policies, Covid-19 has exposed the connection between climate change and infectious disease, with those who have been exposed to air pollution dying at a higher rate (Wu et al. 2020).

Covid-19 has also highlighted the role of nature in mental health and socialization. We have been forced to slow down and pay attention to nearby nature and the role it can play in our mental and physical health. Urban parks, or the lack thereof, are making headlines for their role in nurturing quarantined people's mental and physical health (Surico 2020). Throughout the lockdown, government, regional, and city officials have recognized the importance of space, from country parks to city parks and urban green spaces, as vital for physical and mental well-being. Getting out of buildings, into natural green space, walking, or *forest bathing* has long been recognized as beneficial and a prescribed option for general practitioners. Even observing the ordered complexity of fractals, which are self-similar scales found within nature, can reduce stress. This is a key relief needed during Covid-19.

The (re)discovery of the joy and refuge of nature, specifically local nature on doorsteps and in our gardens, has led to newfound delight in fractal minutiae around us and a slowing down of the pace of urban life. This slowed pace may be key to increasing the restorative benefits of nature. Isolation and quarantine have slowed down lives, providing the time to notice, in real time, the unfolding of nature as seasonal changes emerge. This noticing of the *otherness* of nature and the seasons has been linked to higher concentration and restoration of attention for office workers in downtown central business districts. Consequently, the incorporation of time may be key for successful biophilic design, which can highlight the changing patterns that a building's non-human aspects create. This may prove to also be key for resilience in current uncertain times.

The connectivity with nature from slowing down from Covid-19 has also been balanced with the heightened awareness of social injustice and those who lack access to space, nature, and safety. Access to high-quality urban green space is beginning to be recognized as a public good by many cities, and the unequal access to it has spurred recent urban greening initiatives and been an integral part of updated resiliency plans (Loder 2020). Incorporating some of the work done by cities and research from relational and political ecology work can help to bridge this traditional blindness in biophilia. To be socially just, ensuring the right to nature access, to fresh air and water, and to natural light in living spaces must be equally available to all:

> Biophilic design is justifiably critiqued for its inequity: the health, happiness and productivity of humans is privileged over that of other species, and (*de facto*) the approach is most accessible among clients of means. (Africa et al. 2019: 2)

Addressing this barrier and imagining a more inclusive biophilic design need to be more prominently addressed at all scales, from single rooms, to cities, and to the entire planet.

21.4.1 Linking Biophilia to Larger Ecological Systems: Rewilding and Ecosystem Design

Successful ecological and urban landscapes can join up existing urban green spaces for greater access and can create pollinator pathways, which further supports life on the planet. For example, parks and roadside verges in London's National Park City initiative can help achieve their regional goal to green and rewild the city for people and nature. This initiative is “an acknowledgement to how vitally urban lives are bound up with and enriched by nature” (Macfarlane 2020). Such greening and rewilding pathways are being extended across living walls, roofs, courtyards, and gardens of the urban built environment (e.g. British Land 2020). As building designs blur outside/inside envelops, pollinator pathways can now continue right up to the biophilic desk plant, rewilding the building and enabling living biophilia.

Biophilia – and in particular the encouragement of a deeper connection to nature – has the potential to shift nature-based design and policy from the nice-to-have towards a holistic, ecosystem-friendly approach, enabling deeper regenerative meaning and uptake by buildings, cities, and regions. This has been happening in some design community circles which are viewing the non-human (nature, place), human (culture), and built environment habitats through a different biophilic lens. Practical examples at a project level include biophilic design workshops that have incorporated mindfulness approaches and encouraged the exploration of the relationship with place. This places the design team in a state of mind that asks the land for permission to build and seeks reciprocity with soils, native plants, and biodiversity.

This kind of evidenced-based biophilic research and practice embraces *salutogenic* thinking, the medical concept (Antonovsky 1987) that encourages a focus on factors that *improve* and *support* human health and well-being rather than on factors that reduce illness (Brown 2016). With the health and well-being of humans intrinsically linked to the health and well-being of the planetary ecosystems, the combination of biophilic and *salutogenic* design approaches may provide a more holistic framework to link ecosystem, human, and non-human dimensions. Considering that, at a building scale, research attention has tended to focus on threats to health, and a more holistic way of thinking would also be useful to foster health-promoting environments (Loder 2019).

On a larger scale, an emerging trend is the Bio-Leadership, i.e. a concept of an ecosystem made of people and projects transforming leadership by working with nature (Roberts 2020). Within the design and policy world, the concept switches from a mechanistic perspective (where the world is seen to function as a machine) to a natural fluid approach. This framework has been used to describe the hoped for next era of our relationship with the environment. This new way of envisioning the nature-human relationship in design and policy aims to nurture a *co-evolving mutuality* (Mang et al. 2016) and may provide hope for both a more equitable and regenerative future. If combined with work on equitable access to nature, along with evidence on the benefits of access to nature at multiple scales, this large-scale application of biophilic principles can play a part to restore both human and ecological health.

21.5 Concluding Remarks

Human disconnection with nature has already negatively impacted mental and physical health. Buildings today are often designed, constructed, and operated *apart from* nature, rather than as *a part of* nature. Over the last 30 years (since World Commission on Environment and Development 1987), sustainable design and construction has been a core element in the built environment, and yet climate and biodiversity indicators have worsened, while the impact of building design and practice on health outcomes is increasingly researched but still remains opaque. Evidence from the last 30 years has shown that contact with nature in general can improve human health, but there are gaps in the application at different scales and a lack of understanding of which research to apply to which situation.

Conversely, biophilic design is growing in popularity, but it still suffers from a lack of specificity on research outcomes and variables. There is a tendency for it is to be dismissed from many design circles as *nice to have but dispensable* versus an effective intervention to improve health and performance. The research on nature and health to date supports many of the biophilic design attributes outlined above; however, in practice biophilic design is often limited to a few variables, which limits its application in design practice. Furthermore, there is still much that is not known about the potential benefits of biophilic design interventions individually and as a whole. This gap has not been overcome by the confusion of *green* design interventions in green buildings over the last few decades, which may or may not have had any link to evidence-based or biophilic design. It is also complicated by the differing underlying paradigms in nature and health research and design: research that examines nature as a linear input with an expected outcome does not align well with the more philosophical sense of place and lived experience goals of biophilic design.

Lastly, effective integration of evidence-based research and design on nature and health requires an acknowledgement and understanding of how it can be applied at different scales. This is particularly true when attempting to align building-level, neighbourhood-level, or city-level initiatives with regional resiliency or climate change initiatives. There is still a need to provide a synthesis with respect to the available knowledge about the relationship between nature design and policy interventions, natural systems, and health. This seems to be confirmed by the growing demand from policymakers. For instance, in the *Urban Green Spaces: Brief for Action* published recently, the World Health Organization (WHO 2017) emphasized the need for a change in urban health initiatives with a strong focus on the creation, promotion, and maintenance of green spaces, with an explicit call for expert advice (WHO 2017). How this expertise is developed is a current gap in both education and practice.

The discussion above argues that understanding the strengths and limitations of the most influential research on health and nature can help it support and align with biophilic design. This knowledge can result in a more effective and holistic understanding of how nature can be incorporated into our buildings, neighbourhoods, and cities. Critically combining research on health and nature with biophilic design principles may also provide a more holistic and just approach to connecting us with nature and encouraging sustainable behaviour. This can further support regenerative policies and action. As we look to life with and after Covid-19, the shape of the future built environment remains unknown, but it provides an opportunity for re-evaluation and new insights about our human, natural, and built environment relationships.

Acknowledgements This book chapter is based on research carried out as part of the COST Action CA16114 RESTORE "REthinking Sustainability TOwards a Regenerative Economy", supported by COST (European Cooperation in Science and Technology).

Author Contributions Conceptualization: Maria Beatrice Andreucci and Angela Loder; literature review: all authors; writing – original draft preparation: all authors; writing – review and editing: Maria Beatrice Andreucci and Angela Loder; visualization: Maria Beatrice Andreucci and Beth McGee; funding acquisition: Maria Beatrice Andreucci, Jelena Brajcović, and Martin Brown

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Chapter 22
Design the Urban Microclimate: Nature-Based Solutions and Technology at Nexus

Silvia Coccolo, Marco Delli Paoli, Alessandro Stracqualursi, and Maria Beatrice Andreucci

Abstract This chapter outlines the general impacts and direct consequences climate change is producing in urban areas, especially in terms of negative influence on urbanites' thermal comfort, and how green infrastructure combined with appropriate building technologies could increase our climate-adaptive capacity and reduce the various health risks associated with urban heatwaves and soil sealing. The study focuses on urban microclimate and energy balance in the built environment and discusses key challenges for successful implementation of integrated design solutions, at different scales, for climate change adaptation. Through the development of two experimental renovation case studies – i.e. the former slaughterhouse of Velletri and the heritage "Leo" penicillin factory in Rome – the authors investigate the microclimatic impacts of different environmental design strategies, showing in particular the effectiveness of combined landscape technologies, leveraging on vegetation and soil permeability to mitigate the urban microclimate, as well as improving the outdoor thermal comfort of urban people.

Keywords Microclimate regulation · Landscape technologies · Urban energy balance · Outdoor thermal comfort · Urban temperatures

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_22

22.1 Introduction

Urban climate has been widely investigated in the last decades, especially studying phenomena of increase or decrease in air temperature between urban and rural areas, defined, respectively, as urban heat/cool island effect (Ng 2010; Morris et al. 2016). Unsustainable urbanization is ongoing, the climate is changing, and European cities are predicted to be exposed, more and more in the next years, to multiple climate hazards.

According to the literature, several design strategies exist to mitigate the effect of urban heat island (UHI) and cool island effect (Yang et al. 2016), by manipulating the urban energy balance. In this frame, the urban design plays a major role in the adaptation to the extreme climatic events (Santamouris 2007). An adaptive urban design should aim at balancing the environmental energy fluxes affecting the city, through bioclimatic strategies, integrated at different scales within the urban context (Olgyay 1962; Givoni 1969), for example, (i) varying the albedo (the ratio of irradiance reflected to the irradiance received by a surface) to reduce net radiation, (ii) improving the ventilation affecting human heat load, and (iii) augmenting the evaporative and shading potential. Green infrastructure – especially trees and permeable surfaces – has proven to be effective in producing positive effects on the outdoor thermal comfort (Akbari et al. 2001; Picot 2004; Bowler et al. 2010), being able to absorb the solar radiation impinging the city surfaces, and mitigating the adverse climatic conditions by radiative cooling. A city comprises thousands of microclimates, which vary as a function of its design, and physical properties. Within this context, it is evident that each area of the city is part of a heterogeneous balance and as such should be designed and optimized, being interconnected to the entire city.

The objective of this chapter is to underline the importance of redesigning the open space and the architecture of abandoned urban areas, as an opportunity to mitigate the urban microclimatic conditions and improve overall quality of life of the urbanites.

The main factors that influence human thermal comfort are those that determine heat gain and loss, namely, metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed, and relative humidity. Psychological and physiological parameters, such as individual expectations, as well as body reactions to the environment, also affect thermal comfort (de Dear and Brager 1998). It is a well-established fact that thermal comfort is strongly correlated to outdoor urban environment (Charalampopoulos et al. 2016; Nouri and Costa 2017; Saaroni et al. 2018). Michelozzi et al. (2005) and Legambiente (2018) highlighted the problems and challenges related to thermal discomfort in Roman urban open spaces. More importantly, the exceptional 2003 summer heatwave, when peak temperatures reached record values, had a strong impact on the population in terms of mortality, with a total of 944 excess deaths observed (+19 %). According to Legambiente (2019), from 2005 to 2016, in 23 Italian cities, heatwaves caused about 23,880 deaths, including 2000 in the city of Rome. Additionally, due to climate change, cities will face long-term heatwave increases of 370–400% (2021–2050) and 1100%

(2050–2080), which correspond to approx. 28 days per year (against the current two days). Heatwaves are directly correlated to death rates, expected to increase up to 135–388 units in 2080, in the city of Rome (Legambiente 2019).

A paradigm shift in urban planning and design is consequently necessary in order to effectively face the previously mentioned problems, calling on climate adaptation strategies and trying to improve the urban living conditions.

Several studies have been performed in the city of Rome, since the seminal work of Colacino and Lavagnini (1982), in order to quantify the UHI phenomena affecting the city: analysis performed through satellites and ground-based sensors (Fabrizi et al. 2010); modelling of UHI phenomena and their reduction, thanks to the albedo of urban surfaces (Morini et al. 2017); and correlation between the UHI phenomena and the energy demand of buildings (Guattari et al. 2018). Finally, other studies have been conducted on the open space and green infrastructure design within the city and its effective role for the improvement of the quality of the urban built environment (Andreucci 2017a; Andreucci et al. 2019).

One method developed to assist architects and urban designers refers specifically to the computation of urban energy exchanges and the urban energy balance, whose formula (Erell et al. 2011) is described below:

$$Q* + Qf = Qh + Qe + \Delta Qs + \Delta Qa \qquad (22.1)$$

where $Q*$ is the total wave radiation, Qf is the anthropogenic heat flux, Qh is the convective heat flux, Qe is the latent heat flux, ΔQs is the net storage heat flux, and ΔQa is the net horizontal heat advection. All fluxes are expressed in W m^{-2}.

Formula (22.1) has been applied to test the energy exchanges and balance of two selected experimental design projects under investigation: the heritage industrial district and former penicillin factory *Leo*, in Rome, and the old slaughterhouse (also called *Mattatoio* within the text), in Velletri (Fig. 22.1).

22.2 Selected Study Site

Among the industrial buildings, the 1950s heritage former penicillin factory *Leo* in Rome (abandoned since 2003) represents an emblematic construction, due to its relevant size and dangerous industrial processes, being harmful to people and the environment. The *Leo* factory covers an area of approximately 4.5 ha, close to the Aniene River Natural Reserve and some iconic workers' housing settlements. This complex urban area can be considered almost unique in Rome, characterized by post-industrial and social heritage as well as vital ecological networks.

The *Mattatoio* in Velletri was constructed on the site of the old slaughterhouse (built in the nineteenth century) and nearby the historical centre of the city of Velletri. The structure was realized at the beginning of the twentieth century, in an area of about 3000 m^2. It used to be structured in two main areas, the administrative part and the industrial one. The complex has been restructured and modified until

Fig. 22.1 Historical photographs and drawings of the case studies. Above: *Leo* Factory in 1950 (left) and 1959 (right)
Middle: current state of the buildings in the *Leo* Factory. Below: old structure of the *Mattatoio* in Velletri

1990, when it was transformed first into a deposit and then in a veterinary centre; it was finally dismissed in 2005. Being abandoned, the industrial complex degraded fast, and several parts of the structure, as well as the roof, are nowadays destroyed. The *Mattatoio* (about 10,000 m^2) is composed of a central building, with a concrete structure, and four other one-storey buildings, located around the main one.

Both Velletri's and Rome's brownfields currently represent problematic areas, producing negative social and economic impacts on the city and the community (Camilli and Zandonini 2018). The *Leo* factory, in particular, is characterized by severe social degradation, and as underlined by the report from Medici Senza Frontiere (2018: 25): "the situation presents important and urgent social and health needs", while the *Mattatoio* represents at the moment an opportunity which is untaken, being segregated in its degradation, abandonment, and abuse.

22.2.1 Meteorological Data

Both the *Leo* factory in Rome and the *Mattatoio* in Velletri are located in central Italy, and according to Köppen-Geiger classifications (Peel et al. 2007), both areas belong to the "Csa" hot dry-summer Mediterranean climate. The climatic data for the city of Rome are defined by the tool Meteonorm 7.3.0 (Meteonorm 2013) providing the hourly data for a typical meteorological year. The climatic data for the city of Velletri are measured by the *Agenzia Regionale per lo Sviluppo e l'Innovazione dell'Agricoltura del Lazio* (ARSIAL). The weather station, "Velletri *Cantina sperimentale*", is located about 2 km from the *Mattatoio*. This distance is not representative of the investigated area's microclimate; nonetheless, assuming the horizontal homogeneity of the wind, as well as the tool's accuracy in mapping the radiative properties of the site, it is possible to assume the reliability of the data for our purpose.

The meteorological data – air temperature, solar radiation, relative humidity, rainfall, wind speed, and direction – are summarized in Table 22.1 (Meteonorm 2013). It should be noted that the summer season in Rome is warm, with an average temperature of 27.3 °C during the month of August.

22.2.2 Environmental Design Renovation Strategies

The environmental design renovation strategies of the former *Leo* factory can be considered from a twofold point of view, as follows:

Table 22.1 Meteorological data for the city of Rome

Month	Beam radiation (W/m^2)	Air temperature (°C)	Wind speed (m/s)	Wind direction (°)	Relative humidity (%)	Rainfall (mm)
Jan.	82.5	8.8	0.9	136.9	67.2	53.6
Feb.	103.9	9.6	1.2	147.8	63.0	41.7
Mar.	137.9	12.6	1.4	159.0	64.6	37.7
Apr.	157.9	15.4	1.3	174.8	67.0	47.8
May	198.7	20.6	1.2	186.5	61.8	36.6
Jun.	216.1	24.2	1.4	198.9	59.3	14.9
Jul.	261.3	27.2	1.6	202.8	55.2	15.3
Aug.	217.0	27.3	1.4	203.2	58.6	27.9
Sep.	162.1	22.3	1.2	179.3	64.7	55.8
Oct.	125.6	18.9	0.8	184.6	69.8	62.7
Nov.	81.3	13.7	1.0	158.8	71.2	93.9
Dec.	65.8	10.0	0.9	150.0	69.1	91.4

Source: Meteonorm (2013)

A new function for the buildings is proposed in the form of a homeless shelter for asylum seekers. The Asylum, integrated with other public services, is aimed at increasing the social inclusiveness potential of the via Tiburtina area (the ancient road in Italy leading Rome to Tivoli). In order to minimize times and costs of construction and reduce its environmental impact, the renovated scenario levers on natural materials like wood and plants, used both in flexible and modular systems, placed along the envelope of the buildings, and in the open space. The buildings' roofs represent another "layer" to be redesigned in order to mitigate the UHI effect, using reflecting materials (i.e. with high albedo values), *green* and *brown* roofs, to mitigate the microclimate. New tree-lined rows define the routes and vegetated linear barriers that mitigate traffic noise and air pollution while improving the thermo-hygrometric conditions through evapotranspiration and shading (for tree species' selection aimed at microclimate regulation, refer to Table 22.2). New permeable surfaces – on ground (rain gardens and bio-swales) and on the buildings' roof (extensive and intensive green roofs) – contribute to the reduction of the UHI effect, in summer. Increased permeable surfaces and a new *water square* located in the south edge of the complex allow also a significant amount of rainwater to be collected, ensuring a sustainable water management (Fig. 22.2).

On a larger scale, the restoration of the socioecological connection is proposed. Focusing on tree planting design and new pedestrian and cycle paths, the proposal aims at guaranteeing improved connectivity between the residential areas, the Aniene Natural Reserve, and the new Asylum, structuring new public and semi-public area, for the benefit of people and the environment.

The restyling project of the *Mattatoio* involves the biological and ecological transformation of the former slaughterhouse into a business incubator, with integrated services. Key design goals in this case study are to improve the accessibility to the *Mattatoio* premises and to its main open space, the *piazza* located in front of the complex; to optimize the outdoor and indoor microclimatic comfort; and to minimize the environmental impact of the new construction.

Table 22.2 Tree planting for enhancing microclimate regulation: species-specific information

Tree species	Hardiness	Soil pH	Drought tolerance	Microclimate regulation
Acer buergerianum	6b–8	<7.0	Moderate	High
Alnus glutinosa	3–7	<5.5–<7.5	Low	Moderate
Fraxinus excelsior	4–8	<5.0–<8.0	NT	High
Liriodendron tulipifera	6–9	<5.5–<7.5		High
Populus alba	4–9	<5.5–<8.0	Moderate	High
Populus nigra	5b–?	<5.5–<8.0	Moderate	High
Pyrus calleryana	6–9	<5.5–<8.0	High	Moderate
Quercus robur	5–8	<5.5–<7.5	Moderate	High
Salix alba	4–?	<7.0		High
Ulmus minor	5–?	<5.5–<7.5		High

Source: Adapted from Samson et al. (2017)
As far as *drought tolerance* is concerned, the entries in the above table have been rated according to available literature as low, moderate, high, or no tolerance (NT) (Source: Samson et al. 2017)

Urban Green Infrastructure *«The elements of biodiversity, Natural Capital, and organised systems linked to any urban area, with intrisic qualities or degraded, including individual environmental technological devices, integrating biodiversity in the built environment, such as green roofs and bio-swales, permeable paving, rain gardens, and other sustainable urban drainage systems, in order to promote through the provision of ecosystem services, environmental protection, economic feasibility, well-being, equity and social inclusion.»* (Andreucci, 2013)

Fig. 22.2 Integrated environmental technological design levering on green infrastructure

The area can be reached via two driveways that flank it, a pedestrian path that gives access to the main *piazza* and two public bus lines. The proximity to the historical centre, the easy accessibility to the site, the panoramic view, and the flexibility, in terms of subdivision of the interiors, have been identified as main strengths supporting the project' future implementation. On the other side, a large parking lot, limiting the available space for the pedestrians on the main *piazza*, the difficult accessibility to the buildings – due to poor vegetation management (mostly invasive species, i.e. *Ailanthus altissima* Mill. and *Robinia pseudoacacia* L.) – and the state of decay of the structures represented major problems to be solved.

In the project, part of the existing vegetation has been maintained, creating *green filters* between outdoor and indoor environments. Irrigation is provided by a rainwater harvesting system realized by converting the old concrete silo into a storage tank, in addition to a wastewater phytoremediation system located on the south side. Newly planted trees and shrubs mitigate noise and air pollution (especially in parking areas) and offer shade in the open spaces most exposed to direct solar radiation. Inside the Ugo Tognazzi *piazza*, the bare walls on the east side are covered with climbing plants to assist the drainage of stormwater runoff, improve the air quality, and provide cooling to the buildings' interiors.

The site morphology and its strategic position in the urban context offer great opportunities to create an attractive public space for citizens and visitors. The envisaged project includes a new slow mobility plan for the site, providing more space to appreciate the panoramic beauty of the place, and the restoration of the Ugo Tognazzi *piazza* to its original function of pedestrian area and gathering place for the citizens of Velletri.

22.3 Methods

Three tools are applied to test the design characteristics of the project sites: Ecotect (Marsh 2006) to study the sun shadow range; Revit Insight 360 to analyse the solar incident radiation and the yearly cumulative irradiation; and CitySim (Robinson et al. 2009), computing the energy behaviour of trees and the herbaceous layer, in time and space (Coccolo et al. 2018). More in detail, the following analyses are performed in the two sites.

Mattatoio

i) Mean radiant temperature, to understand the urban microclimatic conditions
ii) Predicted mean vote, to compute the indoor and outdoor thermal comfort
iii) Urban daylight, to understand the liveability of indoor and outdoor spaces, before and after the renovation

Leo Factory

iv) Cooling potential of green infrastructure
v) COMFA budget, to compute the pedestrians' outdoor thermal comfort
vi) Urban solar potential, to understand the indoor and outdoor liveability, as well as the solar potential for integrating renewable energy sources

22.3.1 Mattatoio

The microclimatic analysis of the site is performed with the tools Ecotect and Revit Insight 360. The simulations are realized for the winter and summer seasons, both for existing and renovated buildings. The objective of the study is to understand the impact of the architectural design on the outdoor environmental conditions. The simulations provide three main outputs:

– Mean radiant temperature (MRT)
– Predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD)
– Illuminance values (lux)

The mean radiant temperature is an artificial measure to express the degree of exposure to environmental radiation, and it is defined as the “the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non uniform space” (ASHRAE 2010). The mean radiant temperature, *MRT* (°C), is calculated according to the following equation (International Organization for Standardization 1998):

$$MRT = \left[\left(\theta_g + 273.15\right)^4 + \frac{1.1 * 10^8 {v_a}^{0.6}}{\varepsilon D^{0.4}} * \left(\theta_g - \theta_a\right) \right]^{\frac{1}{4}} - 273.15 \tag{22.2}$$

where θ_g is the globe temperature (°C), v_a is the air velocity (m• s^{-1}), θ_a is the air ambient temperature, ε is the globe infrared emissivity (-), and D is the globe diameter (m).

The mean radiant temperature is affected by the solar shortwave radiation (direct, diffuse, and reflected) as well as by the terrestrial longwave radiation (atmospheric and environmental) (Kántor and Unger 2011). The MRT is more sensitive, compared to the air temperature, to the shadow generated by trees, the site topography, and the building design (Mayer et al. 2008). Additionally, the mean radiant temperature has a major impact on thermal comfort of pedestrians, because it is strongly affected by the urban design and configuration, e.g. urban canyon’s width, height and orientation, radiative properties, albedo, and infrared emissivity of the urban surfaces (Ali-Toudert and Mayer 2006; Berkovic et al. 2012; Lindberg et al. 2013; Taleghani et al. 2015).

The predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) were previously defined to compute the indoor environmental conditions (Fanger 1970) and can be used, with limits, in the outdoor environment (see, e.g. German VDI 9787 Part 2, 2008).

$$\text{PMV} = \left[0.028 + 0.303 * \exp\left(-0.036 * \frac{M}{A_{Du}} \right) \right] * \left(\frac{H}{A_{Du}} - E_d - E_{sw} - E_{re} - L - R - C \right) \tag{22.3}$$

where 0.0228 + 0.303 * (…) are empirical base fitting coefficients to convert energy balance of the body in the PMV value, $\frac{M}{A_{Du}}$ is the mechanical energy production of the body (W/m^2), $\frac{H}{A_{Du}}$ is the internal remaining energy (W/m^2), E_d is the vapour diffusion through the skin, E_{sw} is the evaporation of sweat on the skin, E_{re} is the latent heat lost through breathing, L is the sensible heat exchange through breathing, R is the radiative energy balance of the body, and C is the energy exchange through convection.

In the application to the outdoor environment, it is necessary to consider that the skin temperature parameter will be different due to the external conditions’ values, which include solar radiation and ventilation parameters, as well as the clothing. In addition, it is important to underline that the PMV range scale has been originally calculated with an empirical method based on tests on volunteers (see Table 22.3).

The extremes of -3 and +3 indicate the uncomfortable conditions but not the physical extreme conditions that can occur externally. It is possible that on an extremely cold winter or extremely hot summer day, PMV values can vary between -9 and +9. In the analysis below, the values have been converted to fall within the range scale defined in ISO 7730 standard and in order to be directly comparable between indoor and outdoor environment.

The urban properties of the ground cover are summarized in Table 22.4. The ground cover is subdivided into four main typologies: concrete, asphalt, bare soil, and mixed (concrete and bare soil).

The renovation of the site improves the permeability of the district, reducing the man-made surfaces throughout the site and manipulating them to reduce their surface temperature. As an example, the current asphalt is replaced with draining and light-coloured asphalt (Table 22.5). Thanks to this simple technology, the surface temperature of the material decreases by about 11 °C during warm summer days, with an average difference of 8.3 °C. The main problem of this type of reflective asphalt is the maintenance, due to the decrease in its reflectivity passing from 0.33 to 0.17 after 6 months of use (Kyriakodis and Santamouris 2018).

22.3.2 Leo Factory

The urban energy model for the *Leo* factory is realized with the tool CitySim, in order to analyse the outdoor environmental conditions in the selected urban area. The geometrical design in DXF format and all the thermo-physical properties of the urban factory (albedo, conductivity, density, specific heat, and thickness) are entered in the software. The impact of green infrastructure on the urban microclimate, as well as on the outdoor thermal comfort of the pedestrians, is determined simulating the evapotranspiration potential from trees and the herbaceous species layer. Since climate stress leads to a decrease in urban biodiversity, the design of the new herbaceous layer is based on the use of wildflowers, particularly suited to improve urban biodiversity (Hobbs 1988). The greening model (Coccolo et al. 2018) is based on

Table 22.3 Predicted mean vote, seven-point thermal scale, extracted from ISO 7730

Thermal sensation	Predicted mean vote
Hot	3
Warm	2
Slightly warm	1
Neutral	0
Slightly cool	−1
Cool	−2
Cold	−3

Source: International Organization for Standardisation (2006)

Table 22.4 Properties of paving materials and soil in the *Mattatoio* before the renovation

Material name	Thermal conductivity ($W \cdot m^{-1}K^{-1}$)	Density ($kg \cdot m^{-3}$)	Specific heat ($J \cdot kg^{-1}K^{-1}$)	Area (m^2)	Ground cover (%)
Concrete	2.10	2400	849	267	6.9
Asphalt	0.75	2243	900	1120	29.0
Mix of concrete and soil	2.00	2000	1051	235	6.1
Bare soil	1.50	2098	1500	2244	58.0

Table 22.5 Solar reflectance values for the two asphalt typologies as function of the wavelength: light yellow and conventional black

	Solar reflectance values			
Surface type	All spectrum (300–2500 nm)	UV (300–400 nm)	Visible (400–700 nm)	Infrared 700–2500 nm)
Light yellow asphalt	0.35	0.11	0.24	0.42
Conventional black asphalt	0.04	0.04	0.03	0.04

the FAO (Allen et al. 1988) and Campbell (Campbell and Norman 1998) evapotranspiration models.

Two simulations are performed: the current situation and the renovation. In the renovation scenario, the urban landscape in the southern area of the site is improved, planting 28 trees, belonging to the species of the local riparian forest – *Salix alba* L., *Populus alba* L., *Alnus glutinosa* L., *Ulmus minor* Mill. (Celesti-Grapow et al. 2013) – 7-meter-tall, with an average leaf area index (defined as one-sided green leaf area per unit ground surface area) corresponding to 3 (i-Tree Canopy v6.1). General species-specific information orienting tree planting design aiming at enhancing microclimate regulation have been summarized in Table 22.2.

The outdoor thermal comfort is computed, thanks to the COMFA* budget - an updated version of the thermal energy model COMfort FormulA (Brown and Gillespie 1986) - based on work by Kenny et al. (2009), able to quantify the energy fluxes exchanged by the pedestrians with the outdoor environment (metabolic heat, radiation absorbed, long-wave radiation emitted, convective heat losses, and evaporation). A pedestrian is virtually located inside the *Leo* factory, and his thermal comfort, i.e. the energy exchanged between the human body and the outdoor environment, is computed as follows (Vanos et al. 2017):

$$B = M_h + R_{RT} - C - E_{s+i} - L_s \tag{22.4}$$

where M_h is the metabolic heat generated by a person, R_{RT} is the radiation absorbed, C represents the convective heat losses, E_{s+i} is the evaporation, and L_s is the longwave radiation emitted by a person. All values are expressed in W m^{-2}.

The total "comfortable hours" are computed during a typical meteorological year, by including the physical and geometrical properties of the urban space, as previously described. Table 22.6 summarizes the COMFA* thermal scale, expressed through the energy budget and the corresponding thermal sensations. The neutral thermal sensation corresponds to −50 to +50 W m^{-2}, while a thermal sensation can be considered acceptable when the values are in the range −120 and +120 W m^{-2}, which correspond, respectively, to a “slightly cool” and a “slightly warm” thermal sensation.

The properties of urban paving materials and soil are summarized in Table 22.7. Indeed, the ground cover plays a major role in the outdoor thermal comfort, due to the radiative and convective exchanges. It is subdivided into three main typologies: water, vegetation, and artificial ground covering.

22.4 Results

22.4.1 Mattatoio

22.4.1.1 The Mean Radiant Temperature

The mean radiant temperature is analysed during the coldest 8th of January and hottest day 2nd of August of 2017 across the monitored data. During the winter day, the MRT varies between 3.0 and 6.0 °C. During the summer season, the MRT reaches 30 °C in the sun-exposed surfaces. The area, which is protected by the surrounding buildings, presents an important difference in temperature, by 10° lower. As an example, the shelter between the central buildings casts a shadow on the path that presents an MRT equals to 23 °C, representing a comfortable outdoor environment during a hot summer day. Consequently, the impact of the city design plays a major role in the environmental conditions. During the winter time, due to the cold conditions (average air temperature equals to 6 °C), the impact of the urban design is lower, and the studied space presents an average MRT of 3 °C (Fig. 22.3).

Green infrastructure, and especially trees, plays a major role in mitigating the urban environmental conditions (Andreucci 2017c), and this is evident during the summer day, in the southern part of the district. In the renovation, this area is

Table 22.6 Thermal sensation as a function of the COMFA* budget

Thermal sensation	COMFA* budget (W m^{-2})
Cold	≤ −201
Cool	−200 to −121
Slightly cool	−120 to −51
Neutral	−50 to +50
Slightly warm	+50 to +120
Warm	+121 to 200
Hot	≥ 201

Source: Kenny et al. (2009)

Table 22.7 Thermal properties of paving materials and soil in the *Leo* factory before the renovation

Material name	Thermal conductivity (W·m^{-1}K^{-1})	Density (kg·m^{-3})	Specific heat (J·kg^{-1}K^{-1})
Concrete	2.1	2400	849
Concrete tiles	1.5	2100	1000
Gravel	2.0	2000	1051
Bare soil	1.5	2098	1500

redesigned and converted in a park. This affects the outdoor thermal comfort, creating a pleasant environment, with an acceptable MRT.

The study of the MRT after the renovation underlines two main factors: the improvement of the indoor environmental conditions and the mitigation of the outdoor environment.

Indeed, due to the isolation of the buildings, and the replacement of the existing windows with thermal efficient ones, the indoor temperature during the winter time increases by 3–5 °C on average during the season. It is also important to underline the decrease of the indoor temperature, by 7 ° to 10 °C on average during the warm season. This variation is quite important mostly in the topic of climate change, knowing that the temperatures will increase, inducing an important increase in the cooling needs of buildings. It is also interesting to notice that the increase of the glazing within the facades, as well as their thermal properties, impacts the solar radiation, which is reflected by the buildings. Additionally, the insolation is applied inside of the envelope not to impact the thermal mass of the building that plays a major role in absorbing and storing the solar irradiation during the daytime and re-emitting it during the evening/night. This effect is partially reduced by the external insulation of buildings or the high glazing ratio, inducing more extreme (hot or cold) microclimatic conditions.

22.4.1.2 Predicted Mean Vote

The indoor and outdoor thermal comfort is computed, thanks to the predicted mean vote. The values of MRT have been calculated to define the variables of the thermal balance equation, provided by the standards (UNI EN ISO 2005, 2006, 2009) in relation to the function performed in the different environments. In this case, it is interesting to notice the impact of the urban form on the indoor microclimatic conditions and of the greening design on the southern part of the square on the PMV, as the thermal perception of the pedestrians is improved, from *warm* to *comfortable*. In this area of the square, the contribution of the shadowing from the neighbouring buildings to the overall outdoor comfort is also significant.

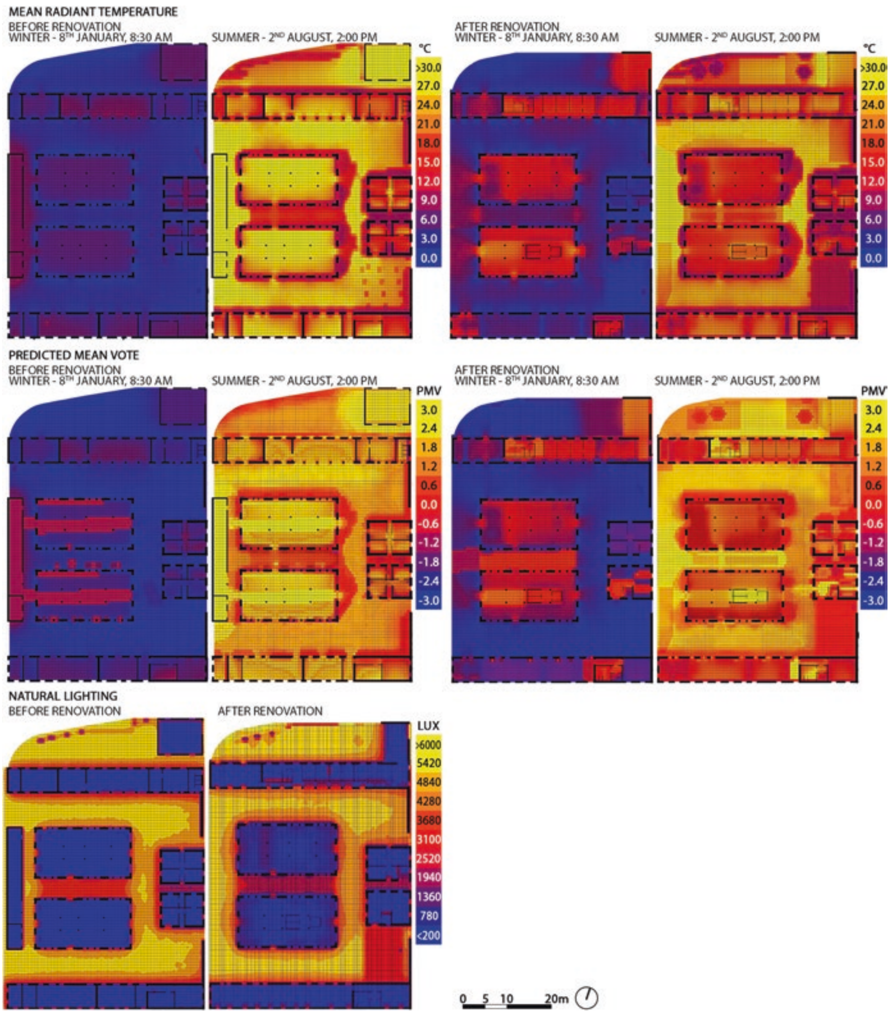

Fig. 22.3 *Mattatoio*. Above: Mean Radiant Temperature, before (left) and after (right) renovation, winter and summer seasons. Middle: Predicted Mean Vote, before (left) and after (right) renovation, winter and summer seasons. Below: Daylight illuminance, before (left) and after (right) the renovation, annual values

22.4.1.3 Urban Daylight

The study of the urban daylight underlines the available daylight in the indoor environment, as well as the outdoor spaces. Indeed, light plays a major role in the human's health and well-being, and it is essential to improve it within the urban design. A correct indoor and outdoor lighting level is essential, mostly in dense urban environments, where its availability is reduced (Ng 2010).

The first part of the analysis focuses on the indoor lighting level, assuming the required value between 300 and 500 lux for indoor office activities, as it is required by the Standard ISO 8995-1:2002(E)/CIE S 008/E:2001. The results correspond to the average annual values. The main factor affecting the indoor illuminance is the increase of windows on the facades, which ensure the correct daylight levels in the indoor environment, for example, 300–350 lux in the offices and 400 lux in the meeting room. This result is quite important, as before the renovation the indoor illuminance was lower than 300 lux.

In the outdoor environment, the level of daylight is directly related to the urban form: the urban canyon between the buildings and oriented east-west receives about 3000 lux, which is the half of the open square, where the available lux corresponds to 6000. The envelope of the buildings plays also a major role: indeed, due to the renovation and the new design of the facades, the buildings reflect the solar radiation, increasing the outdoor lighting levels. It is consequently quite important to select the correct type of windows, reducing the glaring effect. It is also interesting to note that due to the district design, the daylight availability varies during the seasons, as well as the time of the day, impacting the liveability of the spaces.

It is evident that currently no metrics exist to quantify the outdoor daylight, and consequently it is difficult to compute it within the urban environment. But it is clear that as a function of the illuminance available in a square, it will impact the presence of people using the area.

22.4.2 Leo Factory

The analyses of the urban geometry, the shadow range, and the permeability of the site's surfaces demonstrate the presence of both UHI and cool island effects, which varies as a function of the time of the day, as well as the seasons.

22.4.2.1 Urban Solar Potential

The Ecotect analysis of the former *Leo* factory highlights the impact of industrial design on the outdoor environmental conditions. Indeed, during the winter season, due to the density of the site, the volumes within the complex produce a constant winter shadowing. On the other side, the buildings facing via Tiburtina are exposed to the sun, which is comfortable during the winter season but uncomfortable during the summer.

The renovation aims to improve the use of daylight within the district design by a complex shading system, able to screen the southern front during the summer, and to allow for the useful solar gain in winter. Moreover, the variation of buildings' geometry and the appropriate clearing of other existing structures optimize the natural lighting of the indoor and outdoor environment, guaranteeing good levels of visual comfort. Where the above solutions are not possible, new glasses and windows with longer spans have been positioned improving the internal illumination.

The northern part of the site shows a complete lack of natural light along the entire north front. The cumulative insolation on the buildings' envelope shows that the average value during winter corresponds to 0.5 kWh/m^2 per day, for the vertical envelope (with a minimum value of 0), and about 1 kWh/m^2 per day on the roof. During the summer season, the values reach around 2.5 kWh/m^2 per day for the vertical walls and peak up to 5 kWh/m^2 per day for the roof.

Figure 22.4 shows the outdoor illuminance (lux) (*ante* and *post* renovation), during winter and summer season, directly influenced by the new materials and the organization of volumes. As previously underlined, no metrics currently exist to compute the illuminance within the outdoor environment, but it is clear that both the materials and the urban geometry affect the daylight, and the liveability of public spaces is directly related to the available daylight.

22.4.2.2 Outdoor Thermal Comfort and Green Infrastructure

In order to understand and compute the impact of green infrastructure on the district design, the surface temperatures are measured, as well as the impact on the outdoor thermal comfort. Figure 22.4 shows the yearly average surface temperature of the site, before and after the intervention. The southern area, covered by the trees and herbaceous species, presents, on a yearly basis, a reduction in the surface temperature by about 1 °C, dropping from 24.9 °C to 23.6 °C. The cooling effect is clearly more evident during the summer season, when the vegetation reduces the extreme warm and hot events.

The impact of green infrastructure is evident when analysing the outdoor thermal comfort. Indeed, the total hours characterized by a tolerable thermal sensation for a standing relaxing outdoor activity (COMFA* budget between −120 and +120 W m-^{2}) correspond to 6154 in the ex ante scenario and to 6462 considering the beneficial effects of the proposed renovation. It is more evident during the summer season, when the outdoor thermal conditions are mitigated, thanks to the shading provided by trees and the air cooling provided by the evapotranspiration.

During the summer season, the comfortable hours correspond to 1616 in the existing situation, rising up to 1708 after renovation. This implies that, thanks to the greening, about one additional hour per day can be predicted. Additionally, it is important to note that the local urban forest (Zürcher and Andreucci 2017) improved by the project will impact not just the large area inside the former *Leo* factory, but it will also benefit the surrounding districts.

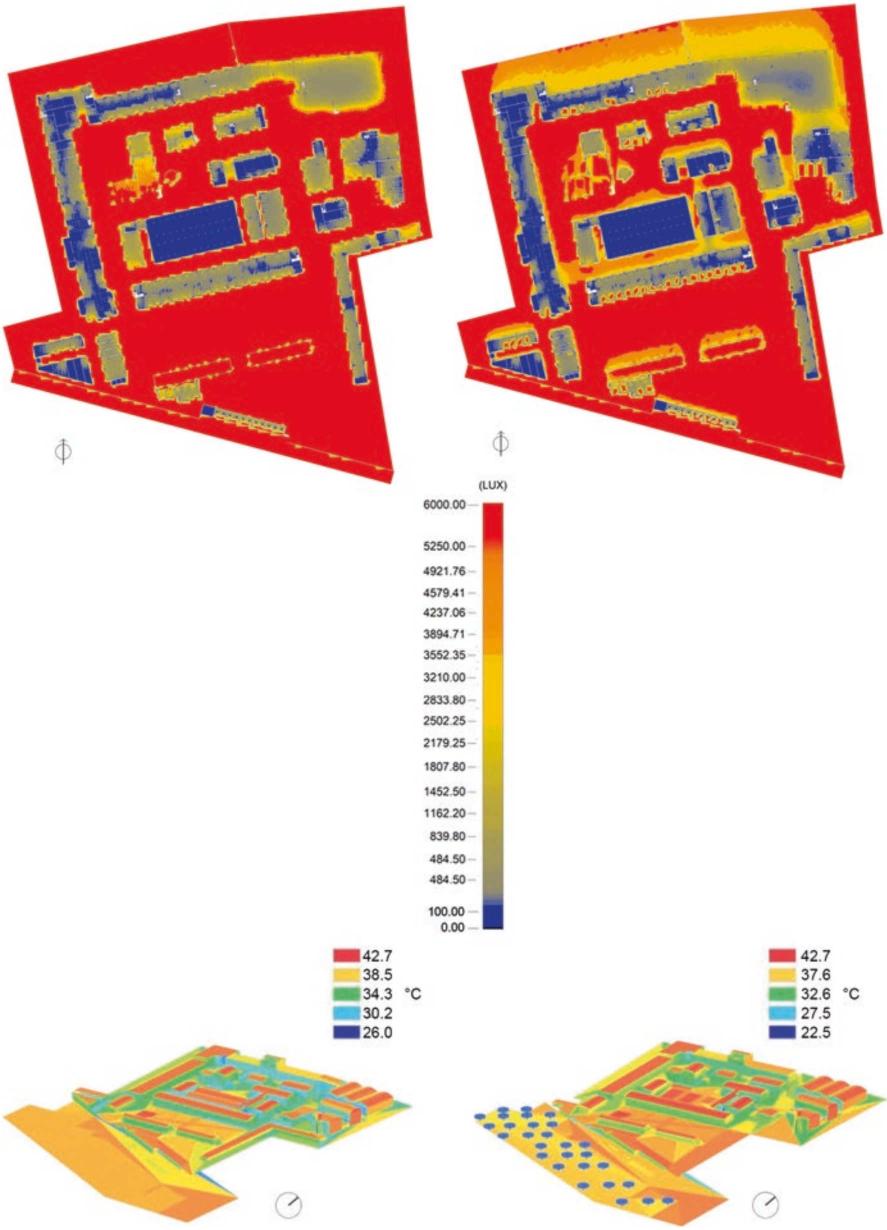

Fig. 22.4 *Leo* Factory. Above: Daylight illuminance before the renovation, winter (left) and summer seasons (right). Min. 100 lux (blue), max 6000 lux (red). Below: annual surface temperature of the *Leo* factory: Existing design (left) and the renovated design (right)

22.5 Concluding Remarks

This chapter shows the impact of urban and building renovation coupled with green infrastructure implementation, particularly in the context of abandoned industrial areas, on the urban microclimatic conditions (Andreucci 2017b). The study is performed in the *Leo* factory, in Rome, and in the *Mattatoio* of Velletri. The urban design renovation plays a significant role in reducing the urban heat island effect through climate adaptation strategies, as already underlined by previous studies (Mahzouni 2018).

The efficacy of the projects is declined within the urban energy balance (Erell et al. 2011). More precisely, by reducing the surface temperature, thanks to a new green infrastructure (trees and herbaceous layer) and their evapotranspiration potential, which affect the latent heat flux (Qe) and improve the outdoor thermal comfort (up to one hour per day in the *Leo* factory), as also underlined by previous studies (Akbari et al. 2001; Bowler et al. 2010; Picot 2004). The radiative environment ($Q*$) is improved, by the district redesign, creating comfortable outdoor environments. The proposed building shapes optimize the solar gains throughout the year, i.e. they are higher in wintertime and reduced during the summer season. These factors directly affect the net all wave radiation, improving the urban energy balance. Additionally, the colour of the surfaces is analysed, as well as the glazing properties of the windows: the simulations on the illuminance show the potential of the urban renovation on the indoor and outdoor daylighting levels. The renovation project aims to improve the energy efficiency of the buildings, as well as the pedestrian mobility, directly impacting the anthropogenic heat flux (Qf), as also presented by previous studies (Guattari et al. 2018). The selection of outdoor surfaces (both in buildings' envelope and in the outdoor environment) aims to increase the thermal mass, in order to store the solar radiation during the daytime and re-emit it during the night-time, improving the net storage heat flux (ΔQs). Finally, the convective heat flux is improved, aiming to increase the natural ventilation during the summer season, reduce the cooling demand of buildings, and improve the outdoor environmental conditions.

The current work presents several aspects which can be investigated as future works:

- The analysis of the urban climatic conditions of the city of Rome and the potential of the renovation at the city scale, with the integration of the proposed study methodologies in urban planning scenarios
- An on-site monitoring campaign, with the use of drones for urban thermography, and integrating the population in developing new ideas for green infrastructure design, as well as monitoring of the current state of neighbourhoods
- The development of the urban daylight, with on-site monitoring, as well as the use of the virtual reality to understand and optimize the pedestrians' perception (thermal and visual) of the space

Author Contributions Conceptualization: Maria Beatrice Andreucci; writing – original draft preparation: Silvia Coccolo, Marco Delli Paoli, Alessandro Stracqualursi, and Maria Beatrice Andreucci; writing – review and editing: Silvia Coccolo and Maria Beatrice Andreucci; visualization: Marco Delli Paoli, Alessandro Stracqualursi with Maria Beatrice Andreucci supervision, and Maria Beatrice Andreucci

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Chapter 23
Evolution of the Approaches to Planting Design of Parks and Gardens as Main Greenspaces of Green Infrastructure

Maria Ignatieva

Abstract This chapter will analyse the role of planting design in shaping modern greenspaces – the main stepping stones of urban green infrastructure. Moreover, several theoretical concepts, such as green infrastructure, urban greenspaces, two natures, urban biotopes, and "biodiversinesque" landscape style, are considered. This chapter discusses the dual identity of greenspaces, shaped by two main forces: design (plants as living spatial elements that are combined according to design principles) and nature (plant communities/biotopes with their specific species composition and seasonal rhythms). The text also traces the development of the two most representative types of greenspaces – gardens and parks – by exploring the main steps of planting design history through an interdisciplinary (historical, design, ecological, and botanical) perspective. Parks and gardens were the quintessence of a complex political, economic, and social situation as well as aesthetical ideals; they reflected the natural environment of a specific region or country. The evolution of parks and gardens came a long way from altering/manipulation, improving, beautifying, and commercializing to finally attempting to mimic nature. This chapter is based on examples from Europe, the USA, Australia, and New Zealand. The main aim is to demonstrate the importance of addressing local ecological, cultural, and social peculiarities when designing a new generation of sustainable urban greenspaces and green infrastructure.

Keywords Dual identity of greenspace · Living spatial element · Urban biotope · Two natures · Biodiversinesque style

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_23

23.1 Introduction

Because of globalization, urban landscapes share many common features such as the unification of landscape architecture approaches, the use of similar plant materials, and the sharing of cultural preferences or visions of *convenient* and predictable urban landscapes (Ignatieva 2010).

In this research, urban green infrastructure (UGI) is understood as a network of natural, semi-natural, and designed and non-designed (*spontaneous*) greenspaces within urban areas, at all spatial scales, which aims to deliver a wide range of ecosystem services. This definition is based on the critical interpretation of green infrastructure (GI) by Benedict and McMahon (2006) who acknowledged the interconnected network of natural areas and other open spaces that conserve natural ecosystem values and functions on a big scale. The adopted definition also considers the ideas of Tzoulas et al. (2007) and the latest definition of GI by Dover (2015), who considered:

Networks of high-quality green spaces and other environmental features (such as pavements, car parks and roads), which can support life (urban biodiversity) and promote ecosystem services. (Dover 2015: 3)

The adopted definition refers to UGI as a network of greenspaces at the city scale, where different types of greenspaces are the stepping stones in this network. Such a definition allows to offer a framework that can advocate, integrate, and implement progressive planting design solutions that support biodiversity, ecological functions, and ecosystem services of the future city at different scales, i.e. big city or landscape, intermediate (such as neighbourhood or an individual greenspace), and site-specific design.

The dominant contemporary attitude to UGI and urban greenspaces is generally the consumer's attitude. Plants are seen as a construction material (similar to architecture) without consideration of their biological and ecological requirements. Developers keep offering conventional unsustainable models of housing based on high consumption of energy and resources (large footprint housing models with extensive hard surfaces and manicured lawns). Turf areas, private gardens, public parks, and urban streetscapes use similar landscape design patterns, which lead to a homogeneity of green areas and unsustainable management practices (Ignatieva 2010).

The important question that needs to be answered today is how do we find strategies for creating different types of sustainable urban greenspaces, the main stepping stones of green infrastructure that can be accepted from social, ecological, design, and planning points of view?

23.2 Methodology

This chapter is based on an analysis of several theoretical concepts: green infrastructure, urban greenspaces, biotopes, and *biodiversinesque* landscape style (Ignatieva 2018). Publications in SCOPUS and Google Scholar were analysed using these key terms: urban greenspaces, green infrastructure, planting design, and native and designed nature. An analysis of the main concepts and findings from several research projects where the author was the leader or a participant has also been performed, i.e. *Low Impact Urban Design and Development* (Ignatieva et al. 2008), *Lawns as Ecological and Cultural Phenomenon* (Ignatieva et al. 2015), and *Biophilic, Resilient Green Infrastructure: Perth as a Case Study* (Ignatieva et al. 2020). Garden history, particularly planting design history, is used as a unifying theme throughout this chapter.

23.3 Greenspaces

Greenspaces are defined and understood in a different way depending on the discipline (design, planning, social science, or ecological science). One of the main components, which allows to distinguish these spaces from others, is the vegetation or associated living (natural) elements (Taylor and Hochuli 2017). In this research, urban greenspaces are defined as areas in the urban environment that are covered with some form of vegetation and associated living creatures. Urban greenspaces can range in their vegetation origin. They can be *natural* (such as remnants of particular native biomes, which very often are conservation reserves or protected areas); *semi-natural* (remnants of native vegetation or secondary vegetation at different successional stages), which is modified (in terms of structure and composition) and used for recreation or other human activities; *ruderal* (wastelands, overgrown abandoned railways, unmanaged spaces between buildings, etc.); and *human-made* according to particular design styles and a management plan (parks, gardens, street plantings, etc.).

Greenspaces provide a wide range of social, economic, and environmental benefits and vary in their ownership. They can be private or public and thus can be maintained by a private person, city government, or local council. Greenspaces can be part of different land-use categories (residential, commercial, industrial, etc.). There are several ways to classify greenspaces. In most literature sources and governmental documents, urban greenspaces include gardens, parks, street-tree plantings, grassed sports fields, green roofs, roadside plantings, urban forests, wetlands, and grasslands (Taylor and Hochuli 2017). Some authors classify greenspaces as involving land-use parameters and define the following categories: park greenspaces, protection greenspaces, institutional greenspaces and residential greenspaces (Zhao et al. 2010).

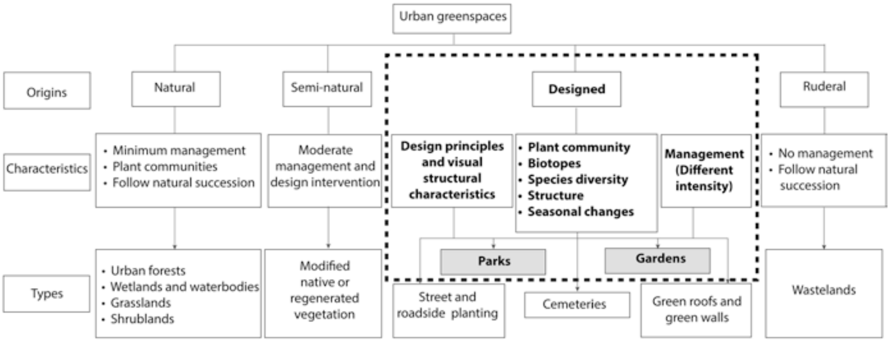

Fig. 23.1 Urban greenspace typologies

Greenspaces, especially designed ones, have a dual nature and are shaped by two main forces – design and nature (Fig. 23.1). On the one hand, they are created using design principles of space organization in an outdoor environment similar to architecture or interior design. Designers see different landscapes and their components (greenspaces) as a composite space. Such space is created by the sequence of the spatial arrangement of geological landforms, built structures (architecture), and living vegetation. The goal of any designed greenspace is to create a special journey for a visitor, a prescribed experience by navigating the movement of people and directing their attention. Thus, plants are seen as a living spatial element aimed at fulfilling several functions (screening, recreation, shelter, etc.). For example, big trees provide three-dimensional form by establishing the basic skeleton of an outdoor environment, while shrubs complement and reinforce the compositional qualities of these large trees.

To create a special visual experience, landscape architects have to offer a whole range of different plant assemblages. The choice of plants in planting design is based on their visual and structural characteristics (e.g. height of the plant, form, habit, texture, colour, and associated sensory qualities such as smell and soundscapes). Then designers must consider the ecology of an individual plant (growth form, e.g. tree, shrub, herbaceous plant, or succulent), its growing peculiarities and soil requirements, and a combination of plant communities to assess whether it fulfils the climatic requirements and is ecologically compatible (Robinson 1992). There is also a visual *grammar* of planting design where plant assemblages and overall planting design should follow main principles of visual composition: harmony, contrast, balance, emphasis, sequence, and scale (Fig. 23.2).

Designed greenspaces, or landscape architecture spaces, have a huge variety of possibilities. Plants of different geographical origins, forms, heights, and colours are planted together to create the desired composition. On the other hand, greenspaces are plant associations. Once planted, they will follow natural processes. Each plant that naturally establishes by itself or is deliberately planted will compete for light, for water, and for nutrients. By combining plants and using different soils and materials, as well as through maintenance, landscape architects create a whole range

Fig. 23.2 Left: The Garden in the Madre Island (Lake Maggiore, N Italy). Right: The Dream Park, Enköping, Sweden. Planting design principles (contrast, sequence and scale) and design characteristics (colour, height, form and texture) as a visual design grammar

of urban biotopes. Urban biotope (from ancient Greek terms *bios* = life and *topos* = place) can be defined as a section of the earth's surface (terrestrial or aquatic) with a similar abiotic environment to its characteristic biological community.

Some designed greenspaces are very complex, consisting of several types of biotopes. For example, parks and gardens are a mosaic of biotopes such as urban forest (woodlands, groves, shrublands), hedges, lawns, and linear plantings (alleys, road- and riverside plantings). Even edges of pathways and roads, as well as cracks in hard surfaces, which can support some living plants, are specific biotope types.

Each plant community in greenspaces has a composition (species diversity), structure (number of layers/strata, i.e. canopy, understory, ground cover), and seasonal rhythms. Plant communities also change over time (succession processes). Addressing this dynamic characteristic of plant components in greenspaces is especially challenging, since it is very often in conflict with achieving a desired aesthetic effect. Most landscape compositions from the very beginning of history relied on specific maintenance and management regimes that aimed to keep plant associations in the requested shape. Thus, the plant community would stay at a particular stage of its development, for example, in flowerbeds or shrubberies. Some plant communities, for instance, naturalistic planting schemes, will allow a specific sequence of successional stages under constant control (i.e. a specified maintenance plan).

In designed plant associations, maintenance and long-term management play the role of mother nature. The landscape architect decides and directs the plant composition and structural diversity (diversity of plant life forms and spatial arrangement of species). Thus, a designer can choose species from different biomes. Crossing over geographical barriers and climatic zones has become possible because of acclimatization experience and the trading of many exotic species, as well as advancements in different maintenance techniques such as irrigation, weeding, mowing, pruning, and fertilizing.

Traditional maintenance operations in gardens resulted in creating specific environmental conditions that gave an advantage to one group of species and eliminated the others. From an ecological point of view, these maintenance operations are disturbances that reinforced the growth of a specific group of plants. Weeding and using mulch is another good example of how maintenance can be used as a natural factor to keep ornamental plantings at a particular stage of development. Weeds are pioneer plants and these first species, which will react to any disturbance, will appear in a designed freshly established site. To control these undesirable natural pioneer plants, which can compete with desirable ornamental plants, there is a special maintenance intervention: mulching and applying herbicides. Thus, weeds are not able to compete with ornamental species and the latter are given more opportunities to adapt to climatic and edaphic factors.

The next part of this chapter discusses the development of the two most representative types of greenspaces, gardens and parks, using examples from Italy, France, Great Britain, Russia, Australia, and New Zealand. The main focus will be the twofold character of greenspaces.

23.3.1 Gardens as Paradises for Soul and Body

From the very beginning in human history, gardens were conceived as an attempt to create an ideal world where humans could harmoniously interact with nature. The rules of garden design and the plant material choice changed over the centuries. Gardens were the quintessence of a complex political, economic, and social situation, as well as religious and aesthetical ideals, and a reflection of climate and the interpretation of the natural environment of a specific region or country.

In medieval Europe, a garden was a paradise – mostly a *hortus conclusus* (enclosed garden) located inside fortified castles or in monasteries. The structure of the garden was symmetrical and symbolized a garden paradise, a materialized Garden of Eden.

Most plants used in such gardens were obtained from the surrounding native plant communities. Central and Western Europe is in the temperate zone where deciduous forest trees like oaks (*Quercus robur* L.), hornbeams (*Carpinus betulus* L.), limes (*Tilia cordata* Mill.), ashes (*Fraxinus excelsior* L.), elms (*Ulmus laevis* Pall. and *U. glabra* Huds.), beeches (*Fagus sylvatica* L.), maples (*Acer platanoides* L. and *A. pseudoplatanus* L.), birches (*Betula pendula* Roth), poplars (*Populus* spp.), and willows (*Salix* spp.) prevail. Many of these forests were cleared for agriculture, but many others survived and were included in royal hunting forests and reserves. Trees and shrubs in gardens were arranged following a formal garden approach. The very special type of modified grassland vegetation, the lawn, appeared during this time. Gardeners cut pieces from *good* pastureland or meadow, brought these pieces to the garden, and then maintained them by using simple garden instruments such as wooden mallets and scythes, which allowed more grass to dominate durable sod (Ignatieva et al. 2020). Such first lawns were looked on more as low-height meadows and even, in some cases, were embedded by planting extra ornamental plants such as violets (symbol of the Virgin Mary and Flower of Paradise) and and strawberries (symbol of the Trinity and Heaven). These grassed garden carpets looked quite biodiverse and were in the stream of the paradise paradigm (the Garden of Eden must have had many species). Artistic representations of late medieval gardens show that each country had its own local representatives of meadow flora. Such *flowery meads* in medieval gardens have inspired the twenty-first-century tapestry biodiverse alternative to conventional turf surfaces (Smith and Fellowes 2015). Lawn, as a purely human invention for pleasure, started to conquer European gardens during this late medieval period.

Most medieval garden plant associations were still based on native species and inspired from plant communities really existing in the surroundings; however, they were already using a management technique that could help control natural forces and keep the desired ornamental effect - for example, green carpet effect (lawns) - and arrange garden trees in organized rows or a quincunx pattern. Fruit and exotic species known in Roman times and reintroduced in this period also enriched medieval European gardens. Many plants in gardens had not only ornamental and symbolic meaning but were also useful (Hobhouse 2002).

Italian Renaissance gardens symbolized the microcosm of man in his ultimate perfection, eternal paradise, and the unchanged essence of beauty. The majority of garden vegetation consisted of evergreen native trees that were in abundance in the surrounding Mediterranean forests, woodlands, and shrublands. For example, the iconic Villa Lante, Villa D'Este, and Boboli Gardens have a *bosco* (forested bosquets) made of local holm oak (*Quercus ilex* L.) and strawberry trees (*Arbutus unedo* L.), alleys of cypresses (*Cupressus sempervirens* L.), and specimens of stone pines (*Pinus pinea* L.), hedges of laurels (*Laurus nobilis* L.), laurustinuses (*Viburnum tinus* L.), and box trees (*Buxus sempervirens* L.) for parterres. The Renaissance garden principle *green on green* worked perfectly well with this evergreen vegetation.

Native forests, as in Villa Lante, were an important part of the philosophical program since they symbolized the transmission from the Golden Age of Man, represented here by native vegetation, to the perfect geometrical villa, symbolizing modern civilization. This *adjunct forest* had minimum maintenance and even had intact ground cover. Five or six main native species were chosen as a design element to create a symmetrical perfect garden that took a high level of maintenance (especially clipping trees and shrubs) to keep vistas, rhythm, and compositional balance. The rare and exotic plants on which the owners focused had special places in such gardens – the so-called *giardino segreto* (secret garden) and *orangeries*. Inside hedged bosquets, trees and shrubs could grow freely (without clipping), creating special plant communities that could also support a variety of plants and wildlife. Interestingly enough, such spatial organization of the Renaissance pleasure gardens has allowed the creation nowadays of very valuable biodiversity hotspots. For example, Boboli Gardens is one of the most important greenspaces in modern Florence, supporting a variety of living creatures in the middle of a crowded city.

In the seventeenth century, French formal gardens and parks were among the most powerful tools to show the monarch's power over kingdom, court, people, and nature. Such parks were huge (hundreds of hectares) and had highly organized parts consisting of closed park *rooms* – bosquets and open parts with highly ornamental parterres. In such parts of the garden, any spontaneous living plant was eliminated

Fig. 23.3 Left: Boboli Gardens (Florence, Italy). Middle and right: Park Vaux-le-Vicomte (France). Enclosed vegetated bosquets may provide suitable habitats for urban flora and fauna

by a huge army of gardeners who constantly clipped, weeded, mowed, and cleaned the garden's vegetation. However, these highly manicured parts were surrounded by previously existing or planted native broadleaved woodlands with only cut perspectives, which allowed visual connectivity and were used for horse riding (Fig. 23.3).

The essential material for *green architecture* was quite limited and based on the above-mentioned native mid-European broadleaved forests species and some introduced species that were widely used before in ornamental gardens, such as box trees. Newly arrived ornamental plants were used in *orangeries* and some of the parterre types. Similar to Italian gardens, French historical parks also represented a significant urban biodiversity resource. Particularly in enclosed (hedged) vegetated bosquets, urban flora and fauna found an important biotope that experienced only indirect disturbance (hedge clipping) and where plants could grow freely in the inner cores of bosquets from the seed banks and follow the steps of natural succession processes typical to natural vegetation (Fig. 23.3).

23.3.2 Designing "Ideal" Park Nature

English landscape gardens of the eighteenth century shifted from a rigid geometry to curvilinear, non-symmetrical, and even biomorphic lines that imitated natural forms. This switch towards untamed nature occurred for a combination of reasons (political, economic, social, and philosophical). Englishmen wished to liberate themselves from existing political structures and other forms of authority. The landscape garden was a metaphorical model of society: the free will of the Englishmen was reflected in the winding stream and the free (not clipped) growth of trees.

English broadleaved forests (though very fragmented at that time), reforested woodlands, and emerald-green pasturelands were the perfect subjects for manipulation. However, the existing landscape of forests and open woodlands was subject to improvements to look more *beautiful*, according to the taste of the educated landlords and intellectuals of the period. This beauty should follow the special design rules similar to the composition rules of the seventeenth-century romantic landscape paintings of French and Italian masters. Landscapes should have background, midground, foreground, and layering. Thus, trees, woodlands, and open grass-dominated spaces should be arranged in a way to achieve a series of views or pictures. Created landscapes were definitely inspired by existing landscapes, but they had to follow particular artistic canons. Thus, there were sweeping lawns and open pastures, undulating lakes (mostly artificially created), and artfully placed clumps of trees, temples, and sculptures positioned in a rhythmical way with focal points and vistas, which all together should create an improved idyllic version of *nature*.

Lancelot *Capability* Brown, the main English *improver* of the landscape, came with the standard park formula – curvilinear landscapes with gentle rises, offering a wide-open, rolling landscape; emerald-green grassland and scattered woodlands accentuated with clumps (groups) and single free crown trees; romantic bridges and pavilions with scenic vistas; and visually connected landscapes (borrowed views). All English park landscapes were created by combining these elements with carefully chosen plant species. Plant characteristics such as colour, texture, height, and form should be grouped in a way to provide contrasting light and shade and to create a special mood. This improvement attitude was very much part of the overall mania in the country for improvement. Planting woodlands fulfilled important afforestation goals; open grassed areas were used for grazing or hay production; waterways and drainage contributed to landscape reclamation (Rutherford 2016). The finance and resources involved in creating a landscape park were tremendous. Digging, moving (creating the desirable ideal topography), planting many new trees, and creating grassed surfaces required intensive labour.

From an ecological point of view, such parks created new plant communities such as woodlands and grasslands, using native and some exotic species, which were managed by establishing a particular maintenance scheme. The shape of woodlands had desirable curvilinear lines. The composition of woodlands and woodland belts was based on local broadleaved trees. Some conifers, such as Scots pines (*Pinus sylvestris* L.) or larches (*Larix* spp.), were used in some parks as a nurse species for growing broadleaved trees. The majority of trees for new parks were grown in nurseries until a certain age and then delivered to the park's space, so that mature trees could be placed according to landscape design plan. Trees for groups, forest belts (trees planted in a linear pattern), and isolated individuals were chosen mostly based on their ornamental quality. For example, one of Brown's favourite specimen trees was the cedar of Lebanon (*Cedrus libani* A. Rich.), which was introduced to Britain in the seventeenth century. Such trees were used for contrasting shades of green and for providing a variety of colours and forms. Since these groups were located on open pastures or lawns, they had no understory vegetation (Fig. 23.4). Occasionally, some of the existing ancient oak forests or surviving fragments of forest and native meadows were included in the parks but still underwent a *softening* procedure to fulfil the design goals. The pleasure ground, which was located closer to the house, contained more frequently mown lawn, shrubberies with native and exotic deciduous, and evergreen species; the borders of such shrubberies were reinforced by bulbs, perennials, and annuals. Pleasure grounds could even have flower gardens; however, usually, they were hidden from wider view. Such artificial plant assemblages needed constant maintenance to support desirable design function and appearance.

Fig. 23.4 Left: Blenheim Palace Garden (UK). There is no understory vegetation beneath the tree groups. Middle: Rousham Gardens (UK): frequently mown lawn next to the main building in the pleasure ground and the park's lawn behind the *ha-ha* (sunken fence). Right: Chatsworth (UK): *Capability* Brown park's formula - curvilinear landscapes with gentle rises, emerald-green grassland and scattered woodlands accentuated with tree groups and single free crown trees

Green sward, a specifically grass-dominated community with chosen grass species (which were all native to Great Britain), was the essential element of open park spaces. There were different types of lawns. The more intensively maintained turfs were located closer to the house. There were also specially created *park lawns* based on pastureland grasses. There was also a grassy clearing in woodland sowed with hayseeds and clover, with the aim of smoothing landforms and creating waving lines in the landscape, which were called *lawnde* (Rutherford 2016).

The maintenance of the landscapes was quite intensive as well, and this was one of the essential conditions for creating pictures and different experiences. Biodiversity was higher only in less intensively managed areas of landscape parks. The English climate was extremely favourable to the different lawn grass species, such as *Lolium perenne* L., *Poa pratensis* L., *Festuca rubra* L., and *Agrostis* spp. These grassed areas in time supported a variety of herbaceous species from the forest fringes.

By the end of the eighteenth and beginning of the nineteenth century, Brown's park formula was criticized for its monotony. The followers of the picturesque school encouraged more *rough* nature. However, their vision of nature was still about manipulation. They aimed to create a *correctly picturesque* scene. According to (Impeluso 2007: 99), this nature "must be tamed and made more comfortable". Thus, *raw* nature (the natural plant communities) was never appreciated and was subjected to the correction of *flaws*. The English landscape park is a vision of the ideal nature created by educated wealthy landowners.

In garden history, the English landscape garden is acknowledged as the greatest British achievement in the visual arts. As Walpole (1717–1797) said "We have given the true model of gardening to the world; let other countries corrupt or mimic our taste" (Mayer 2011: 59). *Capability* Brown not only changed British landscapes but created the model for inspiration and imitation in the nineteenth and even in the twentieth and twenty-first centuries. The English landscape park model was imitated in all colonies, in the European continent, and beyond.

In other countries, British ideas were copied but interpreted according to local cultural and climatic contexts. Parks in the English manner appeared next to the old formal residences of kings and noblemen. In many countries, such parks incorporated remnants of natural vegetation, which were modified accordingly. For example, in Russian capital city of St. Petersburg, there were many untouched native conifer forests where *tsars* wanted to establish their English parks. In Pavlovsk Park, the eighteenth-century residence of the Russian *tsar* Paul I, indigenous vegetation was used as a foundation for the future park.

23.3.3 Urban Public Park Formula

The eighteenth-century landscape park formula was used as a framework for public parks of the nineteenth century, in England, and then in the rest of the world. For example, in Birkenhead Park in Merseyside, England, Central Park and Prospect Park in New York, and Hagley Park in Christchurch, New Zealand, the main landscape garden principles are clearly visible. The difference in such parks is their accessibility to the public. Designers used artificial mounding and considerable intervention through engineering – site drainage and innovative traffic circulation (separation of pedestrians from vehicles). The new type of parks required flexibility in design structure to serve citizens in their growing needs for exercise and entertainment. From an ecological point of view, such parks were quite complex ecosystems consisting of several types of plant communities and their fragments (lawns, shrubberies, woodlands, streams, etc.), which were unified by roads and green promenades and used for different public recreation purposes. The development of public parks was the result of the industrial and scientific revolutions and of the changing political, economic, and philosophical systems. The new middle class required a different aesthetical vision to satisfy a diversity of tastes and opinions. Now plants could be grown in commercial plant nurseries and be transported by train and boat across the globe. The new *gardenesque*-style was based on art and botanical science. The *islands* of garden soils with plants were spotted on the lawn, which became a unifying element, the canvas, of a park's space. Plants were chosen mostly for their ornamental quality (as a piece of art and botanical curiosity) and observed as a single individual (a specimen plant) or in flowerbeds and groups (Fig. 23.5).

Fig. 23.5 Left: native nature, the remnant of paperbark (*Melaleuca* spp.) wetland forest in Perth (Australia). Middle: designed nature in gardenesque style with botanic islands on lawns and specimen exotic trees (Queens Gardens, Perth). Right: planting design with native plants in one of Perth's public parks

The introduction of exotic plants was a means of “elevating art over imitating nature” (Aitken 2004: 14). In the *gardenesque* garden, there was no thought about *non-organized* nature (*no weeds, no dry leaf*). Botanic gardens such as Kew in London led the fashion for displaying exotic plants. Particularly, newly arrived plants with colourful flowers or leaves and unusual texture or form were in favour and flux in gardens. *Gardenesque* compositions fluctuated between two canons: naturalistic and formal garden styles. Compared to landscape gardens, public parks' open spaces displayed exotic ornamental plants from different parts of the world. A public park could have a remnant of woodland or modified natural remnants, which could have some *unspoiled* nature with some understory and naturally grown vegetation. However, the majority of park ecosystems were planted woodlands and alleys, lawns (regularly mowed), hedges, and mixed groups consisting of introduced trees, shrubs, and herbaceous species in combination with mosaic and carpet flowerbeds.

Such groups (kind of botanic islands on lawns) created a new type of biotope where the main components were garden ground, densely or loosely planted species, and accompanying weeds issuing from on-site germination or colonization from the nearby lawns. The maintenance operations in new public parks and private gardens were mowing lawns and keeping them green, weeding flowerbeds and shrub groups, and pruning (keeping plants *clean* and *obedient*). The availability of new exotic plants resulted in creating a variety of plant combinations at different heights, colours, textures, and forms that in many cases lost the aesthetic sense.

This passion for exotic plants also resulted in changing some of the landscape gardens of the eighteenth century when new exotic specimen trees such as *Sequoiadendron giganteum* (Lindl.) J. Buchh., *Sequoia sempervirens* (D. Don) Endl., and *Cedrus atlantica* (Endl.) Manetti ex Carrière and shrubs (first of all, different rhododendrons) were added to the garden and disrupted the picturesque paradigm.

Thousands of foreign plants arrived in Britain. The Royal Botanic Gardens at Kew and private plant collectors contributed to creating a pool of *desirable* plants that could grow in Britain. In private gardens of the new middle class, the lawn was the canvas for displaying rare and interesting specimens of exotics, topiaries, and flowerbeds:

> There is always room for one or more plant from just one more country. Imagine the pleasure of seeing conifers from the Americas, Morocco, Lebanon, China and India growing in your garden and knowing you possessed them all. (Fox 2004: 9)

During the second part of the nineteenth century and throughout the twentieth century, there was a process of *plant* selection for the *global tropical garden paradise*. This selection included species from different tropical and subtropical biomes (Americas, Africa, Asia, and Australasia), such as species belonging to the genera *Plumeria*, *Hibiscus*, *Casuarina*, *Bougainvillea*, *Strelitzia*, and *Orchis*, and a wide range of palms from different geographical zones, which were planted in public parks and private gardens (Ignatieva 2010).

23.3.4 Gardenesque Triumph over the World

The main principles of nineteenth-century public parks, with their open-spaced grassed parkland landscape pattern supported by *gardenesque* individuals and *botanic islands on lawn*, were accepted in modern global urban parks. Such success of the Anglo-American model was possible with the technological advances of garden equipment, creating global nurseries and global landscape architecture firms who shared the Western vision of creating urban greenspaces.

The *gardenesque* style, based on many exotic plants, made a significant contribution to the ecological crisis. Ornamental plants escaped from gardens, became invasive, and threatened native vegetation. The style is also contributed in creating similar, unsustainable urban biotopes-habitats and homogenization of biota (Stohlgren et al. 2013).

British Empire antipodes – Australia, New Zealand, and the Pacific Islands – experienced unprecedented problems with invasive plants and animals. At the same time as many plants from Australia and New Zealand were becoming very fashionable in Victorian England and started to be cultivated by many garden enthusiasts there, English gardening taste arrived in these countries together with fashionable plants. Here *gardenesque* style flourished because many plants that in England could grow only in greenhouses can grow out of doors. Public parks borrowed the English design principles of organization of space and public parks – the so-called *democratization* of public space. Pieces of *ideal* English parkland with open lawns provided a picturesque touch. Besides, parks were beautified with botanic *wonders* – gifts from local and other colonial botanic gardens. For example, the original design of Melbourne's Domain gardens (the land around the Government House) in 1872 was reminiscent of Liverpool's Sefton Park with classical *gardenesque*-design language.

23.3.5 Two Natures

English lawns were introduced to Australia and New Zealand as the important aesthetic heritage of England. They served as a connecting element of public parks, private gardens, and other types of greenspaces. European grasses adapted to New Zealand's temperate climate quite successfully. In Australia, however, establishing turf was more difficult due to the heat, frequent droughts, and unsuitable soils for European turf species. Most lawn grasses originated in the native or secondary grasslands of Europe. In the southern hemisphere, all suitable turf species were non-native species and required irrigation. For the first Australian settlers, green lawns and familiar garden plants were their best friends in the constant struggle against dirt and summer heat (Gaynor 2017). The designed and maintained garden was a symbol of their British heritage and the European civilization, which contrasted with the native vegetation associated with indigenous wilderness. For Europeans, such native bushes and forests looked very untidy and dangerous and very different from British idyllic *improved* nature or open public parklands. European trees, such as oaks, limes, ashes, beeches, elms, and chestnuts (*Castanea sativa* Mill.), were among the first species to arrive in the new lands, since they were part of ideal English nature. In temperate areas of New Zealand, such broadleaved trees adapted to the new environment well, but in Australia, very often, these trees had a harder time.

This separation of urban landscapes, where lawn and exotic decorative plants in parks and gardens are kept apart from native bushland, is the foundation for the existence of two different *natures* in Australian and New Zealand cities (Ignatieva et al. 2020). One nature is a *native nature* or *bush* – that is, the native vegetation surrounding urban areas and their remnants within urban boundaries. The other nature is *designed and managed*. The urban nature, developed during European colonization, mostly consisted of introduced Western design greenspace typologies and exotic plant assemblages from different world biomes: European deciduous forests, plants from South Africa Cape floristic region, Northeastern and Northwestern American conifer forests, South America, India, China, Japan, and many others. In many cases such designed greenspaces relied on high-energy maintenance and water input.

Some native species found their way to be included and appreciated in European gardens. For example, eucalypts were widely used in Australia; some settlers included them as specimen trees in newly established parks. Some gardeners cleared the understory and used the bush as a background and *smoothed* it by planting exotic conifers and ornamental shrubberies. Lawn very often was worked as a special buffer zone between these two natures and demarcated the boundary between indigenous (wild) and controlled (neat) urban areas. However, lawn grass species, for example, *Cynodon dactylon* (L.) Pers., became invasive and conquered the *improved* native forests and shrublands, thus creating hybrid plant communities.

The introduction of the *gardenesque* style and the planting of exotic plants marked the beginning of the invasive species crisis. Many plants escaped from agriculture, botanic gardens, and private gardens. The difference in the speed and the degree of naturalization and invasiveness in Northern, Central, Eastern, and Western Europe is very small compared to the New World. Central European original flora consisted of 2400 vascular plants. More than 12,000 plant taxa have been introduced since 4000 BC, and only 279 (2.3%) have been naturalized in natural plant communities (Müller and Sukopp 2016). Europe has less than 2% of widespread aliens (Stohlgren et al. 2013).

In New Zealand, native flora consists of 2500 indigenous plants (80% of them being endemic). However, since Europeans arrived in the 1840s, over 25,000 exotic plants have been introduced, and one-tenth of them have already become naturalized, with 4 more escapees each year (Meurk 2010). Similarly, since the end of the eighteenth century, 26,242 plant species have been introduced into Australia. About 2739 have become naturalized (Randal 2007). Recent studies (Phillips et al. 2010) show that the largest numbers of Central European plants were introduced into Australia between 1840s and 1880s and between 1980 and 2010. The gardening industry was the largest importer of introduced plant species (94% of all new alien plant species). Garden escapees are a dominant group (66%) of naturalized alien plant species.

Europe always had one vision of urban nature. It included all types of urban biotopes – remnants of "pristine" forests, semi-natural modified forests, and designed urban parks and gardens. Nowadays, most types of greenspaces in Central and Western European cities are still dominated by native flora (except botanic gardens and specific types of gardens). Due to a small number of naturalized exotic species, there is a quite relaxed approach to the native/exotic issue. However, some naturalized species have appeared in urban forests and native conservation areas. Due to the ecology of European native biomes, which have undergone numerous disturbances, there are effective natural recovery mechanisms for disturbed ecosystems. A large number of native pioneer species in the soil seed bank allow native plants to quickly regenerate through progressive successional steps.

23.3.6 New Planting Design Style: Towards "Biodiversinesque"

The ecological crisis and the dramatic loss of local biodiversity resulted in the search for new planting design styles. By the end of the nineteenth century in England, William Robinson advocated the idea of *wild gardens* with more natural and less formal-looking plantings (with hardy exotic and native plants to grow spontaneously). Similarly, Jens Jensen was passionate about North American indigenous plants and ecological processes of the prairie landscape. He inspired several generations of US landscape architects who designed prairie gardens in the twentieth century and into the twenty-first century.

Europe continued the legacy of the wild garden approach throughout the twentieth century and went down the pathway of creating naturalistic plantings (meadow and prairie planting of Hitchmough and Dunnett (2004) in Great Britain) and reintroducing meadow-like and natural vegetation along urban rivers and waterways, urban rain gardens, and swales. One of the goals was to reinforce biodiversity and connect nature with urban citizens. There was also a growing prioritizing of native plants over exotic in planting design across Europe.

In Australia and New Zealand, dramatic loss and modification of native vegetation due to urbanization and the spread of invasive plants drove the search for more ecologically advanced planting design style. Gardening with native plants using the rich Australian flora was rediscovered and started to be appreciated in suburban private and public gardens during the 1970s. There was an advocating of planting aesthetic *designing Australian bush gardens* and replacing lawns and exotic garden vegetation with Australian drought-tolerant plants. The New Zealand environmental movement, which also started in the 1970s, promoted a shift towards appreciation of native plants. Several nurseries propagating native plants for gardening appeared in both countries. By the end of the twentieth century, there was also a paradigm shift in the minds of people and authorities. Now in Australia and New Zealand when somebody talks about *returning nature to the city*, it means native nature, the remnants of native vegetation (Ignatieva et al. 2020).

Designing with native plants in the southern hemisphere follows very similar principles to gardenesque parks. Native species are chosen because of their valuable design characteristics, such as texture (e.g. fine and coarse texture of *Hebe* and *Phormium* species in New Zealand or *Westringia* in Australia), interesting flowers (e.g. *Callistemon*, *Grevillea*, *Anigozanthos*, *Eucalyptus*), and colour of leaves and stems (e.g. *Leucophyta brownii* Cass., the Cushion Bush). Plants are combined as they were in the nineteenth century gardens, creating decorative layers (high, medium, and low) with particular textures and colours. Groups are arranged as botanic islands on lawns or as perimeter planting. For preventing weed development, the soil in planting groups is covered with mulch. Such urban biotopes dominated by native plants have not reflected any real native plant communities or their peculiar species interconnection with soil and wildlife. In reality, a limited group of native plants is used for creating alternative plantings. Nevertheless, such biotopes partially fulfil the function of increasing native biodiversity and creating the identity of place (Fig. 23.5).

As a result of the analysis of existing approaches for greenspace design and the historical garden and park patterns, a new planting style, namely, *biodiversinesque*, was introduced (Ignatieva 2018). It is based on the respect for the dual natures of planting compositions and the knowledge of ecology (dynamic trait of plant communities) and the research of existing native plant assemblages as an inspiration for planting design. The task of a landscape architect is to find out a way to translate and even replicate ecological patterns, dynamics, and biodiversity into such design language that can also be accepted by the public. Today's planting aesthetic philosophy is turning towards appreciation of *true* nature, i.e. nature as it is. We should understand and learn from the wisdom of surrounding ecosystems instead of *improving* or *beautifying* them.

23.4 Conclusions

Centuries of different planting design styles have shaped parks and gardens according to societal and cultural norms and design principles. Native biomes were a source of inspiration and plant material. The evolution of taste has brought it a long way from manipulation, to improving and beautifying and to commercializing nature. The most recent approach to planting design is the response to the ecological crisis and is based on learning from nature and emulating natural systems (*nature-based solutions*).

In the past, parks and gardens were separated patches – oases in urban environments. In some epochs, there were attempts to create networks of parks, boulevards, and riverine vistas, but it was only at the end of the nineteenth century that the notion of connecting several parks into a network of greenspaces, with the aim of improving the urban environment, came into place.

The development of landscape and urban ecology and its application to urban planning and landscape architecture contributed to the idea of green ecological corridors and the connectivity between greenspaces.

Green infrastructure in the twenty-first century is capable of treating all forms of urban nature holistically. Urban-nature integration at all scales will require locally specific approaches, analysis of natural biomes and urban biotopes, and regional ecological mapping to tailor planning approaches to facilitate best-practice GI. How to adapt GI to the changing and unique climatic, soil, and rainfall patterns of different cities is an important factor. Importantly, guiding the implementation of GI into urban design and planning frameworks will require interdisciplinary work between design, ecological, technical, and social disciplines.

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Chapter 24
Environment in Megacities: Tehran Waterscapes

Manfredi Leone, Ayda Alehashemi, and Giuditta Lo Tauro

Abstract Defining contemporary urban paradigms is the challenge of this time, especially when the urban dynamics are so fluid they spread uncontrollably in over-extended and overpopulated territories. This is the case for megacities, metropolitan areas with more than 10 million inhabitants, which place the emphasis on how to manage energy consumption in such filled places. In this frame, the city of Tehran, the capital of the Islamic Republic of Iran, scene of political and cultural disputes, administrative and economic headquarter of the country, with its nearly 15 million residents and a daily traffic of more than 20 million people, is currently one of the most populous cities in the world and represents an interesting case study, in order to explore the urban dynamics in the use of public space, aiming to an environment protecting-oriented approach. Tehran's urban landscape is a metaphor for its duplicity: on one side, to the north the majestic Alborz mountain range, from which seven water streams flow; on the other, to the south, the desert. The attempt of this paper is to make a historical, urban, and landscape analysis of this controversial city in order to understand how the water system of the city could enhance the public space design processes with a sustainable approach.

Keywords Megacities · Landscape architecture · Urban waterscape · Public space

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_24

24.1 Introduction

Tehran, capital city of Iran, is located between the Alborz mountains to the north, the Karaj Valley to the west, and the Jajrud River Valley to the east, with an average altitude of 1200 m a.s.l. The city stretches over about 18 km from the 1800 m-high district of Darband in the north to the 800 m-high suburbs in the south-east, delimited by the sand of the southern desert, with a slope of 13.5 m/km. This unique topographical situation has made it possible for the city environment to drain water almost naturally. From a geological point of view, the Tehran plain is made of alluvial aggregates deposited by rivers and seasonal streams that flow from the Alborz mountains. There are seven water streams, going from west to east: Kan (perennial), Farahzad (seasonal), Darake (seasonal), Darband (almost perennial), Gholabdareh (almost perennial), Darabad (almost perennial), and Sorkheh-hesar (seasonal). As a whole, the watershed of the rivers and streams reaching Tehran covers a length of approximately 170 Km. Tehran has a cold semi-arid climate (Köppen climate classification: BSk; Kottek et al. 2006) with continental climate characteristics and a Mediterranean climate precipitation pattern; average high temperatures are between 32 and 37 °C, and it can occasionally drop to 14 °C in the mountainous north of the city at night. Most of the light annual precipitation occurs from late autumn to mid-spring, but no one month is particularly wet. The hottest month is July, with a mean minimum temperature of 26 °C and a mean maximum temperature of 34 °C, and the coldest is January, with a mean minimum temperature of −5 °C and a mean maximum temperature of 1 °C.

Urban-wise, the historical settlement developed in the plains and used the ancient underground water supply system of the *qanats* (further in this paper) to irrigate its large and sumptuous noble gardens. Meanwhile, a fair number of small satellite villages developed on the slopes of Alborz mountains after the seventeenth century benefiting from the water of the mountainous rivers; those villages were eventually incorporated into the urban fabric of the city centre.

The same rivers in the modern era, starting from the 1960s, have been the subject of a containment program through canalization by the municipality to fight the danger of flood, with the only result of denying the city a valuable landscape and natural element.

This chapter will focus on the river landscape of the city of Tehran, which, even if as a plain city, has always dealt with the supply of underground and surface water. Specifically, the Maghsoudbeyk Canal, resulting from the union of the two rivers Darband and Golabdareh, which flows for almost 6 km in the north of Tehran, represents the in-depth study case of this contribution.

How can this now forgotten waterway become a future resource for one of the world's megacities? Could this be the kick-starter for a new green corridor that untangles the smog blanket of the highly polluted Iranian capital?

24.2 Tehran Between History and Modernity

A brief historic premise is here necessary in order to let the reader understand how the city of Tehran turned to change its urban paradigms during the centuries, with both the foresight and the recklessness of whom had been governing it.

We do not know the real reasons why the Qajar, a congregation of Turkmen tribes, decided to establish its capital in what, in 1786, was little more than a fortified village, in the plain on the slopes of the Alborz mountains, in the north of Iran. We do not have much historical information about the history of Tehran before that date: we know with certainty that in the ninth century AD it was still a small rural gathering that orbited around the most important centre of Rey, a town located about 7–8 km to the south-east, which at that time represented one of the most important towns in the Middle East for its strategic positioning in the Silk Road path (The Encyclopaedia Britannica 1911).

The destruction of the town of Rey in 1228 by the Mongols represented, fortuitously, the fortune of Tehran, who escaped the invasion, thanks to its impenetrable character – a heap of nomadic tribes hidden in the midst of caves, cultivated fields, gardens, and orchards, irrigated by an intricate system of *qanats* that carried water from the Alborz mountains to the inhabited centre (Khosravi et al. 2017: 65):

> Tehran's primordial urban development can be considered a sort of inhabited garden. An architecture based on the continuous evolution of a negotiation between life and earth, excavated and accumulated, which gave the initial urban fabric a peculiar spatial continuity, internally articulated by living and working spaces, together with elements that are both nomadic and sedentary.

The first attempt of architectural and political unity for the city came in 1553 with a Safavid ruler, Shah Tahmasp I, who fortified the city with a brick wall of raw earth regularly punctuated by 114 towers. Thirty years after Tahmasp, Shah Abbas I – who in the sixteenth century unified and reorganized the Iranian empire under the capital city of Isfahan – settled in Tehran for health reasons after one of the battles against the Uzbeks and modelled the intricate Safavid system in a regular succession of gardens, lined paths, and residential pavilions, anticipating the urban matrix that would give order to Tehran in the following centuries.

24.2.1 Qajar Era (1786–1921) and Pahlavi Era (1921–1979)

On March 12, 1786, Tehran became the capital of the empire under Mohammed Khan of the Qajar dynasty, which would reign almost undisturbed for 130 years. Under the Qajar, the city finally enjoyed an artistic and cultural attention, demarcated by a first phase of real modern urbanization; the city began to expand beyond the walls of the central historical core, to slowly reach the villages located to the north, on the direct slopes of the Alborz mountains, the county of Shemiranat.

Up to that time, the Shemiranat had had a parallel life to that of Tehran, representing the *summer residence* for the aristocracy of the time, according to its location at about 1600 m a.s.l. Under Mohammad Shah Qajar I (1834–1848) and Nasser al-din Shah Qajar then (1848–1896), the city radically changed its urban and political paradigms, including its relationship with the west.

Nasser al-din Shah, last of the Qajars, gave the city not only a new political structure – building the skeleton of a modern central government with nine ministers – but also urban planning through the two city urban plans designed by August Krziz in 1857 and Abdol Ghaffar Najmol-Molk in 1889.

During this period, the city doubled in population (in 1886 the city had 155,736 inhabitants and spread over 18.25 km^2) (Pakdaman 1974).

In 1921, the state official Reza Khan carried out a *coup d'etat* against the last heir of the Qajar dynasty and took the power in 1925, thus starting the Pahlavi dynasty, the last empire before the Islamic Revolution. The Pahlavi dynasty characterized the city by placing a particular emphasis on the infrastructural system, such as the construction of Pahlavi Boulevard (today Valiasr Street, 17,9 km long from north to south), the Mehrabad Airport, and the representative Azadi Tower, as well as the construction of several lines of the subway, the university campus, and several prestigious buildings, with the contribution of numerous western architects and artists. The Pahlavi was a so-called parliamentary monarchy, indeed a monarchical regime, which, however, earning the revenues that derived from the commercial use of the rich oil resources, modernized the country from an infrastructural and cultural point of view. On the one hand, progressive and west-oriented policies, on the other hand the iron fist against popular discontent, created a tense atmosphere between the government and religious people all over the country. This social structure, made of young students, temporary workers, Islamic workers, and fundamentalists, who in the name of freedom of expression against the regime, who in the name of religious conservatism, will swell the ranks of the Islamic Revolution of the 1979, led by Ayatollah Khomeini, who, after the white flag of the Iranian armed forces, overthrew the last Iranian monarchy and proclaimed the Islamic Republic of Iran on February 11, 1979.

24.3 Tales of a Megacity

During the early years after the Islamic Revolution, the city of Tehran and generally Iran underwent a moment of strong political and social upheaval, not only given by the total change of habits and lifestyle resulting from the transition to a different governmental device but also because of the war between Iran and Iraq between 1980 and 1988, the so-called Gulf War or, to put it in perspective, the *imposed war*, which blocked the urban development of the capital for almost a decade and brought the country to its knees.

After Khomeini's death in 1989, Ayatollah Ali Khamenei, still in office, followed by direct designation. According to the current constitution, Iran is an Islamic, presidential, and theocratic Republic, which divides its system between the institutions elected by the people with legislative and executive power on the one hand and the non-elective religious organs that have a *moral* role.

The city of Tehran, the capital, can be defined here as a full-fledged megacity: with its 22 districts which host 9.3 million inhabitants – 15 million considering the metropolitan area – and the 1700 km^2 surface; it is the largest Iranian city and one of the largest capitals of the Middle East (worldpopulationreview.com). The peculiarity of the city certainly lies in its geographical location: it extends from the slopes of the Alborz mountains to 1700 m a.s.l. in the north, reaching 1200 m a.s.l. in the central plain, up to 900 m a.s.l. in the south (Fig. 24.1). This topographical complexity is accompanied by an equally complex demographic and urban condition: for evidently distinct climatic – and historical conditions, as seen previously – the northern districts of the city have hosted the wealthiest social classes for centuries, while in the south a disordered and intricate system of buildings hosted and still hosts the lower classes.

The most recent expansion of the city to the west (towards the nearby city of Karaj) has however shown the other side of the coin of a carelessness towards urban planning devices in favour, instead, of real estate owners and builders. A kind of urban expansion that is not only saturating the western territories of Tehran but which also extends as far northwards as possible, where the prices of apartments per square meter reach exorbitant records, equal to what could be found in cities like New York or Los Angeles. Another critical issue in the Iranian capital is certainly vehicle traffic: although the public transport system is punctual and fully functional (both by metro and urban buses), the city still has more than three million vehicles in transit per day, including private cars and taxi services. It is not unusual, moving by car from the south to the north of the city, not to be able to appreciate the wonderful landscape backdrop given by the Alborz mountains due to car pollution, one of the most serious environmental and climatic problems on the liveability of the city. How much can urban design, and consequently architecture, contribute to reduce these critical issues?

Fig. 24.1 Northern Tehran, view from Milad Tower. (Photo credit: Amir Pashaei 2019)

24.4 Urban Planning in Tehran: An Overview

What we see today is a city in continuous urban expansion, and in order to understand it, it is necessary to analyse and know the tools of urban planning and development implemented by the different governments in charge during different historical phases. It is evident how these devices have set themselves different objectives from time to time and have spoken almost antithetical languages. The problem perhaps arose upstream, in wanting to impose an extremely western-fashioned model on a city that, as seen, proudly retains its own characteristic peculiarities (Emami 2011).

24.4.1 Tehran Comprehensive Plan (1966–1969)

In the three decades following the Second World War, Tehran experienced rapid growth in size and population. While in 1945 its population was 700,000, in 1975, with 4.6 million inhabitants, it was among the fastest-growing metropolises in the world. After the Second World War mainly, without adequate general urban planning, the city continued to grow and expand in a chaotic way. In the early 1960s, while wealthy families began to reside permanently in their homes in Shemiran (the northern area), the old central core and its southern suburbs gradually welcomed more and more migrants and inhabitants from rural areas. In a government centralization scenario, the Shah shaped a city increasingly geographically divided into social classes; in 1966 the Plan Organization – an organ of the municipality of Tehran – organized a consortium of Americans and Iranian companies, Victor Gruen Associates, from Los Angeles and Abdol-Aziz Farmanfarmaian Architects of Tehran, to prepare a comprehensive plan for the city lasting 25 years.

Approved in 1968 and completed in 1969, the plan involved a metropolis expanding towards the west axis of the city. Drawing on Gruen's utopian model of a *cellular* metropolis, the proposed general plan consisted of ten areas, literally *urban cities*, separated by vast green areas spread out by the mountain slopes. Each satellite city provided a commercial centre with shopping centres, corporate offices and cultural structures, and a rigorous grid of multistorey buildings in line with modernist-style utopian cities. Although the proposed plan provided an interconnection between the satellite cities with rapid transit routes, the main means of transport was supposed to be private vehicles, for which a large network of motorways had been planned (some also on two levels), for a total length of 150 km.

This was a typical post-war American model that, one might ask, would have held up in Persian territory. Looking at the tables that make up the TCP (Tehran Comprehensive Plan) project proposal, the comparison with Le Corbusier's project for Chandigarh (India, 1950) is immediate: its green stripes may have been the *formal* model for the green valleys of Tehran, showing a formal and an aesthetic composition abstracted from the context, symbol of its time. The fundamental nucleus of the entire plan was represented by the Abbasabad area, already identified as an area of interest in the plan sketches of the previous decades, to become the new *urban centre* of the city, with a view to the expansion of the city to the north.

The proposed commercial centres of the TCP were never built, but the interwoven highways today constitute one of the main elements of Tehran skyline, in particular in its northern and western parts. Sixty years later, from above, you can see a partial realization of the modernist tableau, of the *American dream* in a Persian land, even if the advent of the Revolution a few years later would have changed the fate of urban planning in the Iranian capital.

24.4.2 Louis Khan in Tehran (1970–1971)

In October 1971, Tehran was the stage of a long-planned celebration for the 2500 years of the Persian monarchy: a sumptuous and eccentric ceremony that saw Mohammed Reza Shah parading through the streets of Persepolis and Pasargadae first and for Tehran then, proclaiming himself direct heir of the Achaemenid Empire, in an excess of megalomania. In this context, in 1973 the American architect Louis Kahn (1902–1974) was called to prepare a plan, in collaboration with the Japanese architect Kenzo Tange (1913–2005), for the design of the urban centre of Abbasabad. Kahn's initial proposal for Abbasabad was based on the general scheme and guidelines of the TCP of 1968. In the first scheme, the complex was limited to the flat terrain irregularly located south of the hills, designated as the urban centre of the Abbasabad district. While the hilly part of the site had been left intact, residential buildings were placed along the northern peripheral highway. In the second phase of the project, Kahn extended the centre of the city northwards in a linear thread: the large square and the stadium were moved to the centre of the hilly part of the site, and the business district took the shape of a diamond. Moving the square over the hills, it detached itself from the urban fabric of the city, like an acropolis, an idea perhaps more in tune with the Shah's vision of an urban centre (Mohajeri 2015).

24.4.3 Shahestan Pahlavi, Llewelyn-Davies International (1976)

After Louis Kahn's death, as the plan had not been completed, a further project was needed. In the late 1973, following the oil embargo, Iran's income quadrupled. Given the huge amount of resources, Mohammed Reza Shah decided to transform the country into a one-party state and invest in its hegemony. The final plan for Abbasabad, prepared by the British study Llewelyn-Davies International (LDI) under the direction of the American planner Jaquelin Robertson, reflects all these transformations. His conceptualization, preparation, and aesthetic inclinations were in tune with the flourishing oil income and the megalomaniac royalty that this same income had spurred. What in Kahn's sketches was to be an urban centre for the community, heralding a crisis between identity, tradition, and modernity, thus became the Shahestan Pahlavi (literally *the imperial site of Pahlavi*), physical manifestation of the new calendar and the new single-party system, with a view on using urban planning to consolidate the power of the Shah. In a period of 18 months, a team of 50 designers therefore prepared an *emergency masterplan* for 554 hectares of open land (Robertson 1978: 47):

> Finally, Shahestan Pahlavi will give Tehran and the nation both a precinct of high amenity and a ceremonial centre with which all citizens can identify. It will symbolize Iran's rapid progress toward becoming a leading industrial nation and world power. It will also demonstrate new commitment to quality development. In its achievement, Shahestan Pahlavi can reflect the highest aspirations of Iranian culture and perhaps provide the country once more with a capital that can elicit the admiration of travellers the world over, like Isfahan in the sixteenth century. Shahestan Pahlavi offers Tehran more than the chance to become just another large capital; it affords an opportunity for greatness.

24.4.4 After the Revolution: From Tehran 80 (1996–2001) to Present Day

At the end of the twentieth century, in the post-revolutionary (1979) and post-Gulf war period (1988), the third phase of urban planning aimed at the reconstruction and redevelopment of spaces after the conflict. The flow of rural migrants increased the population, which in 1986 consisted of 6 million inhabitants, producing new challenges that highlighted the flaws of the previously approved masterplan. Strategic planning was therefore necessary: the first attempt was made in the period between 1986 and 1996, prepared by an Iranian company, the A-Tech, approved by the Superior Urban Planning Council. One of the main elements of the plan, still in force today, was the division of the capital into 22 districts, each with its own core of services. This plan was however rejected in 1993 by the municipality of Tehran, which was unable to meet the expected costs (Emami 2014).

The municipality itself therefore proposed a strategic plan for the period from 1996 to 2001 – the first masterplan of the municipality of Tehran, also known as *Tehran 80* – which had, unlike the previous plans, a series of strategic points that shifted the focus from land use to the management implementation of resources. The plan therefore hinged on five fundamental points: the scarcity of resources, the speed of urban expansion, pollution, the inefficiency of public transport, and the improper bureaucratic system. The new urban axes and the implementation of the green areas had been designed on the basis of the 1968 TCP and Tehran 80, but from 1990 onwards, the municipality introduced the sales strategy of the *zoning variants*: the practice is often defined *sales density* or *sale of air rights*, which actually consisted in allowing an increase in the area ratio in exchange for a tax. A speculative attitude was put in place by the municipality itself, which on the one hand served to flesh out the cash machines of the administrative machine but on the other hand gave way to a trend, still present in the capital, of increasingly tall buildings with more and more valuable materials, to increase their sale or rental prices. The debate has consequently moved during last two decades on the need to regulate the planning of the city of Tehran through a strategic plan and no longer a masterplan, too rigid as an instrument and unable to account for the speed of urban expansion of one of the world's megacities (Andalib 2018: 14):

> The systematic existence of a *plan without planning* can be introduced as the greatest ruin for a period of forty years of preparation of new urban planning plans and programs in Iran, especially in the metropolis of Tehran

24.5 The Water Element

24.5.1 The Iranian Plateau

The Iranian Plateau is a main geological landmark of Western Asia. From a historical point of view, it included the Partia, the Middle and East Persia, as well as the central regions of Greater Iran. It is bordered to the west by the Zagros mountains, to the north by the Caspian Sea and the Kopet Dag mountain range, to the south by the Strait of Hormuz and the Persian Gulf, and to the east by the Indus River; nowadays it is represented by the quadrilateral formed by the cities of Tabriz, Shiraz, Peshawar, and Quetta, for an area of 3,700,000 km^2. It does not have a regular surface but is crossed by mountain ranges of various elevations (from the Alborz, whose highest peak, Mount Damavand, reaches 5610 m a.s.l. to the Dasht-e Lut, the great desert, with an average altitude below 300 m a.s.l.). About 4000 years ago, the Iranian plateau suffered a period of drought, culminating in total aridity as a result of climate change, which is why the inhabitants of the study area devised an ingenious method of water supply, the *qanat* system (Alehashemi 2020: 269):

> In the central part of the Iranian Plateau, these water distribution systems had represented vast innovations in various ways. Most of the cities in this arid region depend on groundwater and the considerable technique of qanat to convey water, however when available, other water resources were exploited, such as rainfall (in the south of the country) or river water (in the foothill of Alborz and Zagros mountains).

24.5.2 Qanats: A Millennial System

The qanat system is composed of a slightly inclined underground channel, transferring water from a water table located at a higher elevation than the cultivated land. At a glance, a qanat is nothing more than a horizontal tunnel that drains groundwater, but digging this tunnel involves a high amount of knowledge, skills, and technologies. The engineering that revolves around the qanat system is a collective knowledge and expertise accumulated over centuries of cooperation. In regions where qanats are the cornerstone of the local economy, the sense of cooperation is quite high. A typical qanat consists of a series of vertical wells that reach the surface, interconnected underground by a gentle low-sloping tunnel. The first well (mother well) is excavated, usually in an alluvial fan, at underground deeper level with respect to the water table. The wells are excavated at 20–200 m intervals in line between the groundwater recharge area and the irrigated land. The current Persian name for qanat tunnels is *rahrow* or *kooreh*, which is in fact a horizontal tunnel dug to gain access to underground water reserves and to transfer water to the Earth's surface. The size of the tunnel is such that the workers can easily go through it and work in it. Those workers, the *muqannīs*, the *craftsmen* of the qanat, were almost seen as sacred figures in Persian culture as they looked as living symbols of the direct association between water and life, for the technical and scientific skills they had, and for the danger that ensued from working tens of meters underground (Manuel et al. 2018).

An interesting aspect of this millennial underground water supply system is certainly the ability that it has had to spread over the centuries in different arid and semi-arid regions of the world, some of which is still active. The qanat system, originated in the northwest of present Iran, around 600–800 BC (Goblot 1979), experienced an important spread under the Achaemenid Empire (550–330 BC), stretching from the Indus to the Nile watersheds, westwards to the Mediterranean shore, and southwards to Egypt and Saudi Arabia. This technology was also adopted in Afghanistan, Central Asia (Pakistan, Oman, Azerbaijan, Iraq), and Chinese Turkestan (Xinjiang region), even if it is not yet certain whether its spread was due to the Achaemenes, the Silk Road, or an indigenous development (Semsar Yazdi and Labbaf Khaneiki 2013). Later in time, the Arabs and the spread of Islam drove the second major diffusion of this system in seventh to eighth centuries AD, across North Africa (Algeria, Morocco), Spain (Madrid), Cyprus, and the Canary Islands. Lately in Italy, particularly in Sicily, the capital city of Palermo was equipped by an intricate *qanat* network (in vernacular Sicilian *ingruttati*) during the Arab period (827–1072 AD), exploiting the existence of two water streams and an air refreshing system exploiting the freshwater flowing in the qanats and the wind towers (Todaro 2000; Leone 2020). We can also find a qanat network system in the New World, specifically in Mexico, Peru, and Chile, brought there from Spanish colonizers during the fifteenth century AD (English 1968).

24.5.3 Water Streams in Tehran

We already mentioned the seven water streams crossing the northern part of the city of Tehran, descending from the slopes of the Alborz mountains: Kan, Farahzad, Darake, Darband, Gholabdareh, Darabad, and Sorkheh-hesar (Fig. 24.2).

This complex and fascinating river network, which nourished the ancient rural settlements in the foothills, has been totally changed during the 1970s due to flood protection. Tehran has faced several episodes of river flooding, especially of flash

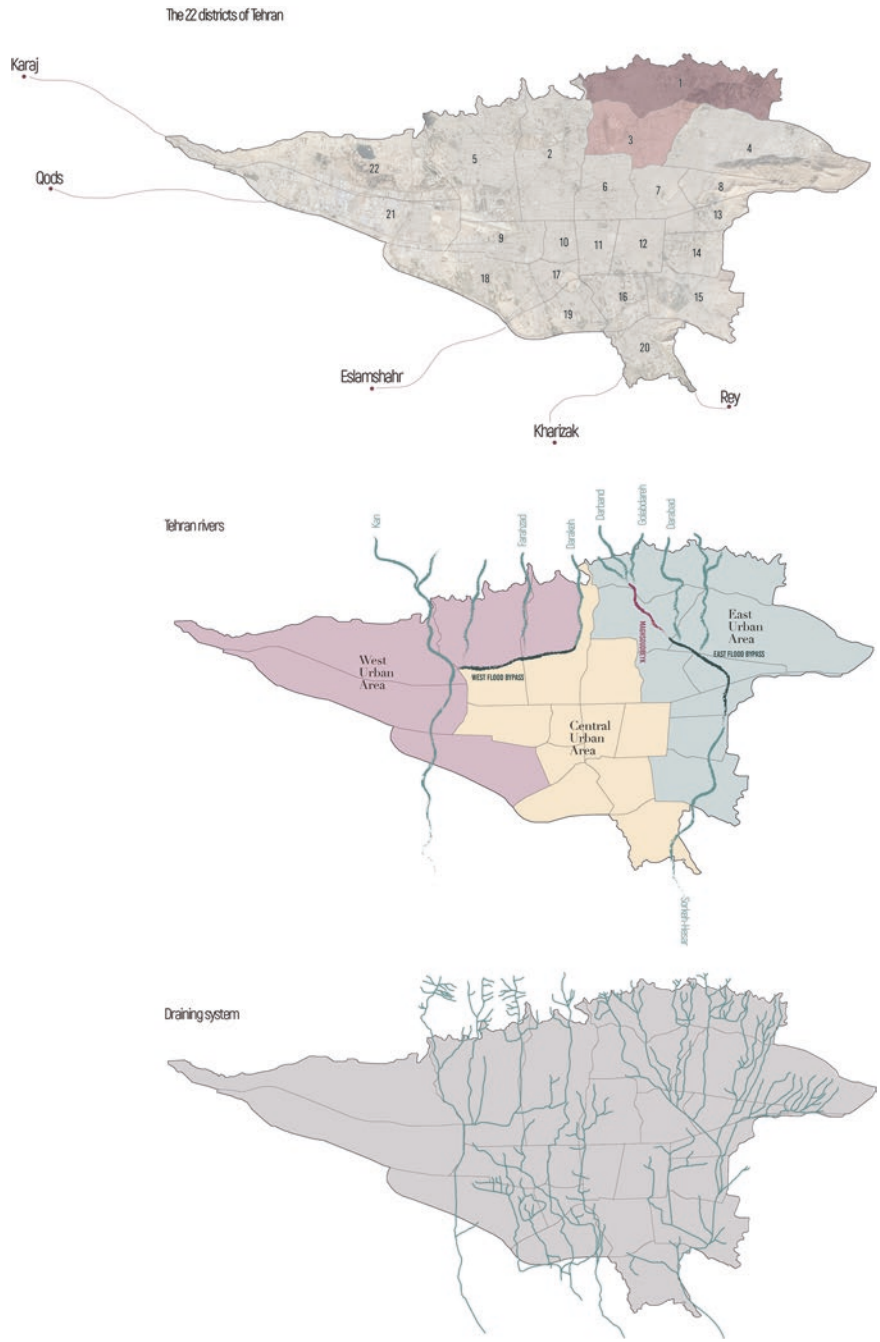

Fig. 24.2 Tehran urban analysis: districts and water systems. (Credit: Giuditta Lo Tauro 2020)

floods: for this reason, two underground bypasses have been constructed during the 1970s in order to drain the water coming from the rivers, both to the western and eastern areas of the city. But despite the attempts of containing the floods – both with concrete flood walls and with the construction of the flood bypasses – the city faced a terrible flash flood on July 26, 1987, when 386 people lost their life due to river encroachment. After this big flood which mostly affected the areas of Darband and Tajrish in the north of the city, almost the 22% (37 km) of the watercourse of Tehran rivers has been completely covered or buried (Chavoshian et al. 2018).

24.5.4 Between Darband and Golabdareh: Maghsoudbeyk Canal

A new paradigm induces citizens and specialists to consider urban rivers not as a limit to city sprawl (channelled, covered, polluted as they may be) but to look at them as an opportunity to improve the quality of urban life. In fact, rivers are increasingly appreciated as part of the urban environment, rather than being considered simply a means of removing wastewater and sewage, and represent one of the most interesting challenges in the actual debate around landscape architecture. As for the planning and intervention strategies prepared by local administrations, the general water stream area of the city does not have an ad hoc landscape plan, but the municipality of Tehran together with the MOE (Ministry of Energy) have prepared over the years a political and legislative framework with this in mind:

– The first global water law of the National Parliament, 1968
– The second revision of the water law by the National Parliament, 1983
– Floodplain Zoning Act of the Superior Council of Urban Planning and Architecture (2007)

In the case of the city of Tehran, there is an official agreement – signed in 2007 – between the Ministry of Energy, the Municipality of Tehran, and the Municipal Council of Tehran for the joint collaboration on the management of rainwater, as well as on the management of urban rivers and on flood control and prevention. There is indeed the need to conserve and revitalize the natural river waterways within the city, to enhance the prevention of floods and to improve ecological design with the minimum amount of human impact on the ecosystem (Chavoshian et al. 2018).

24.6 The Site

Maghsoudbeyk Canal was built in the 1970s along with the canalization of several other rivers in the city; at the naturalistic and historical level, before canalization, it represented one of the most important waterways of the county of Shemiranat, north of Tehran, for water supply, the result of the union of two almost perennial rivers that flow down directly from the Alborz mountains: the rivers Darband and Golabdareh which meet in Tajrish Square. Figure 24.3 illustrates the geomorphological and infrastructural system diagram of the area along the Maghsoudbeyk Canal and how it deals with the altitude and the sloping territory.

Highly relevant from an urbanistic point of view, because it is the link between the above-mentioned network of historical settlements, the Maghsoudbeyk Canal represents a peculiar case study among all the waterways in the city, as an integral part of an urban agglomeration that both surrounds and rejects the presence of this watercourse, relegating it to mere channel, whose presence is manifested only by the sporadic sound of the water flow that emerges among the redundant clamour of the car horns.

In the following paragraphs, we will illustrate the selected study case of the macro-area of Maghsoudbeyk, from the union of Darband and Golabdareh rivers, which flows from Tajrish (in District 1) to Mirdamad (in District 3) for about 5.7 km (Fig. 24.4), before converging in the east flood management bypass.

24.6.1 Urban Landscape

Its dual being at the same time a river landscape and a densely urbanized area represents the uniqueness of the site. As illustrated in Fig. 24.4, the area was subdivided in seven sub-areas: this subdivision was made by combining landscape and urban analysis, in terms of use. These seven sub areas, were classified based on their level of asccebility (from public zones to private zones), but also based on the condition of the river bed (both in width and in morphology, as well as its level of artifitialization, from totally natural to totally canalised).

In-depth field research was subsequently on two areas: Tajrish (to work on an urban district scale) and Zargandeh (to work on a neighbourhood scale), identified as the two most important centres of the whole macro-area. The importance of these neighbourhoods is also underlined by the presence of two *Imamzadehs* (tombs of the Imams) – the Saleh in Tajrish and the Ismaili in Zargandeh – as well as two important commercial agglomerations, the Tajrish Bazaar and the Zargandeh fruit and vegetable market. Profoundly different in terms of social composition – Tajrish is inhabited by wealthy people, while Zargandeh is in all respect a workers' neighbourhood – and architectural types, the aim is to analyse their critical issues and enhance their strengths in order to design a solution that could give an idea of the

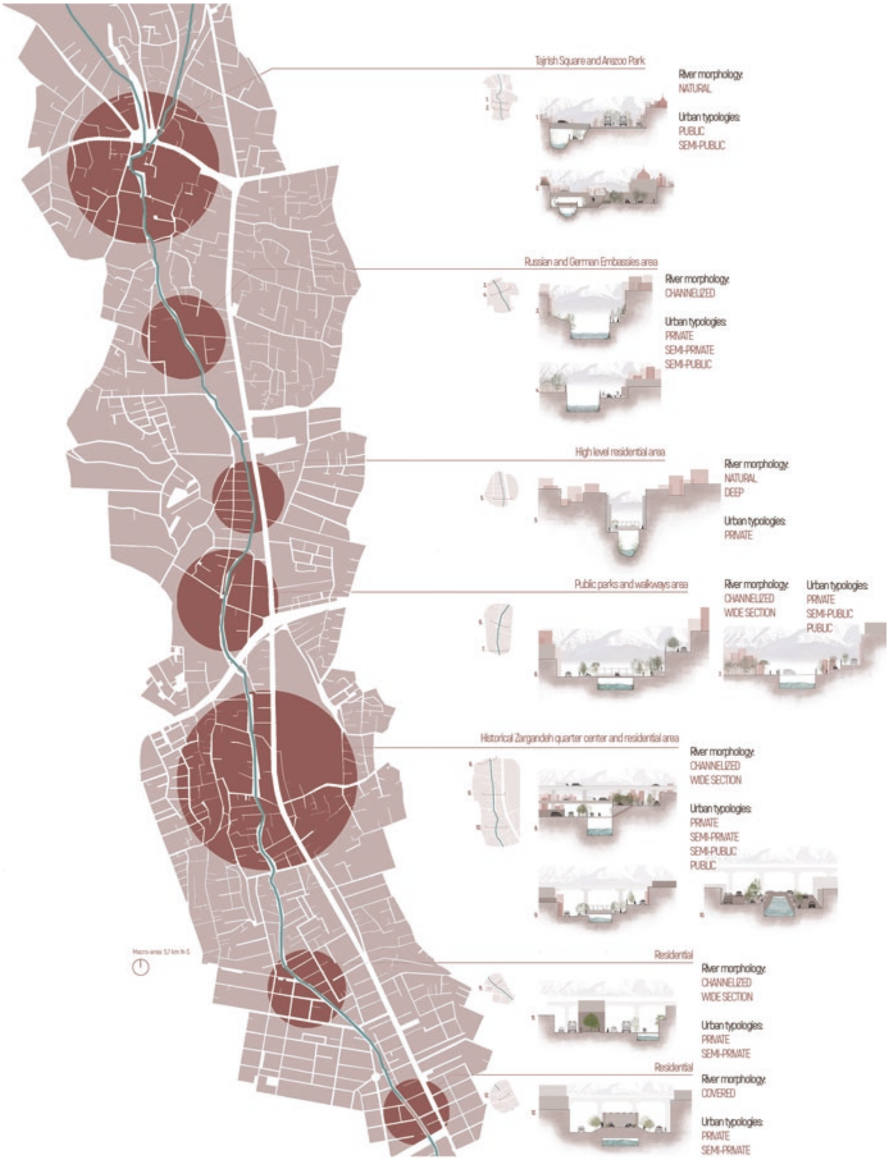

Fig. 24.3 Urban landscape analysis along the Maghsoudbeyk canal. (Credit: Giuditta Lo Tauro 2020)

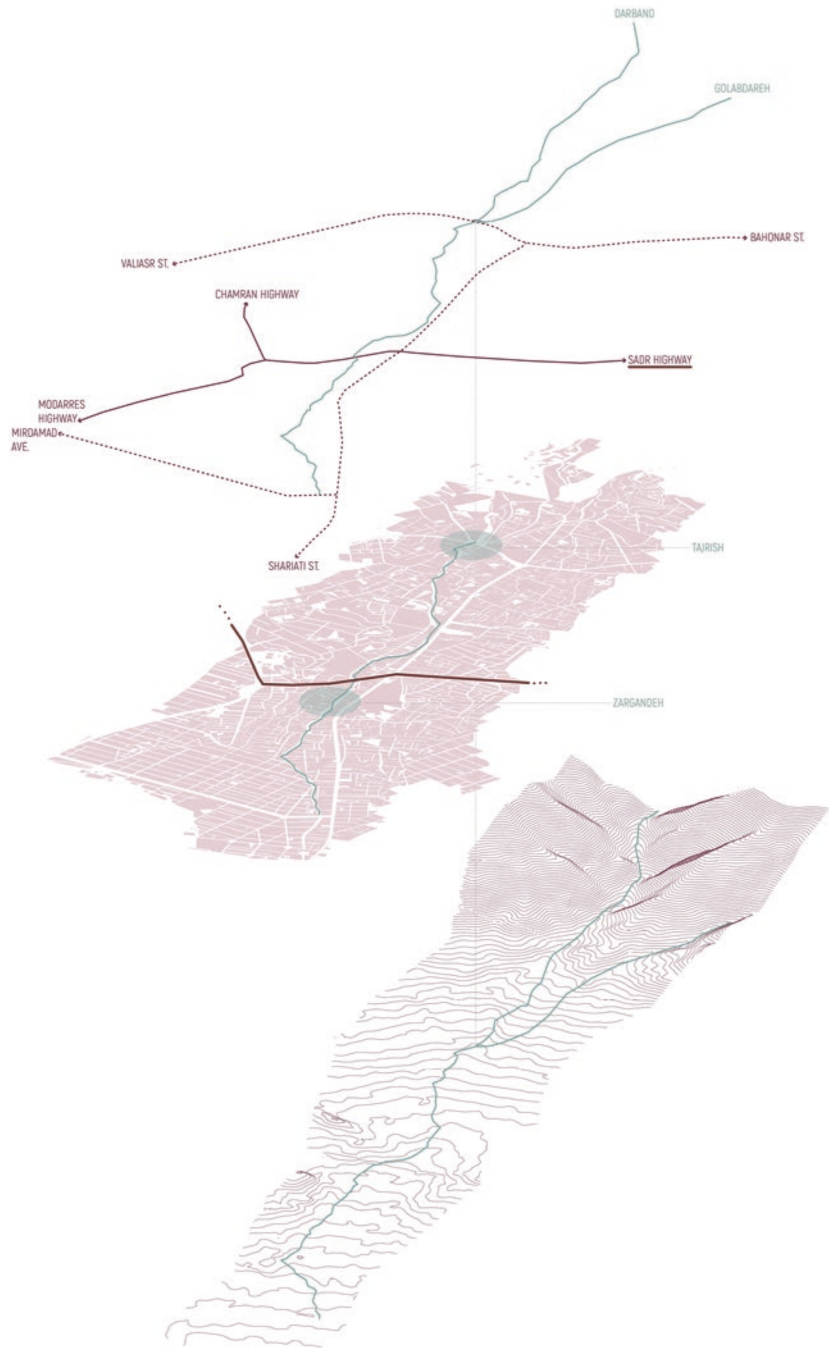

Fig. 24.4 Geomorphological and infrastructural system diagram of the area along the Maghsoudbeyk canal. (Credit: Giuditta Lo Tauro 2020)

presence of the river that connects the two neighbourhoods while trying to maintain the peculiar characteristics of each place.

24.6.1.1 Tajrish Square Urban Analysis

Tajrish Square, in the District 1 of Tehran, is the second most important hub of the city after the historic centre of Tehran, not only for its strategic position in the north but also for the infrastructural connection between the district and the rest of the city: from Tajrish Square, the yet mentioned Valiasr Street cuts the whole city north to south.

In Tajrish Square area, there are two cultural attractors of high importance: Imamzadeh Saleh – the second most important place of worship in the city after the Friday Mosque in the Grand Bazaar – and Tajrish Bazaar.

Tajrish is the centre of the historical Shemiranat County, which has long been considered a delightful summer resort for the wealthy citizens of the Iranian capital, which is why it maintains a socially higher character than the city centre.

As mentioned before, during the Qajar era, Tajrish became a place in which many aristocrats built gardens and luxurious residences, thanks to the presence of the river and a dense network of underground qanats, some of which are still active.

While people were moving from the countryside to the capital city, some settled in Tajrish; as a result, around the 1920s, this area became an integral part of the city, defining the south-to-north development of Tehran. The currently biggest limit of the area is the high noise and atmospheric pollution due to vehicular traffic, as well as the neglection of the presence of the river and a scarce valorization of historical heritage. Tajrish is not only an economic centre, but it represents the connecting point of the city with the Alborz mountains, to Darband winter ski resort. What actually makes this area unique is the high altitude: the square is located at 1612 a.s.l.; looking northwards from there, people may enjoy the panoramic backdrop given by the marvellous mountain range, while on the southern side they may benefit from the view of the city unfolding down to the plain.

24.6.1.2 Zargandeh Urban Analysis

Zargandeh neighbourhood is located in Tehran's District 3 and, together with Tajrish, is one of the ancient villages that stood on the banks of the river in the north of Tehran, while the city was growing across the plain.

With the construction of the Russian Embassy in the 1930s, it was partially inhabited by many Russians who moved there. Extending in a slightly hilly promontory, the urban structure of Zargandeh is made of narrow and very steep streets. The main land uses are residential and office, and there are not many commercial uses, except for the existing fruit and vegetable market. Traffic intensity is mostly due to its proximity to Mirdamad neighbourhood, mainly on Zafar Street. The social composition is extremely varied: the innermost part is mostly populated by proletarians

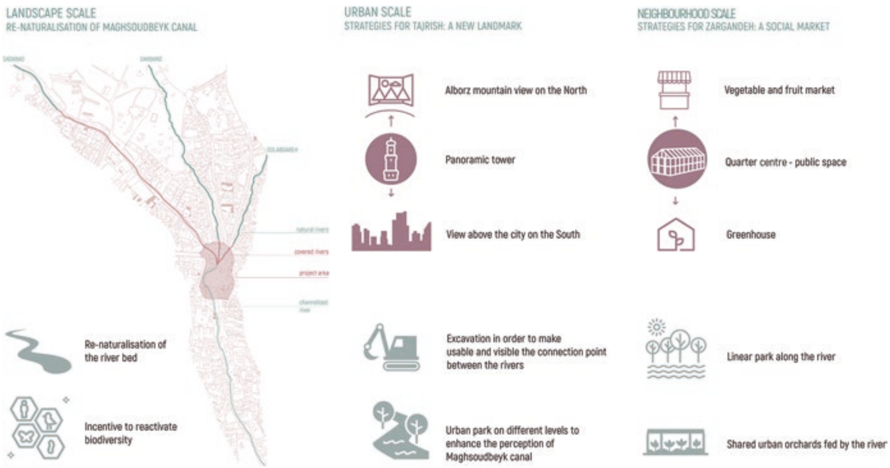

Fig. 24.5 The project: design strategies at three different scales. (Credit: Giuditta Lo Tauro 2020)

living in low and dense buildings, while near the main urban streets the middle class accommodates in 3–4-storey buildings with fine finishes. The main cultural attractors of the area are Zargandeh Park and Imamzadeh Ismaili, with the monument to the Unknown fallen during the Iran-Iraq war. There are several high schools and the Azadi University of Tehran Medicine Department within the hospital.

24.7 The Design

The design process is defined on three levels: landscape scale, urban scale, and neighbourhood scale (Fig. 24.5).

Landscape Scale
In compliance with the Floodplain Zoning Act of 2007, the aim of this project is to improve the environmental quality, where possible, of the river bed, by reconstructing flood terraces and planting riparian forest trees in order to restore biodiversity, which is now completely absent. Where such improvement is not possible due to the irreversibility of the 1970s canalization intervention, the only way to improve the overall environmental quality of the river is to design a system of punctual green *lungs*, making it a green corridor within the urban dense northern area of Tehran.

Urban Scale
In Tajrish Square, the river might become a real attractor for the area. The design process then led to use the dimensions of the historic ovoidal traffic divider in the centre of Tajrish Square to carry out an excavation (Fig. 24.6). This excavation was made to show the convergence point of the two rivers – Darband and Golabdareh – located just under the Tajrish Square, in order to make tangible and visible the

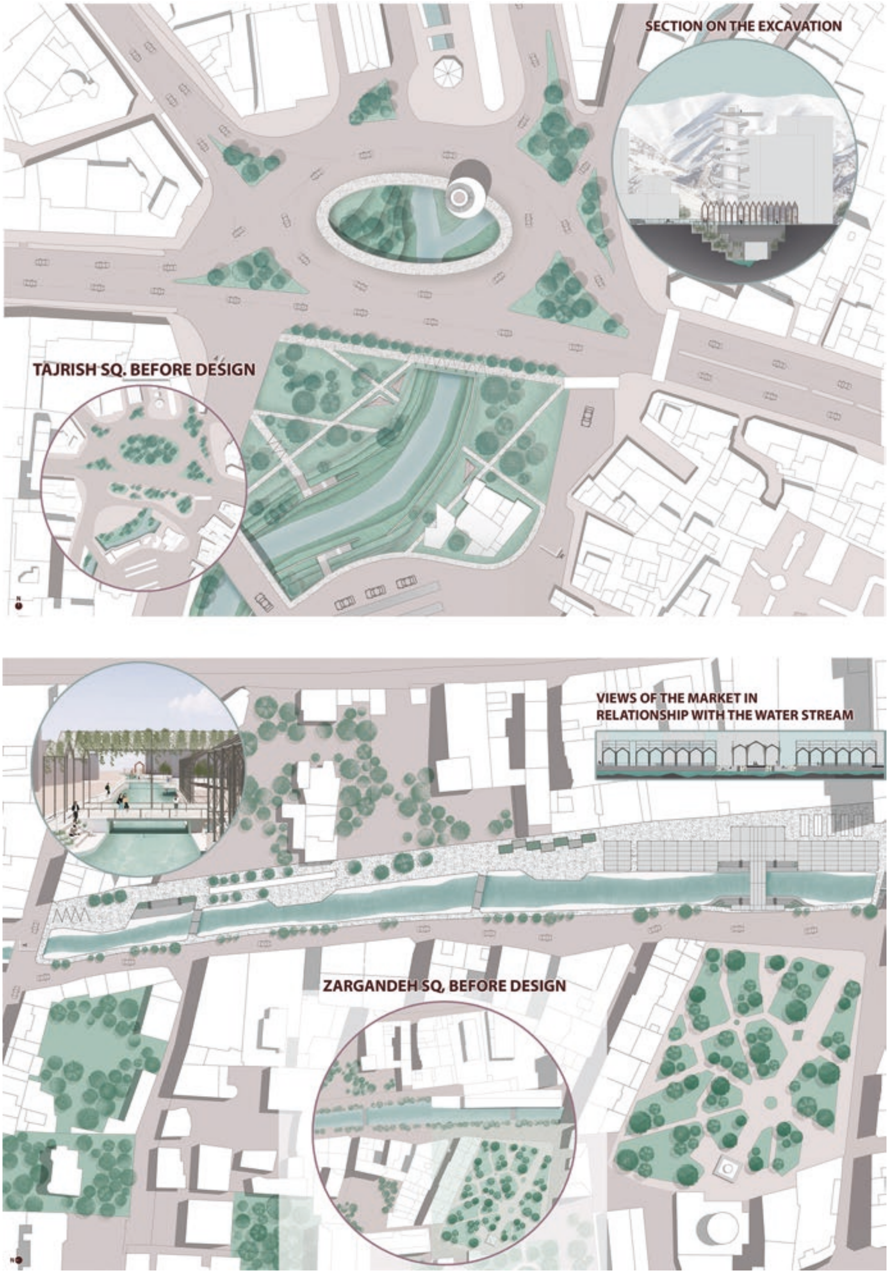

Fig. 24.6 The project: Tajrish Square (top), Zargandeh Square (bottom): comparison between the new design and the existing areas. (Credit: Giuditta Lo Tauro 2020)

connection between the two rivers and therefore the starting point of the Maghsoudbeyk Canal. The project proceeds from the landscape point of view with the design of a park where today a minimal portion of public green stands; pedestrian walkways, seats, trees, and several terraces allow the visitor to overcome the 10 m difference in height between the street and the river level through a system of stairs.

The access to the park is then noted by the presence of a passage arch in weathering steel that incorporates the geometry of the typical Persian arches, in order to create a link between history and innovation. Those arches are strategically positioned in panoramic points facing the bazaar from one side and the Imamzadeh Saleh on the other side; the arch is repeated along both areas of the project in order to make it clear that the parks are part of the same system. At the centre of the excavation, with an access from the street level, the design shows a 40 m high tower.

The tower has a double goal: to become a landmark for one of the busiest squares in the megalopolis of Tehran and to allow the visitor to reach a panoramic point at 1665 m a.s.l., which provides an overall view of the northern slopes of the Alborz mountain range and the controversial and interesting skyline of Tehran, and to appreciate the wide altitudinal range of the city that smoothly develops downwards to the south, as well as a clear view of the unfolding of the river.

Neighbourhood Scale

The last part of the project deals with Zargandeh neighbourhood: not just a system that acts like a landmark for the city – like the solution designed for Tajrish Square – but a project entirely devoted on sharing the spaces of the site (Fig. 24.6). The existing fruit and vegetable market is an important link in the daily lives of the inhabitants, but at the present time the market is inside a dilapidated industrial shed, as well as with a heavy impact on the river landscape.

The adopted design option is a steel building, a light and modular structure incorporating the geometries of the Persian arches, which hosts not only the fruit and vegetable market but also some refurbishment points. The new public space of Zargandeh then becomes the nerve centre of a system made of several accesses to the banks of the river (which here remains channelized) where the visitor can sit and enjoy the mild climate of northern Tehran. The market is the arrival point of a wider system: what is now a one-way driveway therefore becomes a linear park, noted by an entrance portal and a change of pavement as well as by the creation of different paths and two passages that allow the visitor to cross the river from one bank to the other. The link between the market and the linear park is the area reserved for urban gardens and a greenhouse: taking advantage of the river water, shared urban gardens not only increase the social and sharing character of the entire project, but they also provide refurbishment to the market and make the river the real protagonist of the area.

24.8 Conclusions

The city of Tehran, one of the most densely populated cities in the world, in its being so geographically majestic and architecturally rich – even with its social and political controversies – represents an interesting case study for sustainable design approach and still turns on an alarm bell from an environmental point of view. It is important to start from places tangled by horns and highways such as the city of Tehran, by reasoning on how to repair the previous decades of urban sprawl and overpopulation, decades which created megacities that can no longer be sustainable, neither from an environmental point of view nor from a development one. It is for these reasons that this research has set itself the goal of carving out green spaces within the greyness of vehicular pollution, which recall the ancient oasis that in the past centuries made a life in the desert possible. Today, all around, there is no longer the desert but an urban growth at an uncontrolled pace that needs to be tamed. Silently, this research, these water landscapes, flow in the dense urban fabric of Tehran and represent a small stepping stone in the path towards a vision where future cities are more sustainable than the current ones.

Acknowledgements This essay is one of the outcomes of the international collaboration between the Department of Architecture of the University of Palermo (Sicily, Italy) and the Landscape Architecture Department of Imam Khomeini International University (IKIU) of Qazvin (Iran), established during the Water and City International Workshop held in Yazd (Iran) in September 2018. This specific research about Tehran watershed and the design of public space along Maghsoudbeyk Canal comes from the work developed during the master thesis project of Giuditta Lo Tauro, master graduate student at University of Palermo, supervised and led by Prof. Arch. Manfredi Leone (University of Palermo) and Prof. Arch. Ayda Alehashemi (IKIU Qazvin). A 2-month study period between Tehran and Qazvin helped the authors to deepen the research, from September to November 2019. Manfredi Leone is the research supervisor of this working unit.

Author Contributions ML, AA, and GLT supervised the structure and coherence of the whole chapter, and the contents of this essay have been conceived and developed jointly by the authors. AA has more developed the history of Tehran, ML has developed the city planning and water systems topics, and GLT focused on the sites' transformations and design proposals. All authors revised and approved the last version of the manuscript.

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Chapter 25
Cities Facing the Wild

Annalisa Metta and Maria Livia Olivetti

Abstract Untamed ecosystems and plots of wild nature increasingly constitute large parts of contemporary urban spaces. They are often the unbidden result of a long-standing lack of maintenance as well as of the uncontrolled flourishing of weeds produced by the pesticide absolute ban. But they are also something more. Many recently implemented urban open spaces deal with wild nature to solve some of the most urgent tasks of the contemporary cities: reclaiming areas fallen into disuse, designing sustainable infrastructures, revitalizing valuable public spaces, enhancing the ecological footprint of new developments, suggesting new practices and social ritual, reducing management costs, fighting climate change, and satisfying the biophilic desire of nature of urban dwellers. Thus, some questions arise: why and how can urbanity and wildlife come together? Why and how can we design and manage untamed urban landscapes? Which kind of behaviours do they encourage? Which ethical and aesthetical categories do they entail? This paper aims to inquire the role of wilderness in the urban realm, in a critical perspective. On one side, we will explore the proactive value of untamed landscapes as a priceless resource to improve urban quality. On the other, we will wonder about the risks of a possible ideological status of wilderness, as a fashionable label to renew anti-urban positions.

Keywords Wildness · Urban open space · Landscape architecture

25.1 Wild Matters

Urban nature has long been an oxymoron in the Western culture. Although it owes its most complete utterance to the Cartesian thought, the gap between *nature* and *city* has much more remote sources, including even the monotheistic theological scaffolds and the same birth of agriculture, which definitely divided cultivated and left-out lands – the wild, indeed – and, while taking hold of non-migratory living, actually established the otherness between city and nature. Without any apparent

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_25

contradiction or, rather, precisely because of the pretended friction between nature and nurture, modernity has been invoking nature as a thaumaturgical pick for reclaiming the plagues and excesses of urbanization, swinging between various forms of *grafting nature into the city* and *putting the city into nature* (Balmori 2010). According to this trend, wilderness in the city is a sort of last frontier, because it definitively – even, sometimes, apparently – represents the most *natural nature* and the unquestionable opposite of urbanity.

A series of clues, coming from the cultural scenario in which the European contemporary landscape architecture participates, seem to operate in the gears of this rock-hard dualism. They suggest that a habitat where urbanity and wildness mix, until getting blurred and indistinguishable, is finally feasible. It is the same idea of otherness between the two terms which creaks under the blows of thoughts and actions that tend to replace it with unripe or advanced forms of co-presence. The wild is not only in the uncontrolled nature but lives *also* in the city, on the contrary since the beginning shaped as a defensive bulwark from its raids. The encounter between the two worlds comes from hybridization, intentionally triggered by design or arising from the self-determination of living things. It is the *Wild City* (Metta and Olivetti 2020): wilderness and urbanity finally come together, keeping their refreshing content of contradictions and incoherence, suggesting the richness of the seemingly impossible merging of opposite, facing one each other in unpredictable ways.

25.2 Wild European Seeds

Dealing with urban wilderness within a European horizon could sound reductive or naïve, since in modern times the epic of the wild has a colonial flavour. For well-known historical reasons, it took its classic canons in the USA, where the European gaze found a nature of unknown power and dimensions if compared to the motherland's tameness and the metropolis appeared in a *virgin* country as an instant breach into the future, both magnificent and terrible, far away from the reassuring European historical layering. Yet, in European painting, between the sixteenth and seventeenth centuries, the wild is a recurrent and crucial topic, from Altdorfer to Lorraine, Poussain, Rosa, and many other artists who took inspiration from a crumbling Rome where the ruins mixed with lush, messy, and powerful plants, preceding the Piranesi's dramatic visions. The same birth of *protected natural areas* took place in Europe, 10 years before the Yellowstone Natural Park was founded in the USA, when about 1000 ha of forest around Fontainebleau were established as an *artistic reserve*, thanks to the commitment of the painters and sculptors of the Barbizon School. Then, in the first half of the twentieth century, many European countries found just into the wild the rhetorical picklock of their own nationalistic pride, and urban forestation became a strategy for affirming national identity, well before any ecological claim.

Getting to current times, since the first decade of the twenty-first century, many researches and exhibitions have been supporting the thesis that the European wild city can exist. We can consider the conference *Sauvages dans la ville. De l'inventaire naturaliste à l'écologie urbaine* at the *MuséumNational d'Histoire Naturelle de Paris*, in 1996, as the forerunner (Lizet 1997: 10):

> Nature in the city has paradoxical aspects, confuses the categories of wild and domestic, rural and urban […] and opens up to research that is still embryonic today.

The conference depicted a large fresco, at the crossroads of ecology, sociology, urban politics, and design, dedicated to the memory of the phytogeographer Paul Jovet, who explored Paris, during the dark years of the Second World War, in search of (Lizet 1997: 9):

> clues to the unstoppable impulse of wild life in the city, a life-size laboratory for the acclimatization of species that have come from afar.

In 2011 La Cité de la Architecture e du Patrimoine in Paris hosted the exhibit La ville fertile-verse une nature urbaine, gathering the positions of many influential landscape architects, including Alexander Chemetoff, Michel Corajoud, Gilles Clément, and Michel Desvigne. The exhibit highlighted the ecological urgency of the cities within a turning perspective (Gilsoul et al. 2011: 16):

> It is no longer a question of embellishing or restoring the city, as was the case in the 18th and 19th centuries, by multiplying parks, gardens and open spaces […], nor of proposing now abused comparisons between city and nature or between mineral and artificial. The contemporary challenge is to think of the city as a great living system, to be inscribed in its natural environment, and to respect the rules of functioning and balance that, wrongly, it was believed to be able to escape.

The 2014 Rotterdam Architecture Biennale was titled Urban by Nature (Brugman and Strien 2014: 18):

> Looking at the city through the lens of landscape architecture allows us a clear view of the situation. There is just one course of action available to us: if we are to resolve the world's ecological problems, we first need to resolve the problems facing our cities. And the only way we can reach these solutions is by naming and researching them in terms of the metabolism of the city.

Urban Wildlife was among the sessions of the Biennale (Brugman and Strien 2014: 76):

> Wildlife: it consists of urban and wildlife and you think they exclude each other. But it is not true. […] The city is a nature reserve like any other nature reserve, except with a big human presence

According to the authors, the relationship between the natural and the artificial continuously takes place as a pure and mutual exchange. More recently, the first Biennial of Architecture and Landscape of the Ile de France (Versailles, 2019) focused on the ability of spontaneous nature to welcome diversity and increase resilience. These wildlife qualities were already in 2018 the core of the impressive photographic exhibit Paysage français. Une aventure photografique, 1984–2017, curated by Raphaële Bertho for the National Library of France, which displayed the widespread changing of the urban French settlements, from dense built-up areas with enclaves of nature inside to scattered settlements dotting pretended natural environments (Bertho 2017).

25.3 Wild at Work

Celebrating the aesthetical, ethical, and ecological values of spontaneous nature is a recurrent mandate in many projects and inspires numerous urban policies, indeed. Someone adopts this perspective as the only one possible for the *salvation of the cities*, marrying the reasons of the most orthodox ecology with a sometimes fideistic approach. Someone else embraces the cause of the fusion between wildness and urbanity for new opportunistic marketing operations in the global urban trade, interweaving the religion of environmental sustainability with the enhancement of biodiversity, often meant as a real capitalization. Still others, on the contrary, look at this trend with suspicion and skepticism. All of them, in any case, build an increasingly broad and full-bodied debate on the *Wild City*.

Spontaneous ecosystems and wildlife sites are becoming more common in the urban realm, and it is likely that in the future there will be even more space for the urban wild. The social and economic changes underlying the loss of farming practices continue at a rapid pace on the margins of many cities. The growing awareness of the risks associated with the use of artificial chemicals leads to a reduction in the use of herbicides and thus to a greater and more widespread presence of untamed vegetation. Urban spaces sometimes suffer from a long lack of maintenance, with a resulting uncontrolled proliferation of *weeds*. Wild animals are in the city, due to the progressive vulnerability of their habitats and the irresistible abundance of food offered by the metropolis. Moreover, post-industrial societies are changing their ways to face natural systems, moving towards more mutualistic relations, oriented by the urgent need to protect biodiversity and reduce environmental and climate risks. In this scenario, urban design often resorts to wild nature to respond to some of the most pressing issues of contemporary cities: reclaiming neglected areas, designing sustainable infrastructure, revitalizing valuable public spaces, improving the ecological footprint of new settlements, suggesting new practices and social rituals, reducing management costs, satisfying the *desire for nature* of the city dwellers, and so on.

Thus, some questions arise: why and how can urbanity and wildlife come together? Why and how can we design and manage untamed urban landscapes? And further: how can we inhabit wild urban lands? Which kind of behaviours do they encourage? Which ethical and aesthetical categories do they entail? Finally, can landscape architecture work for lush cities, assuming lush in its double meaning, both as luxuriant, verdant, and as attractive, enticing?

The role of wilderness in the urban realm should be read in a critical prospective. On one side, untamed sites are a priceless resource to improve urban quality, in terms of contemporary beauty, healthiness, and livability. On the other, there are some risks of a possible ideological status of wilderness, as a fashionable label to renew anti-urban positions or a cliché of cheap-plaudits practice and politics. We are interested in how the validation of nature is changing and how this affects design, besides having strong political and environmental implications.

The most frequent question we receive about the topic of our research is which is the difference between the *Wild City* and the *third landscape* we everybody well know? Are you just giving it another name? Well, the distance is huge and clear for us. First, the *Wild City* has not an anti-urban attitude, but it speaks about the coexistence of wilderness and urbanity. Wilderness is not a sword to fight the city and expiate its horrible faults, but it is part of the city and the city is embedded with wilderness. As a result, the sites for wilderness are not enclaves of no-man lands, either because leftover or because intentionally protected, where humans are not allowed to enter and linger; on the contrary, they take part among the public spaces of the city, to stay, rest, play, and enjoy. Another result is that in the *Wild City* the untamed nature is no more confined in marginal areas: it is in the most crucial and prominent sites of the city; it is intentionally introduced in the very core of the city, in the most central places, in both topological and symbolic terms. On the other side, the unquestioning success of wilderness in urban public space could be misleading, when it is reduced just to *natural appearance*. Thus, wilderness is not a sort of green sauce to dress our cities; it has nothing to do with *green* with literal greenery but opens to a freer or more effective approach to nature, beyond the evident beauty of trees and flowers.

25.4 Wild Is Proudly Urban

On July 20, 2019, London was officially declared by the mayor Sadiq Khan the first *National Park City* under the motto *Let's make London greener, healthier and wilder*. As we can read in the manifesto:

> As National Park City London will be even greener in the long-term than it is and a city where people will have every opportunity to connect with nature in their daily lives; a city which protects the core network of parks, green spaces, lakes and rivers; a city that is rich in wildlife; a city where culture and nature coalesce.

Starting with a map where every single space of nature was registered on – regardless of the position and function – the promoters demonstrate the pervasiveness and richness of the natural heritage in the London area. It turns out that 8.5 million people and as many trees live in London, including 14,000 wild species. These and other data state that the idea of a *National Park City* is not so new-fangled (Goode 2015):

> Indeed, if we were not so conditioned by deep seated assumptions that a national park must be a pristine wilderness, or that a city must be an entirely man-made entity from which nature should be banished, the idea might have emerged much earlier. It is entirely logical. London is paving the way for a new approach that will be very exciting.

The Charter of the London National Park City contains a series of questions, some naïve, some less conciliatory, all in the formula of *what if*, including what would happen if we rehabilitated nature wherever possible, if everyone could get lost in nature without leaving the city, if we focused on those who will live in the city in seven generations, and so on. It will take time to understand whether the establishment of the National Park City will have real and forceful effects or if it will end in a well-packaged urban marketing campaign, but for the first time we face the formal recognition of the structural and systemic value of wildlife within the city and the idea that city and wilderness can coexist or even be the same.

In Germany, the process of interlacing and overlaying the urban realm with wilderness already started around year 2000, when many housing districts built during the DDR socialist regime were reclaimed. Large amount of open spaces, resulting from urban standards for *green areas*, had been neglected for many years and wildlife had been taking place there. Then, policies and projects accepted and kept these wildlands as crucial, not only in ecological terms but even to testify the landscape identity of those districts, part of the DDR heritage. Leipzig, Dessau, and Berlin are some of the main German cities that recognized the critical role of the untamed nature and reclaimed the districts while keeping and even boosting wild open spaces. More recently, the central government has been funding the program Städte wagen Wildnis (cities dare wilderness) in three pilot cities (Hannover, Frankfurt am Main, and Dessau-Roßlau) in the 5-year period 2016–2021 (SWW 2015):

> The return to nature and wildlife in our cities is desirable, beneficial and even possible! The *Städte wagen Wildnis* project is a joint effort to provide development opportunities for natural successions that occur and can occur in different urban green spaces, to increase the diversity of species and habitats and the quality of life of citizens.

What is interesting in these policies is the precise will to overcome any otherness between the city and nature, to the point of applying the principles of spontaneous nature protection even in the most dense and intense metropolis in the world. While natural parks have been imagined and established, at any latitude, in opposition to the increasing urbanization, London and the German cities argued that the two figures, city and natural park, may coincide as we can see in the Gleisdreieck Park design by Atelier Loidl in Berlin (Fig. 25.1). The *Wild City* mixes the usual typological, environmental, functional, and aesthetic categories, working through overlaps, grafts, and transplants, so that nature and artifice finally lose their boundaries. The *Wild City* thus measures the progressive shift from the *urban culture of nature* to the *culture of urban nature* (Gandy 2012), which is expressed in the spaces of ambivalence (Gandy 2013) or in the *landscape* (Prominski 2014).

Fig. 25.1 Gleisdreieck Park, Berlin. Atelier Loidl, 2011. (Photo credit: Giorgio Repetto 2019)

25.5 Wild Is the Core

The wild in the city has long been confined to the extensive catalogue of spaces – brownfield, *frîche*, *delaissé*, drosscape, *terraine vague*, wasteland – which perhaps only Clément's definition of *tiers-paysage* can summarize without excessive forcing (Clément 2004). In Italian we can call them *paesaggi avanzati*, in the double meaning of the word *avanzato*: they are leftover because they are obsolete or useless – by position, size, or character – and are therefore waste or ruins; at the same time, according to the other meaning that the Italian attributes to this word, they are places of innovation, experimentation, and avant-garde (Metta 2016). The novelty of the phenomenon we are observing is that the *Wild City* is not only made up of marginalia (Gandy 2013): escaped from the uncultivated of abandonment and secrecy, weeds take possession of the most eminent urban places. In the *Wild City* untamed nature leaves the background and gains the proscenium, bringing with it a synthesis between the aesthetics of the sublime and the ethics of scientific knowledge (Morin 1980: 10):

> both the order and disorder of the jungle.

The precursor of this surprising centrality is the Jardin des Bambous, designed by Alexandre Chemetoff as part of the collection of gardens of the Parc de la Villette; it was 1987 and this sunken garden was the first public space in contemporary Europe designed as a messy, dense, and exuberant jungle. Another fundamental step is the Garden in Motion in the Parc Citroën by Gilles Clément, in 1992, again in Paris, where plants grow untamed and nature thrives without apparent constraint. Few years later, Gabriele Kiefer designed the Adlershof Park in Berlin, opened in 1996, making the off-limits central biotope the geometric and semantic heart of the proposal. In Berlin, as well, in 2004 the Nordbahnhof Park was opened to the public as designed by Fugmann and Janotta, who put large portions of uncultivated land at its centre, protected by fences (Fig. 25.2).

In recent years, the number of *central wild parks* has multiplied. They are all quite different one from each other, but basically, they gain centrality adopting recurrent strategies. We will focus on three of them: conservation and exclusion, implementation and interaction, and restoration and waiting. The first one is the case of previously *tiers-paysage* which assumes a nodal and primary role as a result of complex urban transformations, such as the reclamation of disused productive districts or new urban developments, where the wild persists almost intact. Design keeps wild lands and often makes them inviolable. This happens, for example, in the two Berlin parks Adlershof and Nordbahnhof, where large portions of wild lands are fenced and removed from use (conservation and exclusion). Elsewhere, the wild is not unaltered but implemented in collaboration with the biological cycles of spontaneous nature, also allowing its use as a public space, as in the case of Parc Citroën (implementation and interaction). In other circumstances, the wild takes on a central role through its revival in areas already affected by its spontaneous presence and then involved in redevelopment projects. This happens, for example, in the Jardin d' Éole, designed by Michel Corajoud and opened in Paris in 2007 (Fig. 25.3), on the site already occupied by a railway and then turned into the *friche* of the Cour du Maroc. At the lower end of the park, some beds of sand and rubble, similar to the typical grounds of railways, were laid on for the spontaneous installation of nitrophilous plants; this precisely happened, being today a lush ruin prairie (restoration and waiting).

Fig. 25.2 Nordbahnhof Park, Berlin. Fugmann & Janotta, 2010. (Photo credit: Annalisa Metta 2010)

Fig. 25.3 Jardins d'Éole, Paris. Michel Corajoud, 2007. (Photo credit: Annalisa Metta 2019)

The opposite circumstance is that of places that are already the core of the city, where the wild is deliberately introduced as a feature of aesthetic, ecological, social, and, not secondarily, patrimonial quality, meeting the widespread sensitivity to wild nature of contemporary global culture. A well-known case is the Zaryadye Park, by Diller Scofidio + Renfro, with Hargreaves (2017), in the historical centre of Moscow, a few steps from the Kremlin and the Red Square (Fig. 25.4).

In both cases, the wild takes part in creating new conditions of centrality whose primer is elsewhere; in one case, the primer is made by substantial urban transformation, while in the other the fuse is a revenue position already acquired. Conversely, there are some cases in which the centrality emerges from the wild itself: it is the value attributed to the wild already in place that transforms neglected sites into attractive resources. This is the increasingly frequent case of disused railways. Long disregarded and deserted, therefore welcoming for spontaneous nature, they returned to the city in the form of wild infrastructure parks. This is what happens at the Süedgelände Park in Berlin, at the Essenburgpark in Rotterdam, at the Petite Ceinture in Paris, and at the LiKoTo ski run in Lille-Kortrijk-Tournai.

25.6 Wild is Livable

The places of the *third landscape*, as defined by Clément, are not only the délaissé, generated by the cease in previous productive uses; they also include the réserve, places that are not attended by human beings for some unintentional reasons (e.g.

Fig. 25.4 Zaryadye Park, Moscow. Diller & Scofidio + Renfro, with Hargreaves Associates, 2017. (Photo credit: Luca Catalano 2019)

the buffer zones of infrastructures), and the *ensemble primaire*, the nature reserves under legal protection. Although for different reasons, they both escape direct relations with people (Clément 2004: 7):

> The undecided character of the Third Landscape corresponds to an evolution left to all the biological beings that make up the territory, in the absence of any human decision.

Henri Matisse Park in Lille (1996) is the work of Gilles Clément most consistent with his theoretical reflection. Next to the TGV station and the remains of the ancient fortress in the Euralille district, the park is a large, open, and sunny grassland, surrounded by thick tree ribbons. Just there, in the middle of the lawn, Clément located an island of 3500 m^2, with vertical walls about 7 m high, built with the waste from the construction of the station. The island is inaccessible; over the years, a spontaneous forest has been growing there, without any human intervention. Clément named it Île Derborence, in homage to the forest of the same name in the Valais, Switzerland, generally considered the last wreck of the primary forests that once covered Central Europe and was seriously affected by a hurricane in 1987. In plan, the island has the shape of the largest of the Antipodes islands, a metaphor for the extreme distance between the natural world and the urban landscape (Clément 1997: 79):

> I see the city as the only element of the landscape that does not go in the same direction as the landscape.

The Ile Derborence is a simulacrum, a metaphor celebrating the myth of nature and a monument to the absence of humankind. It recalls the sanctuarium of Herman de Vries: he encloses portions of land within insurmountable walls, without access gates and only equipped with windows, through which you can observe the transformations occurring inside, with no apparent and direct human disturbance. The aim is to reflect on the cultural impoverishment of the idea of nature produced by conventional urban parks (Gooding 2006) through the paternalistic separation between nature and urbanity, where one is good and the other is evil (Clément 1997: 89):

> I have seen this disease: the city.

These positions are fully in line with the modern dualism nurture/nature, even though they want to propose themselves as a deliberate and radical attack on the socio-economic capitalist model. The idea that nature, as other than humanity, is the supreme good and the antidote to the city is the same that in the mid-nineteenth century, from Birkenhead onwards, gave birth to the public park as a remedy for urban guiltiness. Although it takes on a different appearance and feeds on ecological knowledge not contemplated at the time, it is based on a similar combination of compensatory ethics and opposing aesthetics (Lambertini 2006). It is basically the same idea of exclusion of places like Tropical Islands, the theme park created in 2003 60 km from Berlin in an ex-hangar for airships, with a wide range of accommodation and entertainment, including a huge artificial beach surrounded by the largest indoor rainforest in Europe; in every season, day and night, visitors of all ages, from all over Germany and beyond, go to enjoy a slice of a cheap paradise. On the Île Derborence and in the sanctuarium of de Vries, nature is uncontrolled, while in the Berlin wild indoor even every single particle of steam fertilizer given to the plants is monitored; in the former, access for humans is banned, while in the latter it is necessary to book in advance one's own bungalow in the forest, but the opposing relationship between nature and city, between wild and civilization, is not so different.

On the contrary, the *Wild City* does not exclude nature from inhabited places, nor does it preclude the access of human beings to nature reserves, whether accidental or planned. Rather, it welcomes and promotes coexistence, even conflict; it does not aim at pacification, finding reasons of quality precisely in the states of friction. The *Wild City* does not share the anti-urban ideology of *tiers-paysage*; conversely it feeds and supports the fusion and contamination with the urban.

25.7 Wild Is Not Cheating

Sanctioning wilderness in the urban public space could be misleading if unquestioned. Indeed, a collateral effect produced by the silent but remarkable success of this trend can be found in the current craze for perennials and urban forests all over the globalized world. The iconography of contemporary urban design offers us the dominant image of flowering meadows of wild herbs that colonize cities everywhere in the world, overflowing with exuberant vegetation, according to a new aesthetic model that enhances the wildness in place of controlled arrangements of cultivated plants. It is an increasingly widespread imaginary, until a few years ago limited to a few pioneering experiences and today so pervasive as to become *style* or *language*. It is of course a gorgeous trend, if it is not reduced to a refreshing wallpaper to easily stick on. We mean the risk to reduce nature just to its appearance, not caring about the main lesson of landscape architecture: form derives from the meeting between cultural and biological processes, to be understood, applied, attended, and celebrated; otherwise design is just cheating. We can attribute to the ubiquitous success of this vogue the exhausted but firm trend of the rampant *green wallpaper* in plenty of contemporary architecture. Snippets of forests climb the facades at all latitudes, kept alive by sophisticated technological prestidigitation, replacing living conditions honestly irreproducible. This means submitting to *intensive care* organisms that would not require any therapeutic relentlessness, if it were not for the forced displacement that makes their survival an audacious and expensive bet to win on the market of real estate and professional assignments. We do not intend to enter into the debate on the biological and even moral congruity between form and function that is often repeated in relation to these arguments, contrasting on the one hand the *domesticated wildland* by Gilles Clément and on the other the *recreated wildland* by Piet Oudolf and their respective epigones. The controversy, not exempt from iconoclasm, is also very old, going back, to remain in modern times, at least to the birth of the Anglo-Saxon garden at the turn of the seventeenth and eighteenth centuries; then it was rekindled by William Robinson, who wanted to distinguish his wild garden (1870) from the picturesque landscapes with wild features, but actually in need of incessant maintenance. We would like to point out that the relation of any plant with the site, its environmental factors, and elements still plays a decisive role in design.

Michael Pollan focuses on the struggles of making a wild landscape from scratch (Pollan 1998):

> A few years ago, I published an article describing in detail my first attempt to plant a natural garden. It was a disaster: the weeds triumphed quickly, and the lawn of wildflowers I had imagined soon degenerated into a sort of abandoned lot. […] It takes the genius of an Olmsted or a Jensen to create a satisfying garden with fewer resources.

The more design aspires to create conditions for uncultivated systems, the more it needs wisdom and initial control in preparing the ground and planting. The structure of the garden should welcome and boost the *other* order of wildlife, allowing all living beings to find their own space and to mix and establish a vibrant community, whose image would correspond to their mutual behaviours. Therefore, over the time, it would reduce management and give back something extremely far from the early arrangement, inside an agreement of complicity between design and life.

25.8 Wild Asks for Design and Care

Preparing the soil, planting the seeds, and supplying water in the early stages are the founding acts of a process aimed to gain, in time, its own functional and formal autonomy. Over time, biological communities will increase and get stronger, making together a resilient whole organism, able to absorb and counteract the changes induced by any disturbance. A crucial point is that these communities will need to be managed as such while gradually abandoning the care for single species or plants. Caring of wild vegetation is a practice addressed to a community of living beings; it is a matter of collective, interlaced, and complex relations, more than just the sum of single biological individuals. As Thomas Rainer and Claudia West state (Rainer and West 2015: 61):

> community-based planting requires *management* of the entire community.

Thus, we need to move from *maintenance* – in its literal meaning of conservation – to get to the most dynamic and adaptive concept of *management*. This transition requires a certain humbleness on designers' side, who should know how to let their own project go at the appropriate time, aware that its self-determination is an integral part of design itself (Rainer and West 2015: 61):

> A fundamental principle of this management approach is that when plants themselves are allowed to follow their destiny – to self-design their own community – more robust plantings will follow.

The result is a hybrid between wild and cultivated: it is in the honest combination of these two parts that the urban environment can get the greatest ecological, environmental, and aesthetic benefits. This requires a review of the procedures usually adopted. In the *Wild City*, for example, pruning is much reduced if not completely suspended; meadows are rarely mowed and can thus carry out their entire biological cycle; there are no weed killers and there are species brought there by the most diverse vectors. This abundance attracts insects crucial for pollination, which in turn produces genetic variety. Shrubs can also develop freely and provide protection and nesting opportunities for birds and small mammals. According with these principles, the way the landscape could evolve can be only partially foreseeable. What is most relevant for our purposes is that care – usually understood as a pure technical or administrative fact, a repeated and constant practice to keep the arrangement of places stable over time – can become a creative matter. This proposition requires rethinking the procedural status of landscape design, which should not end with the approval or opening of the site but should extend over time, involving the different competent actors, including citizens.

Clément indicates non-action or minimal action as an appropriate model of care. The author's thought on care seems to be independent from any conscious commitment with beauty because beauty indeed is meant as a by-product of the natural evolution of the biological life. His ecological and non-patrimonial dealing with the site gives positive value to elements such as instability, contiguity, unproductiveness, biological nomadism, and to what Clément defines *not allowed practice*.

Nevertheless, all this, whether you want it or not, whether you declare it or not, has a critical aesthetic charge.

25.9 Wild in a Changing World

Everything in the *Wild City* is never a matter of only nature or only humans, taken alone. The focus is always on their mutual intermingling. So, in a critical perspective, it is worth to ask what would happen in a totally run-wild city? What if we humans disappeared, maybe in a short time, letting the world go on without us, putting our cities into the bare hands of nature, letting totally uncontrolled wild nature transform man-made sites? What if such a way-back process could start now? These questions are less rhetorical than they could sound. In the current 2020 spring, we cannot by-pass these questions; they are pressing and real because the world is facing a tragic pandemic and cities deserted for months suggest that the 2007 best seller by Alan Weisman, *The World Without Us*, could suddenly and unexpectedly come true. The book describes how vegetal and animal species could face the human lack, providing documentary evidence of nature power, strength, and adaptation in a human-free or human-less situation. Every living being, even pets, would be able to acclimatize itself to the new habitat, sometimes in the almost irreversible conditions caused by the huge chemical pollution, each one taking its proper time. Weisman is among the numerous authors who have figured out a human-less planet. Scientists and writers of different backgrounds have been telling their visions, between the dreamlike and the apocalyptic. They all describe a world remaining at its own mercy or rather coming back to its very nature without humans. Bob Holmes was among the most prophetic voices, starting with the article *Imagine Earth Without People* published in 2006 (Holmes 2006: 36):

> […] imagine that all the people on Earth […] could be spirited away tomorrow, transported to a re-education camp in a far-off galaxy […]. Left once more to its own devices, Nature would begin to reclaim the planet, as fields and pastures reverted to prairies and forest, the air and water cleansed themselves of pollutants, and roads and cities crumbled back to dust. The sad truth is, once the humans get out of the picture, the outlook starts to get a lot better.

These visions are foreshadowing what could happen from now on. Just 4 weeks of human reclusion have been enough to produce a deep and clear change. In Rome, the air is clear, the grass grows freely through the borders and the cracks of the asphalt, and lots of flowers face undisturbed the sun. The only sound is the early birds twitter. Spring is lusher than ever and shows its beauty in a shameless way. In Venice, the canals are full of newborn fishes, and mallards have laid their eggs in Piazzale Roma. In Japan, in the city of Nora, herds of deer stroll around the city. In Lopburi, Thailand, monkeys are hungry for the lack of bananas usually provided by tourists and pour in protest into the cities. The whales in the waters around Manhattan are getting numerous. This perking up of nature has been happening in an incredibly short time, showing us the great generating and adapting force of wild nature in spaces that humans have usually been taking away from it. The experience we are living through therefore forces us to think about what could happen in our cities if such a situation should continue for a while, even a few months. How much urban space would be colonized by plants and brought back to a condition of substantial naturalness? How would the climate change? What new vagrant species, both plant and animal, would land in urban open spaces? How long would it take for the soil to metabolize all the asphalt it is covered with? And what about the wind and the rain to eliminate the fine dust polluting the air? The revival of wild nature is happening in the cities as well in the countryside, where cultivations are totally man-controlled and managed in all their life cycles, from seeding to harvesting to death. What could happen to agriculture if humans would not take care of for a while? How long would this asset, crucial to have food and survive, take before it would be overwhelmed by the wilderness? The increasing priority of these issues is clear in the recent research of Rem Koolhaas, Countryside, The Future (AMO and Koolhaas 2020), where he states that the future of humankind is in the agricultural fields and no longer into the city. It is a radical position – even though not new at all – suggesting that the relation with the wild should be set on an even more complex prospective than the one of urban wilderness.

Among the many challenges that humans have to face, it is the time to ask ourselves which are the undeniable mechanisms to renew the *civil society* and which processes and activities should be modified or even deleted in order to create urban contexts where the presence of all living creatures is allowed and worthy and where everyone can benefit without suffering. Thinking the city and every other human setting intricately connected with the wild could help, perhaps. In a shaky time, the nature that takes everything back is the worldly messiah of the Anthropocene. This idea of nature – swinging between fatalist devotion to the imponderable and neo-positivist deterministic scientism – is conducive to the indolence of our generations and reassures and consoles us, complicit in evading every possibility (and responsibility) of redemption or revival. And then, instead, here is the *Wild City*, this monster that disorients, surprises, and disturbs us, forcing to reposition ourselves, since it moves us away, shamelessly, from our analgesic certainties. It presses us to take an intermediate way between an attitude to remittance with destiny – which celebrates the depletion of the human species from the saving remedies of nature – and the dominant utilitarian posture. *Wild City* is challenging towards an exciting and perturbing complicity among all the inhabitants of the planet, including humans.

Acknowledgements The contents of this essay have been conceived and developed jointly by the two authors. In particular, Annalisa Metta has edited the paragraphs “Wild at Work”, “Wild Is the Core”, “Wild Is Livable”, and “Wild Is Not Cheating”, and Maria Livia Olivetti has edited the paragraphs “Wild European Seeds”, “Wild Is Proudly Urban”, “Wild Asks for Design and Care”, and “Wild in a Changing World”.

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Chapter 26
Biodiverse Cities: Exploring Multifunctional Green Infrastructure for Ecosystem Services and Human Well-Being

Alessio Russo and Katie A. Holzer

Abstract Globally, urbanization has strong impacts on biodiversity, ecological patterns and processes, and ecosystem services. Biodiversity loss due to the rapid expansion of cities and towns may have significant repercussions for human health. However, several studies have reported that increasing and restoring biodiversity in cities can provide several ecosystem services and improve human health and well-being. For instance, higher biodiversity in cities is associated with positive effects on mental health, social cohesion, and crime reduction. In particular, multifunctional green infrastructure, sometimes referred to as blue-green infrastructure, has been effectively used in a variety of ways as a tool to conserve and enhance urban biodiversity efficiently where space is limited. This chapter provides several recommendations for protecting and increasing urban biodiversity through green infrastructure based on ecological design principles. Furthermore, it explores urban green infrastructure case studies, best practices, and policies in the UK and the USA that promote human health, well-being, and biodiversity conservation.

Keywords Ecosystem services · Blue-green infrastructure · Biodiversity · Urban aquatic ecosystems · Ecological design · Urban ecology

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_26

26.1 Introduction

Rapid urbanization, densification, and related changes in the ecosystem have been described as major global threats to biodiversity (Grimm et al. 2008; Botzat et al. 2016). At the same time, we are increasingly becoming an urbanized society where citizens are disconnected from nature, showing a gap between our built environment and the natural environment (URBED et al. 2004).

The ongoing rise in the number and size of cities and the resulting transformation of natural landscapes on different scales present major challenges in reducing the rate of loss of biodiversity and the connected ecosystem functions and safeguarding of human well-being (Haase et al. 2014). Because cities are often built in areas of high biodiversity, they have great potential to either harm or support the native wildlife populations (Rosenzweig 2003; Luck 2007; Parris et al. 2018).

As urban areas expand, landscape architects, urban forest managers, planners, civil engineers, and ecologists often use innovative methods to increase greenspaces and preserve and restore remnant habitats (Lepczyk et al. 2017). Designing ecologically functional urban spaces that protect and enhance biodiversity requires careful planning and resource use over the short, medium, and long term (URBED et al. 2004). The design of such spaces requires specific knowledge and expertise (URBED et al. 2004). In order to become more active players, landscape architects and planners need to become more acquainted with biodiversity planning and design problems, terminology, and methodologies (Ahern et al. 2006).

Land value is high in urban areas, and it is therefore a priority to design spaces which have multiple functions within one footprint. Multifunctional green infrastructure can increase biodiversity while also reducing flooding, cleaning stormwater pollutants, reducing urban heat islands, and increasing human well-being (Liao et al. 2017). These benefits are increased when these spaces are integrated throughout urban areas close to where people live, work, and play (Mattijssen et al. 2017).

26.2 Biodiverse Cities

Nilon et al. (2017) sampled 40 cities from 25 countries to understand how cities from a variety of ecological, political, and economic settings incorporated biodiversity and ecosystem services into planning. They found that Washington, DC, was the city with plans that had the highest number of attributes (94% of those assessed) related to biodiversity while cities in Africa such as Nairobi and Potchefstroom had zero attributes (Nilon et al. 2017). Singapore has developed an index known as the *City Biodiversity Index* to evaluate the biodiversity, ecosystem services, and city governance (Uchiyama and Kohsaka 2019). This index has been applied worldwide (Uchiyama and Kohsaka 2019). However, this index does not include non-native species that may also contribute to human well-being and ecosystem services (Schlaepfer 2018).

The interaction between urban people and biodiversity is a crucial issue in the creation of sustainable, liveable, and biodiverse cities; successful implementation of the related approaches will benefit from deeper insights into biocultural relationships and their regional variation (Botzat et al. 2016).

Many cities are constructed arounds rivers or streams which served as freshwater sources and as transportation routes (Mitsch and Gosselink 2015). This provides an opportunity to protect and expand the greenspace surrounding the waterways which can function as movement corridors (Aziz and Rasidi 2014). The necessity of cities to manage stormwater runoff also provides opportunities for designing those structures to additionally serve as wildlife habitat (Oberndorfer et al. 2007; Hamer et al. 2012).

26.2.1 Biodiversity and Human Well-Being

A growing body of evidence has shown that nature in cities, directly and indirectly, contributes to the health of the population and the quality of citizens' lives (Lee and Maheswaran 2011; Flies et al. 2018; Russo and Cirella 2018). Biodiversity-rich urban greenspaces can improve well-being and foster healthy lifestyles (Irvine et al. 2010; Carrus et al. 2015). Fuller et al. (2007) found a positive association between the species richness of greenspaces and the well-being of greenspace visitors in Sheffield, UK. Furthermore, a study conducted by Kardan et al. (2015) in Toronto, Canada, found that people who live in areas that have more trees on the streets (ten more trees in a city block) report better health perception. Scientific evidence indicates that biodiverse environmental microbiomes make a positive contribution to human health and may account for established correlations between urban greenspace and improved health (Flies et al. 2018). Mavoa et al. (2019) found statistically significant relationships between subjective well-being and both fauna and flora species at multiple scales in Melbourne, Australia.

26.3 Strategies to Enhance Biodiversity in Cities

Biodiversity in cities can be enhanced through a combination of strategies including protection and restoration of existing habitats, construction of new green features, and planning for connectivity (Parris et al. 2018). For example, sensitive urban design that incorporates existing urban ecological knowledge can mitigate the biodiversity impacts of urbanization (Garrard et al. 2018).

Tree planting initiatives have been proposed to maintain or increase native biodiversity (Pincetl 2010; Oldfield et al. 2013). For example, urban and peri-urban forests are becoming an important shelter for native biodiversity (Goddard et al. 2010). Animal species need a range of habitat types to provide their life cycle with the full spectrum of resource requirements (Lepczyk et al. 2017). Several findings stress the importance of preserving the complexity of habitats to increase the diversity of birds in urban spaces (Fernández-Juricic and Jokimäki 2001).

Urban shrinkage (i.e. population decline) has been proposed has an opportunity to restore nature in densely populated inner cities (Haase 2008). In places where habitat has already been lost to urbanization, there are opportunities to enhance remaining areas or create new habitats which can mimic the key features of natural habitat. Studies have shown that many species benefit from entirely novel urban habitats when their basic needs are met (Rosenzweig 2003; Lundholm and Richardson 2010).

In urban environments, there may be significant opportunities for retrofitting green infrastructure and increasing biodiversity (Natural England 2009). These can be achieved by features such as the following:

– Biodiverse green roofs and roof gardens
– Green walls
– Swales and stormwater ponds
– New plantings (e.g. trees and hedges that can connect fragmented habitats)
– De-canalized river corridors (Natural England 2009; Gunnell et al. 2012)
– Wildflower meadow roundabouts

Some of these approaches will be discussed in subsections below. In order to maximize biodiversity in cities, there are several ecological design and management rules (i.e. habitat size, shape, location, types, linkages, and management) that landscape architects and urban ecologists should take into account (Sinnett 2014). For example, considering the island biogeographical theories, several small habitats with interacting populations are more desirable than one small habitat, and a large habitat is preferable to a small or fragmented habitat (Sinnett 2014).

26.4 Green Infrastructure

The European Union defines green infrastructure (GI) as:

> A strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. (European Environment Agency 2019)

In the USA, GI has been defined by the Clean Water Act as:

> The range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters. (EPA 2020)

GI can take many forms, and it is beneficial to consider a combination of green approaches to meet diverse goals in various situations (Hansen et al. 2017). Multifunctionality is a key aspect to the GI concept and approach that provides a variety of functions and a wide range of ecosystem services (Natural England 2009). Additionally, many cities are required to reduce pollution or flooding through regulations and city codes. Green infrastructure can be a cost-effective way to turn rainwater from a nuisance into a resource and provide an amenity which can benefit both humans and biodiversity. The UK governments have officially recognized the benefit of GI in the provision of biodiversity through the publication of the Natural Environment White Paper – *The Natural Choice: Securing the Value of Nature* (Collins et al. 2017).

The four UK governments all have a biodiversity strategy that plans to address threats to "protected" and "priority" species and "priority habitats" identified as the most threatened and conservation-related (Callway 2019). In Wales, the Planning Policy Wales (PPW) positions the "placemaking" definition at the forefront of regional planning policy (Callway 2019). PPW Version 10 includes detailed:

> GI policies and requirements to meet biodiversity duties, recognising that biodiversity, ecological resilience and green spaces are integral components of achieving wider economic and social well-being objectives. (Callway 2019)

Below we discuss four specific types of constructed GI practices which are gaining traction in cities throughout the globe. These practices are used in concert with preserving and enhancing existing greenspaces such as parks, greenways, rivers, and urban forests.

26.4.1 Green Roofs

Green roofs provide several ecosystem services in the built environment, including stormwater management, food production, building temperature regulation, urban heat-island effects mitigation, carbon storage and sequestration, pollution and noise reduction, and the provision of urban wildlife habitat (Oberndorfer et al. 2007; Susca et al. 2011; Peng and Jim 2013; Russo et al. 2017; Van Renterghem 2018). Blue-green roofs can also be used to store water between rain events (Liao et al. 2017). Green roofs improve wildlife habitat connectivity and have led to a boom in urban apiculture (Hofmann and Renner 2018). Green roofs can provide adequate habitat for the urban flora and fauna that can adapt to the harsh local conditions, especially when the soil substrate is deep enough to support plant health (Brenneisen 2006). Wildflower green roofs (Fig. 26.1) support pollinators; however, temporal changes in plant cover, due to the periodic senescence of vegetation, could influence citizens' perception (Benvenuti 2014). In addition, green roofs contribute to the diversity and abundance of arthropods in the built environment creating a foraging ground for bats (Parkins and Clark 2015). Arthropod communities on the roofs can vary greatly depending on the diversity of plants, time since construction, and proximity to other habitats (Ksiazek-mikenas et al. 2018).

Fig. 26.1 (**a**) Wildflower roof in Dublin, Ireland; (**b**) green roof in Amsterdam, the Netherlands

26.4.2 Green Walls

Green walls have been proven to be a design tool that supports biodiversity (Mayrand and Clergeau 2018). Weerakkody et al. (2017) found that plants growing in a living wall at New Street railway station, Birmingham, UK, were capable of capturing a considerable amount of particulate pollution such as PM_1, $PM_{2.5}$, and PM_{10}.

Green walls could serve as vertical corridors making it easier for less mobile species to move from the ground to the roofs (Mayrand and Clergeau 2018). Green walls can also provide suitable nesting habitat for a range of species, e.g. common blackbird *Turdus merula* and house sparrow *Passer domesticus* (Chiquet et al. 2013).

Collins et al. (2017) found that the public valued green walls for increasing urban biodiversity by examining their willingness to pay (WTP). Results indicated a WTP which exceeded construction costs and was positively associated with green infrastructure that increases biodiversity.

26.4.3 Constructed Wetlands

Constructed wetlands (Fig. 26.2) can mimic habitat features of natural wetlands while providing services of stormwater management, flood storage, and places for human connection to nature (Davis and McCuen 2005; Guderyahn et al. 2016). Many cities are located in former floodplains of rivers which have been drained for urban development; therefore, the soil and hydrology of cities often offer an easy opportunity to restore or create wetland features which can provide many of the functions provided by natural wetlands (Mitsch and Gosselink 2015). Constructed wetlands can be large (e.g. ponds) or small (e.g. rain gardens) and appear semi-natural (e.g. bioswales) or entirely constructed (e.g. stormwater parks). They can be designed to be a focal point of a community with walking paths and benches so that residents have a place to observe wildlife in their own neighbourhood (Liao et al. 2017).

Fig. 26.2 Constructed wetlands come in different sizes and degrees of naturalness. (**a**) Small, concrete street-side rain gardens treat stormwater from the adjacent road. (**b**) Medium-sized wetland parks treat water from apartment buildings in a dense urban core. (**c**) Large constructed wetlands treat stormwater from an entire suburban neighbourhood

Constructed wetlands can reduce urban flooding by providing a place for runoff from roofs, roads, and parking lots to soak into the ground or release slowly after detention (Davis and McCuen 2005). Constructed wetlands filter water and reduce many common urban stormwater pollutants including heavy metals, hydrocarbons, pesticides, fertilizers, and suspended sediment (Clary et al. 2017; Liao et al. 2017). These pollutants can harm local wildlife if discharged directly to streams (Davis and McCuen 2005). For example, endangered salmon in the Northwestern United States are frequently killed by stormwater pollution shortly before reproducing; however, they are able to survive when the stormwater has been filtered through constructed wetlands (McIntyre et al. 2015).

Constructed wetlands have been known to enhance urban wildlife for a long time, and studies have shown them to be important habitat for a variety of birds, amphibians, turtles, and dragonflies (Adams et al. 1986; Hamer et al. 2012; Holtmann et al. 2018). These features are sometimes the only place in a city where wetland species are able to access standing water with the aquatic plants that they rely on (Holzer et al. 2017). Habitat value often increases with the presence of aquatic vegetation, shallow side slopes, and proximity to other habitats, and some native species even preferentially use constructed wetlands over remnant natural wetlands because they more frequently had the features that they need (Adams et al. 1986; Scheffers and Paszkowski 2013; Holzer 2014).

Larger wetlands tend to provide more habitat and recreation area while smaller wetlands may be easier to fit into planning designs (Liao et al. 2017). A variety of aquatic plants generally improve wildlife value. Maintenance needs to be considered when designing and selecting plants to ensure that the system can function with minimal maintenance and so that it can be accessed for occasional dredging to remove accumulated sediment and vegetation.

Fig. 26.3 The yard on the right supports a larger diversity of species than the yard on the left in Davis, California, USA

26.4.4 Domestic Gardens

Domestic gardens provide a vast, unique, and undervalued resource to boost urban biodiversity (Goddard et al. 2010). They are "hidden treasures of information" in the urban ecosystem that are closest to where citizens live and have the potential to contribute to ecosystem services from larger-scale green infrastructure (Cameron et al. 2012; Beumer and Martens 2015).

Individual yards can contribute to a combined effect by providing important connections between larger habitat patches (Goddard et al. 2010). Yards with a variety of vegetation including trees, shrubs, and flowers provide opportunity for more wildlife species to use (Fig. 26.3).

Programs such as the Audubon Society's Backyard Habitat Program (backyard-habitats.org) and the US National Wildlife Federation's Garden for Wildlife Program (nwf.org/Garden-for-wildlife) provide incentives and expertise which can help residents improve the habitat values of their yards.

26.5 Case Studies

The following case studies in the UK and USA describe efforts to increase biodiversity in cities with green infrastructure. They demonstrate ways in which cities have planned and implemented constructed features alongside preservation and restoration. This complementary approach amplifies the mutual benefits to biodiversity and human well-being.

Fig. 26.4 Sandford Park, Cheltenham, UK: new sustainable perennial planting scheme to improve biodiversity

26.5.1 Urban Greening Projects in Gloucestershire, UK

The *Urban Greening* project of 1.4 million British pounds aims to create about 250 ha of habitat across a variety of urban sites in Gloucestershire in the UK.

The scheme has been funded by the European Regional Development Fund, the University of Gloucestershire, Gloucester City Council, Tewkesbury and Cheltenham Borough Councils, Gloucestershire County Council, the Environment Agency, and Gloucestershire Wildlife Trust.

The project is meant to achieve a number of environmental benefits including the increased biodiversity of target species, improved and interconnected habitat networks, reduction of flood risks, improvements to water and air quality, increased amenity value of sites, increased human well-being, and improved sites as valuable public greenspaces with increased biodiversity. Green roofs are promoted in development proposals, and constructed wetlands have been created to reduce flood risk while improving water quality and wildlife habitat. The scheme includes a variety of projects including improvements in maintenance schemes, development of wildlife corridors, planting of woodland, orchards and native hedgerows, river restoration, construction of sustainable urban drainage, and sustainable planting (Fig. 26.4) (Cheltenham Borough Council 2020).

26.5.2 Bristol European Green Capital Award and Biodiversity Action Plan, UK

Bristol received the European Green Capital Award in 2015 because the city:

> demonstrated a well-established record of achieving high environmental standards… that aim to inspire and promote best practices to all European cities. (Bristol Green Capital Partnership n.d.)

An example of these environmental standards is the Bristol Biodiversity Action Plan (BAP) that was adopted in 2008 (Bristol City Council 2020).

The Bristol BAP sets the general mechanism for the protection of biodiversity and species in Bristol. It also acknowledges the benefits of nature for people and helps identify ways of better supporting and engaging people in the protection of biodiversity in the city (Bristol City Council 2020). Bristol has embarked on multiple complementary projects to improve biodiversity in the city. One project provides resources to improve the wildlife value of domestic gardens with a particular focus on people who have recently immigrated from other countries. Another project increases the urban tree canopy with a special initiative which had each child in the city to plant a tree (Bristol City Council 2020).

In particular, the Bristol BAP aims to:

1. Provide a strategic overview for biodiversity conservation.
2. Highlight priority habitats and species that are of particular value in Bristol, both within the national and local context.
3. Highlight threats and issues affecting these priority habitats and species, together with objectives, targets, and actions to address them.
4. Encourage a common approach to biodiversity conservation and sharing of best practice.
5. Encourage education and community action and involvement as a key part of the biodiversity process.
6. Promote biodiversity conservation as an essential element of sustainable development.
7. Promote the importance of Bristol's biodiversity at a local, regional, and national level.
8. Develop Bristol as a centre of excellence for urban biodiversity conservation (Bristol City Council 2020).

26.5.3 Green City, Clean Waters Program in Philadelphia, Pennsylvania, USA

The city of Philadelphia, Pennsylvania, is undertaking the largest comprehensive green infrastructure project in the USA (Philadelphia Water Department 2011). The Green City, Clean Waters program is a multifaceted green infrastructure project which involves preservation of open spaces, restoration of streams, conversion of vacant and abandoned properties to community spaces, and construction of rain gardens and wetlands on public and private lands. One goal of the project is to *green* 10,000 acres of urban Philadelphia by 2035 (by treating that acre's stormwater with green infrastructure), and it had already completed over 1000 by 2019. The program has received overwhelming support from the public with >90% of neighbourhood residents responding positively (*ibid.* pg. 44).

Philadelphia was established over 300 years ago, and portions of the current sewer system have been in place for over 100 years. Historically, the growth of the city incorporated very little greenspace and was dominated by hardscapes and grey infrastructure. This has led to combined sewage overflows of the pipe system where raw sewage enters the waterways and reduces health and liveability for humans and wildlife. The ageing infrastructure requires repairs, and regulations require reductions in combined sewage overflows. The city of Philadelphia has used this opportunity to retrofit its infrastructure with green solutions rather than merely updating grey infrastructure.

The Green City, Clean Waters program is planned and implemented by a partnership of the city of Philadelphia, the Pennsylvania Department of Transportation, and local residents and organizations. The program uses innovative green infrastructure approaches as opportunities to meet their regulatory obligations while helping to revitalize their city (Philadelphia Water Department 2011). They determined that this approach would have overall environmental, economic, and social benefits that will more than offset the cost of the program (*ibid.* pp. 17). The city has formalized the approach by creating incentives and requirements for the green infrastructure in their regulatory code. They state that (*ibid.* pp. 13):

> We now look at our City's streets with an eye that seeks opportunities to peel back the existing concrete and asphalt and replace it with a new landscape, rich with vegetation that welcomes the rain—storing, draining, and cleaning it.

A few large successes of this project to date utilize green roofs and constructed wetlands in projects including freeway rain gardens, a rooftop park, and vacant lot conversions. Large freeways bisect Philadelphia, fragmenting the landscape and producing polluted runoff which drains to the waterways. Through this project, public land beside Freeway I-95 is being converted into rain gardens which treat stormwater, provide arthropod habitat, and create green walkways for local residents. These linear wetlands can serve as movement corridors for people and arthropods while reducing pollution for fish and other aquatic life downstream. A parking garage near downtown serves as a 1.25-acre blue-green roof park with a grass amphitheatre. This roof stores and cleans stormwater while providing a vibrant place for recreation and relaxation. Public and private land throughout the city has been used opportunistically for greenspace and stormwater treatment with thousands of facilities already installed. These often double as safe community gathering spaces such as vacant lots which now provide picnic shelters for local residents. The city says of the approach that:

> Our vision is to unite the City of Philadelphia with its water environment, creating a green legacy for future generations while incorporating a balance between ecology, economics, and equity. (Philadelphia Water Department 2011, pp. 3)

26.5.4 Pleasant Valley Plan District, Oregon, USA

Areas of new urban development have the unique opportunity to incorporate green infrastructure from the beginning planning stages. The Pleasant Valley region of the Portland metropolitan area, Oregon, USA, is a ~1500-acre rural area which is planned for urbanization over the next few decades. A Concept Plan for the transition was developed which prioritizes green infrastructure (Pleasant Valley Project Partners 2002). It incorporates restoration of riparian buffers along existing streams and building green infrastructure into the neighbourhoods with various constructed wetlands such as rain gardens, stormwater planters, and ponds. These are connected by multi-use paths to give residents a sense of place with the surrounding landscape (Fig. 26.5). The plan was created by multiple jurisdictions with input from community members and realized through city codes, manuals, and planning documents (City of Gresham 2005; Portland Bureau of Planning 2005).

In the state of Oregon, all cities have an urban growth boundary (UGB) which separates dense land-use zoning from rural and agricultural areas. This limits urban sprawl and allows for centralized planning of new neighbourhoods. The southern edges of Portland and Gresham, Oregon, are being annexed into those cities through a recent expansion of the UGB in Pleasant Valley. This area was predominantly rural residential, pasture, and active tree nurseries but is planned to soon include several thousand new residences, a town centre, and multiple new schools. The Pleasant Valley Concept Plan was created by the Metro Regional Government with extensive input from Pleasant Valley residents, Multnomah and Clackamas counties, the cities of Portland and Gresham, developers, non-profits, and environmental groups.

One goal of the Concept Plan was to "preserve, enhance, and restore natural resources" throughout the area during urbanization (Pleasant Valley Project Partners 2002). The natural resources in this area centre around Kelley Creek and its tributaries which provide habitat for many species, including endangered salmon. There are two strategies which work together towards obtaining this goal. The first strategy is to set aside land from development along the stream and its tributaries. These riparian buffers are then being restored from their present agricultural state to rich plant communities with funds paid by the developers. The second strategy is to treat the stormwater from the new roads, roofs, and parking lots with constructed wetlands of various sizes and incentivizing green roofs. Roof water from many homes is captured in rain gardens, while road runoff is treated in street-side stormwater planters. Any water that does not infiltrate flows through large constructed wetlands near the streams.

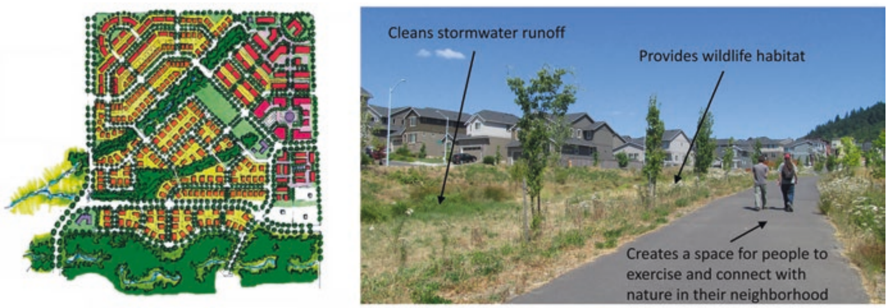

Fig. 26.5 The Pleasant Valley Concept Plan incorporates stream protection and restoration with stormwater treatment wetlands and walking paths

The riparian buffers and constructed wetlands provide habitat and movement corridors for native wildlife species. Natural resources were prioritized by establishing these buffers in the planning process before citing new roads and land-use zoning. Several species of rare birds, amphibians, dragonflies, and damselflies have already been observed utilizing the new wetlands within the first few years after construction (Holzer, personal observations).

These wetlands have been planned as an amenity to the community by incorporating a multi-use path which takes residents from their homes to these natural and semi-natural areas. Residents often comment that these nature paths are their favourite part about living in the new neighbourhoods.

26.6 Conclusion

Urban green infrastructure offers a unique opportunity to address multiple urban problems in one footprint. By stacking functions, it allows for an efficient use of limited urban space. A wide variety of techniques and designs now exist such that some type of green infrastructure can fit into almost any neighbourhood or project.

Previous studies have shown that investing in urban ecological infrastructure and the ecological restoration and regeneration of habitats such as wetlands, lakes, vacant lots, streams, rivers, and parks that exist in urban areas is not only environmentally and socially desirable but also very often economically advantageous (Elmqvist et al. 2015). In fact, higher socioeconomic status is correlated with higher biodiversity – this has been described as "the luxury effect" which describes a relationship between "wealth" and "biodiversity" (Leong et al. 2018).

The integration of locally contextualized biodiversity-led green infrastructure design into the planning and policy contexts contributes to a city's sustainability and resilience and offers adaptability to tackle local contextualized problems such as urban heat island, flooding, air and soil pollution, safety and well-being, and loss of biodiversity (Connop et al. 2016). Far from being dead zones, urban areas have the ability to support a wide variety of wildlife species when ecologically appropriate urban greenspaces are present (Lepczyk et al. 2017). Emerging research demonstrates the importance of biodiversity to human well-being; however, there is still research to be done to identify the spectrum of influence that biodiversity has on surrounding spatial scales (Taylor and Hochuli 2015).

Future research can focus on providing more evidence that recognizes the role of specific ecosystem services, goods, and processes through which biodiversity can support good health and well-being for city dwellers (Lovell et al. 2014).

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Chapter 27
In Consideration of the Tree: The Importance of Structure and Function in the Realization of Ecological Design

Naomi Zürcher

Abstract The focus of ecological design is to *minimize environmentally destructive impacts* in designing the built environment. To support this intent and to better sustain the integrity of the urban ecosystem, we must give much greater consideration to the structure and function of an indispensable part of that ecosystem – our trees – and the impact our built environment imposes on them and their ability to provide the ecosystem services benefits we increasingly depend on. Almost all tree species planted in our urban centres evolved in a forest somewhere in the world. It is therefore essential that we incorporate an understanding of forest systems – how that forest tree manages itself – as a basis for spatial development within the urban forest ecosystem. We need to invest this understanding into all aspects of urban forest management, from planning and design to protecting and preserving so that the end result is a sustainable, environmentally compatible composition which can accommodate the needs of our urban trees, the landscapes they populate, and citizen well-being. This chapter will offer an urban forester/consulting arborist's field observations on the tree – its structure and function and how that knowledge can inform ecological-based design from a Building WITH Trees perspective.

Keywords Ecosystem services · i-Tree Eco · Soil · Tree structure and function · Urban forest

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_27

That land is a community is the basic concept of ecology,
but that land is to be loved and respected is an extension of ethics…
We abuse land because we regard it as a commodity belonging to us.
When we see land as a community to which we belong,
we may begin to use it with love and respect.

~ Aldo Leopold

27.1 Considering the Tree: An Introduction

The focus of ecological design is to "minimize environmentally destructive impacts" (Van der Ryn and Cowan 1996, pp. 18) in designing the built environment. In planning and designing the city of today for the world we will have to live in tomorrow, we can no longer afford to continue a design approach which does not address sustainable environmental needs or the cost-effective protection, preservation, and use of vital existing resources. Rather than treating such essential resources as disposables, we must protect and preserve what is immediately available to offset the impacts of our lifestyle – that resilient, benefit-producing urban tree – one of *the* most indispensable elements of a resilient and sustainable urban ecosystem. To support this intent and to better sustain the integrity of the urban ecosystem, we must give much greater consideration to the structure and function of our trees and the impact our built environment imposes on them and their ability to provide the ecosystem services (ES) benefits we increasingly depend on.

The global diversity of the urban forest within the built environment includes trees in a variety of contexts: traditional forest, open landscape, and, more often than not, isolated plantings. The ability of that tree to grow, be it in the forest or the streets of a city, is the combined interaction of its genetic potential, i.e. its capacity: "what you have as a result of your genetic code; a potential source for some future action or product", and the surrounding environmental conditions that enable those capacities, i.e. ability – "what you are doing with what you have; a dynamic or kinetic process" (Shigo 1996, pp. 6).

Almost all tree species planted in our urban centres evolved in a forest somewhere in the world. If we are to enable that forest tree's capacities and provide a sustainable environment in the urban spaces and places we are asking this forest tree to exist, we need to use forest ecosystem logic and incorporate an understanding of forest systems – how that forest tree exists and manages itself, as noted in Zürcher (in prep) – as a basis for ecological design:

- A forest system is a complex adaptive ecosystem – a sophisticated, highly developed community of trees and all their associates – related flora, fauna, and, most importantly, soil with a profile consisting of an organic layer and horizons A (topsoil), B (subsoil), and C (parent material), supporting a mycorrhizal network and containing a functioning soil microbial community, providing air, water and the nutrients, macro and micro, all associates in the forest community depend on, either directly or indirectly.

- Forests are a process of succession, of evolution. Forests don't happen in a day, a week, or a year. They occur over millennia, beginning with the specific soils they populate, formed by varied weathering processes on parent material – the rocks and geological sediments specific to the site combined with the forest's detritus that is processed in the A horizon.
- Forests evolve in direct relationship to their environment – temperature range, the soil's texture, structure and pH, and the availability of light and water will all dictate what species are growing and where: higher elevations or lower, coastal or inland, temperate or tropical, and edge or interior.
- Although a forest may consist of many different species of trees, space above ground is shared in competition while space below ground is shared in community. Trees are social; they are collaborators. They have evolved to depend on a communal rooting landscape – a symbiotic mycorrhizal network providing inter-species communication that enhances self-management mechanisms such as the sharing of nutrients and early warning for defence purposes.
- Photosynthesis delivers the fuel that propels the entire system's functions, providing the chemical energy that enables processes such as respiration. While photosynthesis has traditionally been considered as a function of leaves, trees have other photosynthetic capabilities. Many species of forest trees photosynthesize through their bark. This form of photosynthesis is generally referred to as woody tissue photosynthesis. The active chloroplast population is located mostly in the cortex (corticular photosynthesis), just under the bark, as well as in ray cells and even in pith. As the tree builds up very high internal concentrations of respired CO_2, woody tissue photosynthesis allows the tree to *re-fix* that internal CO_2 as part of its self-management strategies.
- Tree architecture is reiterative – based on the arrangement of fundamental parts such as branches and leaves and thus part of the individual tree's management strategies in relation to its evolving environment. Individual trees, growing within a forest system, will adapt their dynamic architecture, over time, to prevailing environmental conditions and inter-spatial relationships that affect access to light, crown space, or gravitational demands on structure.
- As forest trees increase in height and competition for crown space and light increases, their lowest branches may receive less and less light, and thus, their ability to maintain their own needs and to make contributions to the tree's overall upkeep may be greatly reduced. When this happens, a tree may initiate branch shedding by forming a basal protection zone, literally divorcing the branch from resources supplied by the tree, ensuring its demise. Before the dying branch is shed, all usable resources that have been stored in the branch will be reclaimed by the tree.
- Trees grow with their root crown – their buttress roots – above the soil line, as do all parts of the tree that are covered with bark. Bark, in its entirety, requires air in order to function properly.
- An individual forest tree's root system begins at the trunk – root transition zone referred to as the root crown or buttress area, with the development of at least four first-order roots in each of the four cardinal directions. The extension of these large woody first-order roots, forming the root system's perennial framework, is primar-

ily responsible for structural support, transport, and storage. They branch out horizontally into the surrounding soil – **the zone of rapid taper** – decreasing their diameter as they grow into the fine non-woody part of the root system and, along with their symbiotic mycorrhizal fungi, are responsible for the uptake of water and nutrients. Growth is opportunistic. Root exploration of the underground landscape depends on the presence of oxygen, water, nutrient availability, and a soil temperature that accommodates growth. Almost all of this extension activity occurs within the top meter/3 feet of soil with fibrous roots in the uppermost portion of this range and even into the decomposing forest floor litter, extending **a minimum of** 2.5–3 times the width of the crown, depending on the species and environment.
- Forest soil is always covered by related flora, leaf litter, or other organic forest detritus – a constant recycling and renewing of organic resources. A healthy and diverse soil ecosystem – the teaming life contained within forest soils – is the foundation for forest health and forest diversity.

Reviewing these processes, one can see why our urban trees are not thriving. We have asked our trees to work their ES magic, but we have deprived them of their essential *forest system* needs. Instead of giving them some of their preferences, we have given them little and asked them to endure.

But, the reality of enduring is troublesome as endurance based on such impossible conditions is an act of stressed tolerance. While our urban trees struggle to tolerate those very stressful built environment conditions, we are not enabling their remarkable capacity to do just that. The recognition that you can take the tree out of the forest but you cannot take the forest out of the tree must form the basis for spatial planning and development within the urban forest ecosystem.

We need to invest this understanding into all aspects of urban forest management, especially planning and designing as well as protecting and preserving during the development process so that the end result is a sustainable, environmentally compatible product which can accommodate the needs of our urban trees, the landscapes they populate, and citizen well-being.

So, let's look at the elements that fall within the professional sphere of ecological design – the *where, what, and how* design details that initiate the possibility of growing a healthy urban tree well into maturity – details which, if incorporated and implemented, can result in ecological design; a healthy, invaluable resource; and a healthier urban ecosystem.

27.2 Planning and Design: *Where* an Urban Tree Will Grow

27.2.1 Site Evaluation/Preparation

Spatial resource evaluation and preparation – the *where* the tree(s) will exist – is a must prior to tree selection and must include the following information:

- Does the community into which the tree(s) will be planted have cultural preferences or concerns, such as Feng Shui? These issues must be addressed directly

with community leaders in determining where a tree can be planted. Planning tree planting that involves citizens and considers their input is always more successful for the long-term survival and well-being of the tree.
- What type of planting area is it – open landscape, tree lawn, kerbside cutout?
- What are the proposed dimensions of the tree area?
- Are there other trees already existing in immediate proximity to the planned planting?
- Are there grading issues – too high or too low?
- Are there overhead wires or underground utilities?
- What is the proximity to grey infrastructure – kerb, pavement, buildings?
- Does the pavement already exist – what type of paving material; what is the condition of the material; does the new planting include sidewalk replacement?
- If there are buildings, how tall and what is the proposed planting site's orientation to the buildings as well as to the street – distance as well as direction?
- Will there be re-reflected heat load issues or is the site particularly windy causing excessive transpiration and droughty conditions?
- What is the daylight availability throughout the growing season?

Site evaluation and preparation components are essential elements in the art of growing an urban tree, but it's difficult to talk about where an urban tree will exist without discussing what that tree will exist in bringing us to the critical discussion of that landscape underground – the soil substrate that's underneath all the impervious surfaces. Sometimes referred to as urban soil and all-too-often defying the definition of what soil is supposed to be, as noted by Oxford, https://www.lexico.com/definition/soil n.d.: "The upper layer of earth in which plants grow, a black or dark brown material typically consisting of a mixture of organic remains, clay, and rock particles". But soil is so much more than just a black or brown composite of varied materials. It's an ecosystem unto itself, comprised of the inorganic – the parent material which contributes rock and mineral content, and the organic – the soil food web consisting of an extensive array of microbes and invertebrates. The resulting ecosystem provides roots with life's essentials – air, moisture, and water-based nutrients – an association with a tree's root system that has a direct impact on a tree's health and its ability to grow. The caveat is that the soil can only provide the tree's roots with life's essentials *if* the soil is the living organism it should and must be.

It is also important to put the ecosystem's structure into a relational context. One can summarize important substrate properties as follows: total pore space, water holding capacity, air space, bulk density, and particle size distribution. Without these proper physical properties, nutrients in the compost will not be effective, and without the renewable organic detritus in the form of leaf litter or wood chip mulch which forms the critical organic layer, soils become biologically inactive, thus ceasing to be soil.

From an ES benefits perspective, not only is a living soil ecosystem essential to tree health, but it is also the foremost carbon sink. In addition to determining the site's soil pH, structure, and texture, we have to enable soil's extraordinary carbon sink capacity, requiring a profile with a maintained organic layer as well as A, B, and (possibly) C horizons.

For all things come from earth, and all things end by becoming earth.
Xenophanes (c. 570–c. 475 BC)

The benefits a living soil provides do not begin or end with the storage of carbon. Living soil, in conjunction with tree root systems, also improves urban water resource management by increasing water filtration and infiltration rates, recharging groundwater as well as run off interception and storage, all of which improve the status of both surface water and groundwater.

In addition to the soil, the site must be able to support canopy. Almost all the ES benefits trees deliver are provided by the mature tree's crown – *top* driven. But, you can't have top without bottom!! The crown does not exist in a void. It is only part of a complex system that has at least half of its primary functions underground.

To facilitate these tree-friendly site essentials and, at the same time, avail ourselves of the cost-effective delivery of essential ES benefits:

- We need to stop sealing soil with impermeable surfaces.
- We need to provide tree root systems with an adequate, accessible volume of living soil.

This graphic (Fig. 27.1) offers a direct comparison between different unsealed soil volumes and the tree size each volume can support.

Unfortunately, the reality of our present approach to spatial planning, design, and development has greatly limited our creative assessment in how we accommodate the combined needs of tree and pedestrian – one does not have to preclude the other but it is critical that our design considers both.

For the soil and the tree, the ultimate design is an unsealed adequate volume of living soil, exemplified by cluster planting (Fig. 27.2a), affording trees' roots a

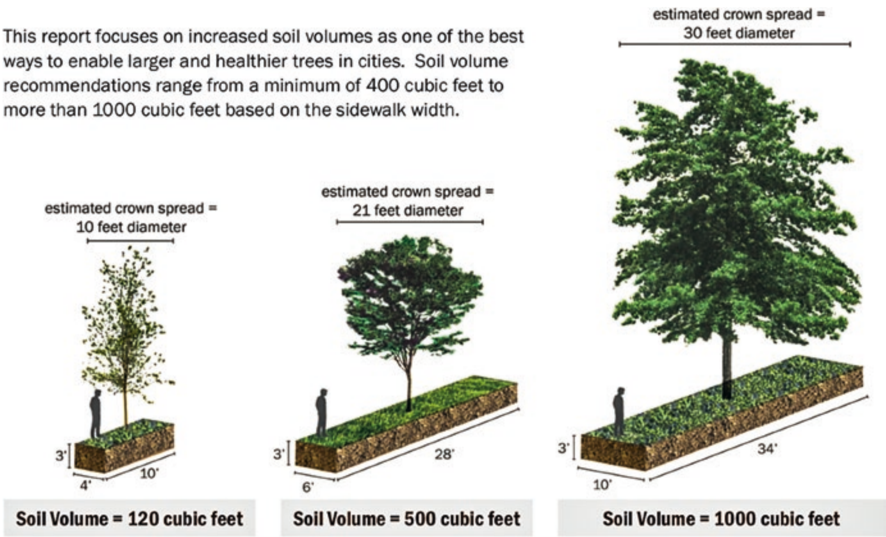

Fig. 27.1 Soil volume comparison. (Credit: Casey Trees, Washington D.C.)

Fig. 27.2 Examples of open soil volume tree planting beds. (**a**) cluster planting Ft. Greene, Brooklyn NY (Credit C. Glaeser); (**b**, **c**) extended curbside tree planting beds with pedestrian access. (Credit: Casey Trees, Washington D.C.)

communal environment, sharing a larger unsealed volume of living soil while requiring less total space in the landscape than the classic, isolated, linear kerbside plantings. The result is a planting that, as trees mature, requires less maintenance to deliver an enhanced range of ES benefits to the residential community.

Where space does not permit such a configuration, there are well-documented alternative strategies to achieving an open, adequate root-accessible soil volume – strategies that use forest ecosystem logic and the need for urban water resource management to focus our creative efforts on providing a larger area of unsealed soil. Figure 27.2b, c offer examples of unsealed soil design concepts using extended kerbside tree planting beds that have been separated for pedestrian access.

While the introduction of pedestrian access will potentially reduce the total soil volume, this situation can be addressed through the use of various substrate mitigation techniques.

The incorporation of root paths or soil trenches allows for continuous rooting opportunities. Root paths should be at least 4 inches/10 cm in width and 12 inches/30 cm in depth and extend at least 12 inches/30 cm into the open tree area so that the root path opening is in immediate proximity to the root ball. The walls of the resulting trench should be compacted and lined with strips of aeration or drainage board (Fig. 27.3a). The path/trench should then be filled with un-compacted soil, having the same pH and soil texture classification as the soil within the tree planting bed.

In areas being considered for tree planting where pedestrian usage needs or other site limitations reduce the accommodation choices, we need to manage those limitations so that walkable surface design decisions, combined with elements such as root paths, can potentially still offer the tree(s) being planted a greatly improved growing environment.

There are now a number of seemingly environmentally-friendly paving options, but the extent to which the substrate needs to be compacted will greatly affect the amount of soil that is living and accessible and is contributing to urban water resource management. It is this fact that should be paramount in driving our decision. When soil sealing paving is applied, the substrate – the soil – must be compacted to meet an engineering specification. The results of this requirement are never good. First, a compacted substrate that is then sealed encourages root growth where it does the most damage to surrounding infrastructure – just under the surface of the paving – where condensation accumulates and pockets of air exist. These basic, essential tree root needs are normally accessed in the soil, but when soil is compacted, the macro- and micropores that are an integral part of soil structure, water drainage

Fig. 27.3 (3**a**) Root path construction and schematic. (Credit: Casey Trees, Washington D.C.); (3**b**) *Cercidiphyllum japonicum* retrofit repaving with CU-Soil®. (Credit: Urban Horticulture Institute Cornell University)

capacity, and air and moisture retention are eliminated. The soil microbial community can only exist in the presence of air, moisture, and organic elements. Soils deprived of all their attributes are no longer viable and they can no longer function, not as a living organism, a carbon sink or as an essential associate of trees' roots or anything else environmentally beneficial.

While pervious, porous, and permeable paving is still sealing the soil, it may not be to the same extent as completely impervious paving. What needs to inform our decision is which choice would offer the tree(s) the greatest possibility for unimpeded root growth. Following is a discussion of the alternative walkable surfaces in production today, along with their *tree/soil* advantages and disadvantages

Dry-laid pavers continue to offer trees' roots the most accommodating form of walkable surface treatment. Unmortared Belgian blocks, cobblestones, or bricks are dry-laid on a bed of tamped-down sand with mason sand filled in between the joints. This installation requires minimal substrate compaction because the sand acts as a cushion which accommodates substrate irregularities while affording the un-compacted soil beneath the sand access to gas exchange and water infiltration. While the application of paving always impacts the presence of an organic layer, the fact that there is gas exchange and water infiltration can support a viable root system which will, through life-cycle processes, contribute fine roots and exudate to the soil. In addition, the dry-laid technique allows for easy adjustment to manage any disturbance.

In addition to the smaller pavers mentioned above, one can also use either dry-laid natural bluestone or travertine. Both of these installations have the same requirements in terms of minimal compaction, resulting in an ecologically sound design. An important difference between these two natural stones is that bluestone holds heat to a much greater extent than travertine. If the installation will cover a larger area that is not shaded by trees, the use of travertine would help reduce the resulting urban heat island effect.

27.2.2 The 3 Ps: Pervious, Porous, and Permeable

Although these three types of paving can be used to facilitate urban water resource management, the technology is not the same. Pervious and porous pavers allow water filtration through the paver while permeable pavers direct the water into the joints that surround each otherwise impermeable paver. Per paver, permeable pavers deliver a lesser amount of water infiltration than the other two options. Porous pavers are pavers made of concrete in the form of an open grid where the holes can be filled with vegetation or stones. Pervious pavers, also made of concrete, contain voids which allow water infiltration across the entire surface of the paver. These pavers are installed over a gravel sub-base which acts as the reservoir for removal of surface water. Often included in the installation are pipes which can move excess water from the gravel sub-base to a larger water infiltration area. In addition, proper maintenance is essential in order to retain infiltration capacity, and each product comes with its own maintenance protocols which include sweeping and vacuuming. While maintenance requirements may differ from standard concrete sidewalks, all hardscape installations require maintenance to extend their functionality and their useful lifetime all hardscape installations require maintenance to extend their functionality and their useful lifetime therefore, maintenance maintenance of such installations should not serve as an impediment to their use. Where these paving solution falter is, as always, the need to compact the soil substrate to a degree which is not conducive to a living soil organism or to tree root growth.

To facilitate the use of pervious and porous paving options so that they can also accommodate tree root growth in a living soil organism, pavers can be combined with open and covered soil designs, using root paths or soil trenches plus root-friendly material such as structural soil. Structural soil, such as CU-Soil®, is based on a stone matrix/soil mixture. The concept of angular, uniformly-sized crushed stone tumbled with a clay loam and organic matter, all in a proprietary ratio, which will, when compacted to the required engineering load-bearing spec, form a matrix which has enough soil and voids as to accommodate gas exchange and moisture retention, encouraging tree root growth and communal root exploration. When combined with pervious or porous pavers, structural soil provides the sub-base material as well as the substrate, positively addressing the pavers' limitations. While CU-Soil® is the US offering, one can find proprietary structural soil blends in Amsterdam, the original location, as well as Sweden and Switzerland.

Structural soil can also be used as a retrofit strategy when paving is being replaced. Thoughtful and careful planning, consisting of pneumatic excavation combined with CU-Soil® and dry-laid paving installation, delivered a successful repaving of the area around this mature *Cercidiphyllum japonicum* Siebold and Zucc. offering the tree a new lease on life (Fig. 27.3b).

Such an initiative comes with a higher price tag than a standard concrete repaving, but the resulting cost to benefit is of no comparison when one considers the enhanced ES benefits which the tree continues to provide combined with avoided costs – reduced infrastructure damage caused by tree root growth and reduced tree maintenance costs as a result of infrastructure-related damage to the tree.

Both root paths and structural soil are especially useful as a conduit to convey tree roots from a planting bed, under adjacent pavement, to an open green space, affording tree roots greatly increased access to an open living soil volume and, at the same time, greatly reducing tree root/infrastructure conflicts.

An additional strategy to increase the root-accessible soil substrate is in the form of soil vaults. The sub-base concept is that of a bridge – modular plastic cells are filled with un-compacted loam and then covered with paving which can be pervious or permeable. Soil vault benefits, which can be limited by the proximity of utility conduit, are especially useful in situations such as parking lots where the extent of sealed soil greatly outweighs the areas where trees have been planted. Careful consideration would have to be given to the type and extent of expected pollutants in order to determine the most appropriate paving solution. In addition, tree planting median configuration should afford as much unsealed living soil volume as possible to compensate for the added abiotic stress of reradiated heat loads and contaminants.

27.3 Planning and Design: *What* Urban Tree Will Grow

27.3.1 Tree Selection Specification

Another component of planning/design is the determination of the *what* – what tree(s) will be specified. Once the spatial resource has been evaluated and prepared, a site-specific tree list can be developed based on an additional set of criteria. While ornamental attributes are always important to designers, site-driven considerations combined with trees' needs must come first, as follows:

- Hardiness – even trees with a broad hardiness range should be selected based on the specific provenance as genetic variables can affect survivability, especially in our current situation of radically changing climate norms as a result of climate change.
- If the specified tree selection is a grafted species, the grafted root stock must also be cold hardy for the site being planted.
- If the tree will be planted in a community with a high incidence of asthma, specify trees that do not exacerbate the condition but have a high rating for air pollution mitigation, a primary causal agent of asthma.
- If the planting site is not an open landscape but rather surrounded by hardscape, avoid trees that have known preferences for open landscape such as *Tilia* or *Fagus* genera.
- Avoid specifying trees for a fall planting that should not be dug in the fall, such as conifers or *Liquidambar styraciflua* L.

The designer/planner of any project which includes the planting of trees should specify criteria for the selection of the tree material for the project as there is a great deal to know about nursery production practices which will directly affect the selected tree's health and ability to grow into maturity. Those production practices which not only influence the potential well-being of the tree but cannot be corrected after the tree has been dug must be addressed in a timely manner. Therefore, it is important to consider adding the following criteria to the specification which will help facilitate the tagging and harvesting of quality material:

- As a result of nursery production practices (Fig. 27.4a), soil is often mounded up against the trunk which impedes an examination of the root-trunk transition area. More importantly, when trees are too deep in the ground, their roots are too deep in the harvested root ball, reducing the number of roots that accompany the field dug root ball, increasing transplant trauma and thus the establishment period. In addition, the tree will now be planted too deep in its new home, impacting access to air, critical to root growth. Last, the roots that remained at the nursery were not only fine roots, but they were woody roots – a loss which directly affects not only storage of water and water-based nutrients but the tree's structural integrity, setting the tree up for potential failure; the nursery must be required to remove

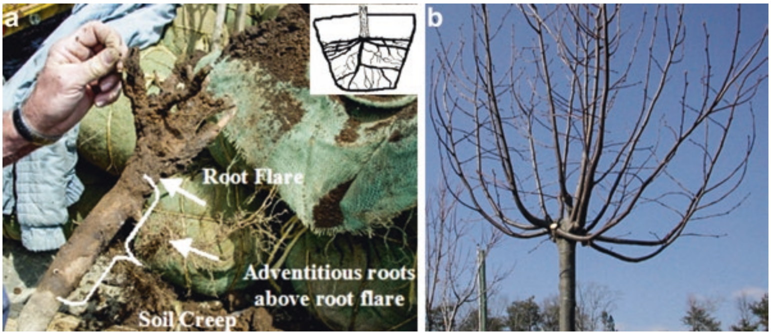

Fig. 27.4 Nursery production practices that affect tree health. (**a**) Soil mounding with roots too deep – field production (Credit: North Carolina State University Extension); (**b**) Results of non-selective pruning – heading cuts. (Credit: Carsten Glaeser)

this surplus soil, down to the root crown before digging, to ensure that has roots where they should be and not at the bottom of the ball.

- Heading back trees to stimulate branching – non-selective heading cuts (Fig. 27.4b) – can result in undesirable groupings of branches originating from the same point in the tree. Only select trees that have branching true to species' characteristic architecture.
- Use field-grown or bare root material, whenever possible – container-grown production techniques have not yet resolved root circling and girdling issues adequately enough to ensure quality standards can be met.

Because of the extent of the variables one can encounter at the nursery combined with the lack of an industry-wide set of standards in most countries in the world, there are further considerations involved with the selecting and tagging of trees at a growing nursery which must be located within the cold and heat hardiness zones of the planting site. First, and foremost, this task should only fall to a tree expert who has a working knowledge of nursery production practices combined with species-specific structure. A full examination of any tree being considered should include:

- The tree's crown, consisting of trunk, branches, and buds, ensuring they are characteristic of the species and of exceptional quality.
- Trees with co-dominant stems and/or included bark should never be tagged.
- The root-trunk transition area should be examined for possible girdling roots, damage, or injury.
- The location of first-order roots with a surveyor's pin; good root structure, critical to tree health and structural integrity, should consist of at least four permanent first-order roots, one in each of the cardinal directions, located within the top 3 inches/7.5cm of soil.
- A grafted tree's graft union must be visible. If planted too deep, the grafted portion can begin to root, weakening the graft structure as well as disease resistance.
- Tagged trees must be marked on the north side for transplanting orientation.

This brings us to the planting of the selected trees which is not included specifically in ecological design concepts. There is, however, a preparatory element which often does fall to designers and that is the specifying of the soil the tree(s) will be planted into. While this is outside my direct area of development expertise, it is not outside my practical knowledge and use of expert resources which I have specified and implemented and that can facilitate this aspect of design. I refer the reader to the work of Phillip J. Craul, Visiting Professor of Landscape Architecture, the Graduate School of Design, Harvard University, who has written three critically important books on the subject of urban soils (1992, 1999; Craul and Craul 2006). He has also published numerous papers on the subject, one of which is entitled *Working with Urban Soils* (1995), available online as open access. In addition, James Urban (2010), a Fellow of the American Society of Landscape Architects who studied with Professor Craul, has authored an invaluable resource which discusses soil within the urban context, from physical, chemical, and biological properties to urban soil assessment and soil-based strategies for both original installations and retrofits. He has also written numerous informative papers on this subject Urban (2014). Furthermore, the Urban Tree Foundation offers open source soil specifications as well as detail drawings on their website.

27.4 Planning and Design: *How* We Construct Our Built Environment

27.4.1 Establishing Value

Given the extent and breadth of the ES benefits our urban trees afford all residents of an urban ecosystem, it is astonishing that this value has not informed the way in which we assess the cost of tree removal and landscape destruction as a result of spatial development.

Historically, urban trees have been quantified for their amenity contribution to the landscape, and their undervaluing has been consistent with that approach. Today we have at our disposal the ability to quantify attributes well beyond the scant amenity concept, using scientifically documented valuation methodologies such as i-Tree Eco (https://www.itreetools.org/tools/i-tree-eco). Available globally, i-Tree Eco assesses the structure and function of existing urban trees in terms of their quantifiable ecosystem services in volume mitigated and the value of that volume in local currency. Moreover, the use of its forecast tool allows for the appreciation, over time, of the resource, as trees provide a long-term beneficial delivery which must be accounted for if said tree is to be removed for any reason other than disease or potential failure.

If planners and designers incorporate the use of i-Tree Eco as part of the resource inventory requirement, any and all removals would have a much more realistic price tag and would provide an incentive for and adherence to protection, preservation, and retention measures included in the scope of the build.

27.5 Building WITH Trees

Our final planning and design consideration is *how* we construct our built environment. While planners and designers do not directly construct, they do so indirectly by the very act of design and the specifications we craft to implement those designs.

When we build, we always consider the elements, not only in terms of materials but how we use those materials to address human needs. The materials we use are usually not living, but we give a great deal of consideration to their choice and application. As a result, building concepts have evolved – we have Leeds green buildings and greened buildings – but our specified construction practices have not kept pace. Although there are numerous strategies for eliminating/limiting damage to important hardscape features, these practices have rarely been applied to trees or their landscapes which fall within the project footprint or in close proximity.

While we cannot expect construction contractors to understand the workings of that natural landscape underground, those of us who plan and design the projects that are to be built must be the initiators and facilitators of the implementation of any and all practices which reduce impact, damage, and/or destruction of environmental resources.

Specifications and the oversight they require are the tools that can effectively realize ecological design in all areas where trees are sharing space with spatial development. Such detailed specifications must include the following strategies within the varied phases of design and build.

27.5.1 Planning Phase

A complete ground-based inventory of all trees and the landscapes they populate, conducted by an experienced professional tree expert, e.g. an arborist, for trees within the project footprint as well as those trees within close enough proximity as to have their critical root zone (CRZ) (Fig. 27.5a) – their critical structural roots – within the project work area. This inventory should not only include GPS/GIS-based location, species, structural metrics, parameters, and condition/risk, but it should also include an i-Tree Eco assessment to determine the ES deliverable. Existing inventory data may be used but only if that data has been collected within the past 2 years. In addition, the soil/landscape must be assessed for texture as well as existing levels of compaction.

Fig. 27.5 Building WITH Trees: (5**a**) Planning – CRZ (Credit: Urban Hort Inst.); (5**b**) Design – Trenchless technology (Credit: C. Glaeser); (5**c**) Pre-Construction – Pneumatic excavation + root pruning (Credit: C. Glaeser); (5**d**) Construction – Ground protection mats (Credit: C. Glaeser); (5**e**) Post Construction - Radial trenching + detail. (Credit: C. Glaeser, N. Zürcher)

27.5.2 Design Phase

The condition and structural stability of the assessed trees are important determinants for retention. For example, trees that are failing or diseased and in poor or dead condition should be designated for removal. An expert evaluation of collected data combined with the total value per tree should assist with determining protection, preservation, and retention strategies and, thus, inform where built structures/installations will be placed and how those installations will be constructed. A thorough understanding of how the project can be built in conjunction with what trees must be protected and retained can contribute to discussions to determine construction strategies facilitating retention, construction equipment plus operating radius and requirements, essential drainage/grading changes, utility installations, as well as storing of excavated soil and staging requirements including landscape protection through specified control of construction debris, spillage, washout, sediment, and parking of project-related vehicles.

To install pipes, conduits, cables, and the like, tree-/landscape-friendly design must consider the use of trenchless technology construction strategies, normally only used to preserve hardscape features, to tunnel under roots (Fig. 27.5b). These strategies, which include microtunnelling/jacking, require sending and receiving pits which must be well sited and be capable of receiving and sending so as to reduce the extent of environmental impacts. The dimensions of the excavation will also determine the need to sheet and shore to add structural integrity.

Horizontal directional drilling, another form of trenchless technology, uses a surface to surface approach rather than a send-receive pit excavation. As with all such processes, adequate space must be predetermined and defined for equipment operation. Each technology has its pros and cons, and the selection of the project-appropriate strategy, including the avoidance of soil heaving, will require knowledgeable experienced partners.

27.5.3 Pre-construction Phase

Once the project has been designed with the work footprint set and the trees/landscapes designated for protection/retention, the following actions must be specified:

- For trees within the project work footprint and with the understanding that it is never recommended to root prune more than one root zone quadrant, any excavation must exclude each tree's protected ecological footprint, as per Dr. Kim Coder's recommendations (2016, pp. 69):

  – DBH 6 inches/15 cm or less: a minimum of 15 feet/4.5 m from the dripline
  – DBH > 6 inches/15 cm: a minimum of 25 feet/7.6 m from the dripline
  – DBH > 36 inches/1 metre: may require a minimum that exceeds 30 feet/9.1 m

and include the establishment of a tree/landscape protection zone (TLPZ)/fence, prior to the commencement of any and all work and noted accordingly on detail plan drawings.

- For tree-populated landscapes at the defined perimeter of the project's work footprint as well as for any areas that have been determined as requiring protection, a TLPZ must be established and a significant protection fence installed prior to the commencement of any and all work with the accompanying requirement that the fence can only be removed and the protected area accessed with prior written approval and in the presence of the overseeing tree expert. TPLZ/fence must be noted on detail plan drawings.
- Once the design has been completed and the project's construction work zone has been defined, the structural (woody) roots of all protected trees along the

TLPZ perimeter that are determined to be within the work footprint should be accessed using pneumatic excavation (PE) such as an AirSpade® with a root diagnostic nozzle (Fig. 27.5c), allowing for the removal and retention of soil without any harm to the tree's roots, enabling easy, fast, clean, and accurate root pruning (perpendicular to the root at the point of the cut), the wrapping of exposed roots using moist burlap, and the immediate replacement of removed soil upon conclusion of root pruning. Area must then be mulched and well irrigated. This enables work to proceed, unimpeded by and without consideration for protected trees' roots within the work footprint.

- All root pruning work must be followed by the thorough irrigation of any and all protected trees and the landscapes they populate 4–5 days preceding the commencement of any construction activities. The thorough hydration of roots improves the ability of protected trees to withstand the stress and trauma inflicted during construction.
- The completion of the design will also have determined the equipment which will be used on the project as well as its operating radius. Such equipment may warrant the need for clearance pruning, especially along the TLPZ fence line. While such work falls to a landscape contractor, it is essential that the specification defines the expertise required to perform such tasks – professionally, a certified arborist or equivalent. In addition, the specification must require oversight from the project tree expert during any and all such operations to ensure the use of best management practices and the upholding of all tree/landscape protection criteria.

27.5.4 Construction Phase

The need to access a TLPZ or traverse any tree-populated landscape requires the oversight of the project tree expert along with additional use-specific tree/landscape protection. The landscape immediately around each tree should receive an installation of wood chip mulch, 4 inches/10 cm in depth with a setback of 6–12 inches/15–30 cm from the base of the trunk, to be determined by the extent of the exposed buttress area.

If access to the TLPZ requires the use of heavy construction equipment, additional protection measures must be introduced in the form of ramped, interlocking ground protection mats (Fig. 27.5d), installed over geotextile/landscape fabric + composted wood chips 12 inches/30 cm deep, the combination of which greatly reduces the probability of soil compaction. Ground protection mats have replaced the use of steel plates and plywood as they provide a much easier installation and a more modular approach to landscape protection.

It is highly recommended that utility service lines be placed in a conduit and located outside the anticipated structural root zone of retained trees. The project tree expert can facilitate this through his/her species-specific structural knowledge.

27.5.5 Post Construction

Following completion of all project work, an inspection must be conducted by the project tree expert to determine the extent of any damage which may have occurred during the project's execution, especially to the protected landscape in the form of soil compaction. Such damage will be based on the existing conditions documented during the initial inventory. Soil de-compaction which enables soil health as well as tree root growth is best accomplished by specifying radial trenching (Fig. 27.5e) with the use of pneumatic excavation (PE), such as an AirSpade® with a root diagnostic nozzle. The procedure uses PE to excavate radially aligned trenches around a tree, with a setback equal to 3.5 times the tree's DBH. The soil from the trenches is removed and retained and, with organic compost added, returned to the trenches.

In addition, it should also be determined if and where subsequent greening might be included in post project site restoration as soil remediation measures should include those areas of the project footprint as well.

27.6 Consideration Conclusions

The considerations which have been offered are intended as a provocative sampling of possibilities. In exploring which considerations of the tree and its soil associate would serve as a creative stimulus in the spatial development design process, my thoughts often turned to Ian McHarg and the concepts he elucidated in his seminal work *Design with Nature* (1969) as well as in his lectures – fundamentally, that all design must be informed by an ecological perspective and that design and its outcomes had to support all aspects of life, not just human but the entirety, not just in a mindful way but synergistically, symbiotically, providing a catalyst for the concepts offered.

When we design, it is critical that we give consideration to what exists, how it functions, and how the form our design will take supports all those functions. If we add an ecological aspect to that design process, then the process has evolved and with that our possibilities. The sustained health and well-being of *all* inorganic and organic components of the urban ecosystem require an interdisciplinary incorporation of art, science, theory, and practice into every aspect of spatial development. Ecologically resilient and sustainable planning and design must focus on implementing creative solutions if we are to reduce resulting environmental impacts and, at the same time, *grow* our urban forest ecosystem.

Respect trees – trees have dignity too.
Learn about trees and their associates
so that you can help make better decisions
for their long-term, high quality survival.

Dr. Alex Shigo, Father of Modern Arboriculture

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Correction to: Improving Extensive Green Roofs for Endangered Ground-Nesting Birds

Nathalie Baumann, Chiara Catalano, Salvatore Pasta, and Stephan Brenneisen

Correction to:
Chapter 2 in: C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17, https://doi.org/10.1007/978-3-030-75929-2_2

As per the investigation report submitted by the internal committee at Zurich University of Applied Sciences (ZHAW), Dr. Stephan Brenneisen supervised the 2006–2010 project and was responsible for the original data analysis used in this chapter. Hence, the author group of Chapter 2 has been updated as follows with the inclusion of Dr. Stephan Brenneisen's name:

Nathalie Baumann, Chiara Catalano, Salvatore Pasta and Stephan Brenneisen

The current affiliation of Dr. Stephan Brenneisen has been updated in the chapter as follows:

Department of Life Sciences and Facility Management (LSFM), Institute of Natural Resource Sciences (IUNR), Zurich University of Applied Sciences (ZHAW), Wädenswil, Switzerland

Based on these changes, the author contributions text at the end of the chapter has been revised as follows:

N.B. suggested the topic, provided the raw data and the images, and prepared the first draft of the manuscript; C.C. and S.P. carried out data interpretation, prepared the tables, revised the manuscript, and adapted the final version according to the remarks and suggestions of the reviewers. S.B. supervised the 2006–2010 project and was responsible for the original data analysis. All authors revised the final version of the manuscript.

The updated original version for this chapter can be found at https://doi.org/10.1007/978-3-030-75929-2_2

C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2_28

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C. Catalano et al. (eds.), *Urban Services to Ecosystems*, Future City 17,
https://doi.org/10.1007/978-3-030-75929-2