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Chapter

Urban Ecosystem: An Interaction of Biological and Physical Components

Hassanali Mollashahi and Magdalena Szymura

Abstract

Urban ecosystems are composed of biological components (plants, animals, microorganisms, and other forms of life) and physical components (soil, water, air, climate, and topography) which interact together. In terms of "Urban Green Infrastructure (UGI)", these components are in a combination of natural and constructed materials of urban space that have an important role in metabolic processes, biodiversity, and ecosystem resiliency underlying valuable ecosystem services. The increase in the world's population in urban areas is a driving force to threat the environmental resources and public health in cities; thus, the necessity to adopt sustainable practices for communities is crucial for improving and maintaining urban environmental health. This chapter emphasizes the most important issues associated with the urban ecosystem, highlighting the recent findings as a guide for future UGI management, which can support city planners, public health officials, and architectural designers to quantify cities more responsive, safer places for people.

Keywords: urban green infrastructure, connectivity, ecosystem services, biodiversity, urban microbiome

1. Introduction

1.1 Urban ecosystem

Urban areas are composed of natural and constructed systems where the human population is more concentrated, and there are complex interactions between socioeconomic factors and biophysical processes [1, 2]. In a city, an ecological process often occurs in habitat patches, which are connected by corridors in a matrix of streets and buildings. The major ecological processes between/among habitat patches include immigration and dispersal agents, also, ecological corridors that can act as links or barriers for dispersal ability [2].

Due to transport networks cities are often the entry points of many alien species [3]. Moreover, in contrast with non-urban areas, urban ecosystems have different physical and chemical properties, which highly influence species distribution and ecosystems functioning [4, 5]. As a whole, urban areas have been usually considered novel in relation to their non-urban counterparts, which are comprised of a variety of fragmented habitats [4]. Overall, in this novel ecosystems the restoration ecology, conservation, biodiversity, ecosystem services, and climate change have been the most discussed topics in literature [6].

1.2 Urban green infrastructure

A bibliographic analysis of urban sustainability indicates that the topic of green infrastructure started to be in the attention of scientists in 2010, when, the awareness of issues associated with climate change was raised and the assessment of urban ecosystem services was more considered. During a period of five years (2010-2015), topics related to health and well-being were more interesting, and the motor theme of conversation became the priority of the scientists studying the importance of green infrastructures. This demonstrates the significant importance of green infrastructure and its association with sustainability [7, 8].

The term "Urban Green Infrastructure (UGI)" refers to engineered and non-engineered habitat structures in connection with natural and semi-natural areas and other environmental features, which are designed to deliver a wide range of services from nature to humans. Green infrastructure comprises different kinds of components (for example, parks, green roofs, urban forests, road verges) which according to several number of parameters (e.g., spatial scale, dimension, location) are categorized [9, 10].

The "Green Infrastructure" can perform several functions in the same spatial area. In contrast to gray (or conventional) infrastructure which usually has one single objective, GI is multifunctional which means it can promote win-win solutions or "small loss-big gain", delivering benefits to a wide range of stakeholders and the public at large [10].

In line with Europe's 2020 strategy, it can act as a catalyst for economic growth by inward investment and generating employment, reducing environmental costs, and providing health benefits among others. This can contribute to the recovery of Europe's economy by creating green businesses and innovative approaches, representing around 5% of the job market. For instance, the Hoge Kempen National Park (6,000 ha) which is located in the eastern part of Belgium, the investment to carry out improvement projects is raised up to €90 million and generating €24.5 million per year in revenues from sustainable tourism alone. In Sweden, 10,000 m^2 of green roofs were installed and an open storm-water system was built to improve the environment both for people and nature, the entire project cost around €22 million but the benefits that have been derived from this investment are already tracking up; for example, decreasing in rainwater runoff rates by half, significant saving energy by residents, increasing the biodiversity by half, unemployment has fallen from 30–6%, and turnover in tenancies is decreased substantially [10]. More example is Canada where the economic value of 13 ES in Canada's Capital Region (Ottawa-Gatineau region) amounts to an average of 332 million dollars, and to a total economic value of over 5 billion dollars, annualized over 20 years [11].

1.3 Ecosystem services

Improving the knowledge about the importance of urban ecosystem services (ESs), and their value especially in the current trend of world urbanization is necessary. Thus, the role of city planners and other disciplines and their collaboration to integrate new findings associated with ESs is necessary [12]. ESs, directly and indirectly, influence human life and thus the economic activities. For examples, the maintenance of soil fertility can secure food production, and/or providing clean air and water through the absorption of pollutants by plants, and our mental and physical health may depend on the accessibility to green spaces [13].

1.3.1 Categorization of ecosystem services (ES) at the urban level

We only consider the ecosystem services classified by the Mapping and Assessment of Ecosystems and their Services (or MAES), Urban ecosystem, 4th report (May 2016). This classification takes into account merely the ecosystem services which are more important and happen in urban areas. These ecosystem services (ESs) are including (i) provisioning services in which the food and water are the most valuable ones, (ii) regulating services including the regulation of air quality, flood and water flow regulation, also, noise and temperature reduction plus pollination, (iii) the cultural ecosystem services such as recreation, education and cultural heritage [14].

There is criticism this classification in which the supporting services is not taken into account. Those supporting services are so-called intermediate ecosystem services and comprise the habitats for species and maintenance of genetic diversity [15].

Apart from the above-mentioned classification system, the three other classifications are also available but they consider the assessment of ecosystem services on much big scale than cities. These three classifications are as follows; (1) CICES (the Common International Classification of Ecosystem Services), (2) The MA (the Millennium Ecosystem Assessment), and (3) TEEB (the Economics of Ecosystems and Biodiversity) [16–18].

1.4 Biodiversity

The urban area often contain threatened species. The spatial structure of the urban landscape, especially patches features (e.g., patch size and their connectivity) are correlated with species richness and biodiversity [19].

More than three-quarters of Earth species are characterized to be extinct at short time intervals which is unprecedented. Mammalia, birds, and amphibians are the groups of animals that have become more popular for the assessment by scientists [20], while insects species have been poorly studied, despite their vital role in ecosystems and in turn well-being. Biodiversity loss of insects is reported as a worldwide phenomenon, (typically in Great Britain and other European countries), where four main drivers of this condition have been presented [21, 22]. Habit lost and fragmentation which is made by the human is considered as the main factor of global biodiversity loss, and then pollution, biological factors, and climate change. In the case of mammals and birds, habit change plays the same role in the reduction of their species [23–25].

1.4.1 Biological factors

Human settlement and infrastructure development is a threat to protected species and negatively impact on the many of the at-risk species [26]. Among those species, beneficial insects like honeybee colonies, birds, and mammals are more endangered. For example, beehives are at risk of collapse by mite parasites and viral infection. Thus the necessity of conservation strategies is a need in urban wildlife, where the species encounter anthropized environments that differ from the natural landscape. With this in mind that many species characteristics such as dispersal ability, sex, even body mass influence the species movement to urban areas. Passerine birds are a good example; where the urban colonization rate of these birds is associated with the color dichromatism [27, 28].

If we consider two groups of specialized and generalist species, the first group (specialized) tend to be more susceptible and poor in adaptation to the habitat changes in novel conditions as they have a special host, and their ability to recover quickly is less; thus, these species are more at risk of extinction. The second group (generalized species) are more adaptable to climate change and can successfully colonize the new environment/urban setting in a short time, showing plasticity, adaptability, and having access to a wide range of food and shelter requirements. Other factors such as invasive species has been reported to show cascading effects on the ecosystem and influence the species communities, and the diversity of many organisms, especially insects. For example, cattle grazing and recreational activities negatively impacted the distribution of a dragonfly (*Ecchlorolestes peringueyi*) in South Africa [25].

1.4.2 Habitat change

Human activities like industrialization, and agricultural intensification, have changed the habitat structure of natural landscape, causing the reduction in food resources and shelter sites for many specialist species. Moreover, urbanization, causing the disappearance of many habitat specialists and their replacement with a few generalists adapted to the artificial human environment. Providing habitat quality and management contribute to biodiversity maintenance. A good example of habitat management is presented by Britain government where the area of flower grasslands was increased for the target populations of bumble species [25, 29].

1.4.3 Pollution

There are several factors causing environmental pollution, declining biodiversity loss. Fertilization and pesticide application mostly occur in agricultural settings. In the case of urban settings, industrial sites, transportation, and sewage increase soil contamination by the heavy metals in green infrastructures, which can reduce not only belowground biodiversity but also influences the vegetation structure of lawns and grasslands patches [25].

Several studies reported the existence of neonicotinoid residues that contaminated the honey samples from *Apis mellifera* hive collected from European honey samples. Neonicotinoids (e.g., Clothianidin, Imidacloprid, and Thiacloprid) have been identified from urban habitats, suggests the reconsideration of pesticide application in urban areas. Thus, due to urbanization and agricultural intensification the awareness should be raised about chronic toxicity and exposure of bees and other beneficial insects and consequently human health [30]. Fipronil is a pyrazole insecticide and is widely used in agricultural areas against larval Culex species. The toxicity of Fipronil has been found in urban runoff waters in California and showed acute toxicity to aquatic invertebrates in south-eastern Australia, suggested to cause disruption to aquatic ecosystems [31, 32]. The toxicity impacts of insecticides such as imidacloprid, bifenthrin, and fipronil are detected, causing the reduction in survival and feeding ability of black tiger shrimp (*Penaeus monodon*), which were also distributed in urban waterways [33]. Moreover, many other kinds of insecticides (e.g., Pyrethroid) have high toxicity on aquatic insects, crustaceans. Aquatic environments are more at risk of disruption where pesticide residues from agricultural and urban runoff are the major cause of biodiversity declines. Bifenthrin was found from urban runoff in river water, affecting the most important prey species for American River Chinook salmon which can cause a significant reduction in their abundance [34, 35].

In Germany, over the 27 years of study, about 80% of the flying insect biomass losses were caused by increases in pesticide application [36]. In a study in Paris, urbanization made a significant reduction in the population of the bird species called "House Sparrows" [37].

1.4.4 Climate change

Urban areas are under the pressures of population growth, urbanization and suburbanization processes, which interact with the climate, leading to the establishment of the urban climate. Urban climate is generally characterized by some particular features such as heat islands effects, dryness, urban flooding, cold, humidity and pollution, which can significantly affect human health [38]. Abiotic stress such as heat waves, drought, and flooding are the three most important factors, having not only socio-economic impacts but also constrains on global food security [39].

1.4.4.1 Urban climate, the heat-related phenomena, and its impact

The urban heat and its extreme impacts on social and environmental aspects on urban residents together with climatic change arising from global warming, alleviating agricultural crops, influencing the resiliency of the urban greenery and therefore a risk for human health. The heat-related phenomena are related to heatwaves and drought which produce negative effects as heat-related illness and heat-related mortality [40–42]. Triggering certain types of diseases have been reported due to hydro climatic treat and long-term exposure to heat-related stresses, for example; respiratory, gastrointestinal, caused by low humidity, high temperatures and lack of water for personal hygiene, and household cleaning [43].

1.4.4.2 Urbanization and sponge city concept

Water flooding is a serious problem in many cities of China. The concept of sponge city was developed for the first time in China in 2014 in order to deal with urban flooding and to attenuate urban runoff, and improve the purification in the concept of urban sustainability. The concept is being developed to make use of 'blue' and 'green' spaces in the urban environment to encourage stormwater management and control [44].

"*The sponge city concept aims to (i) adopt and develop LID (low impact development) concepts which improve effective control of urban peak runoff, and to temporarily store, recycle and purify stormwater; (ii) to upgrade the traditional drainage systems using more flood-resilient infrastructure (e.g. construction of underground water storage tanks and tunnels) and to increase current drainage protection standards using LID systems to offset peak discharges and reduce excess stormwater; and (iii) to integrate natural water-bodies (such as wetlands and lakes) and encourage multi-functional objectives within drainage design (such as enhancing ecosystem services) whilst providing additional artificial water bodies and green spaces to provide higher amenity value*". The integrating of mentioned targets with the management approaches envisaged to gradually solve urban water issues, providing esthetic services and other benefits for urban populations, and that to improve urban habitat based on nature-based solutions to maintain the biodiversity in cities environment. The sponge city concept has a lot of influence on the approaching socio-ecological issues, bringing together the ideas from different disciplines to tackle many challenges linked to water-related issues across the world [45].

1.4.4.3 Global warming and insect's decline

Global warming stimulates the decline of many beneficial insects, for example, wild bees and butterflies. However, global warming shows contrasting trends on the population density of butterflies in Finland. Despite this, the general trend of the world's insect population exhibiting around 50 percent reduction. Likewise, the insect populations which are adapted to the cold climate have declined (e.g. dragonflies, stoneflies, and bumblebees), showing a general reduction in population density of pollinators such as wasps, ants, and beetles in Mediterranean regions [25, 46].

1.5 Connectivity

Connectivity is demonstrated to be a proxy for biodiversity, where species and other ecological flows are able to move through a landscape and gain diversity in their genetic structure, stabilizing the ecosystem. As a result of urbanization, habitat fragmentation leading to the extinction of the threatened species, making the network between urban green infrastructure more important. Therefore, modeling the connectivity between different urban patches in an urban area through designing green corridors is stated to be a realistic direction. Connectivity has two elements; structural and functional connectivity in which the structural connectivity is a useful indicator of functional connectivity, providing information on how to create a better connectedness of urban green spaces [47]. Different methods have been used to analyze the connectivity in an urban landscape. The graph theory method is the most useful tool by which the two concepts of inter and intra-patch connectivity is taken into account. This method is a robust metric, enabling to prioritization of the importance of each patch in the entire system [48].

1.5.1 Connectivity indices

Connectivity has three indices; (i) Number of links (L) between/among habitat patches (node) which provide information about the geographical distance between/among patches, showing the physical structure between patches, (ii) number of components (NC), where a component is a set of patches/nodes which are connected by links; a patch itself is also considered as a component, and (iii) the integral index of connectivity (IIC), which was proposed by Pascual-Hortal and Saura [48, 49]. The connectivity raises when the NL is higher and the NC is lower. Considering IIC, the degree of connectivity within a landscape can be estimated, and also the contribution of each patch into entire landscape connectivity which is the most useful tool, providing significant conceptual improvements in the decision process for planning [50–52]. The IIC shows the importance of every single patch in the overall connectivity which is based on graph structure and binary connection model, which means two patches are connected or not. Assessing this index is based on delta/d (dIIC) or the differences in the IIC value and ranges from 0 to 1 for each patch, indicating the importance of each patch with a higher value in the overall connectivity of the analyzed landscape. The dIIC value has three fractions and each fraction additively leads to the overall value. The three fractions are including $dIIC_{intra}$ or intra-patch connectivity, $dIIC_{flux}$ or inter-patch connectivity when a patch is directly connected to the other one; $dIIC_{connector}$ or stepping stone, which means if a patch/node contribute to the connection of other patches [53].

1.6 Urban microbiome

Microorganisms are a vital component of nature and can be found everywhere or so-called ubiquitous, from the human gut to natural ecosystems like oceans. They belong to bacteria, fungi, viruses, and micro-eukaryotes [54, 55]. In terms of environment, soil microbial communities are a key factor in the biochemical processes that support plant growth and other ecosystem services of GI features [56, 57]. At the urban level, the first assessment of subsurface microbial communities in a truly urban site was investigated in 1992 [58].

Edaphic variables are the factors related to the soil properties (e.g., soil pH) that affect the diversity and geographical distribution of microorganisms like soil bacterial communities; soil with lower pH (>4.5) has lower bacterial diversity [59]. As, in urban areas, the soil physical (moisture and texture) and chemical properties (pH, solid minerals, and organic matter) can influence microorganism communities [60, 61]. Notably, bacterial diversity is significantly correlated with human population density (as a proxy of anthropogenic activity) [62], indicating co-occurrence of human settlements and species-rich regions [63]; the reason for this relationship is unknown.

The results of human activities including heavy metals and other pollutants such as pesticides, fertilizers, salt, exposure to petroleum products impact the soil ecosystem, as these activities and products can alter the structure of soil bacteria communities and have a strong effect on their abundance and diversity [64–66].

Different urban soil types and their locations show that the Phyla Acidobacteria and Actinobacteria, are the most dominant soil bacteria [67]. On the other side, the most abundant fungi are related to the genera Glomus and Rhizophagus. The identified taxa are able to survive in distributed habitats and are associated with key ecosystem services (for example, decomposition and N cycling) [68].

Knowing microbial communities in GI features is important because it can help to guide urban planning for the purposes of improving urban biodiversity or bioremediation as a guide for future GI management. Identifying and understanding the dynamics of microbial communities in urban environments is thus essential for managing microbes beneficially in the context of urban sustainability [69]. Recently and in 2016 the project of Metagenomics and Meta-design of the Subways and Urban Biomes (MetaSUB) have started to characterize the composition of the microbial inhabitants of urban environments across the world. The aim of this international project is to support city planners, public health officials, and architectural designers and to quantify cities more responsive, safer places for people [70].

Growing the world's population accelerates the increase of pollutants and consequently can jeopardize the people's life by being exposure to pollutants. This can also proliferate the spread of pandemic and pathogenic microbiome. Therefore, it is imperative to adopt sustainable practices and enhance the health of the urban environment, considering the implementation of surveillance programs, discovering the genetic characterization and functional diversity of microbes in the cities [71, 72].

2. Conclusion

This chapter attempts to address the important concepts related to urban ecosystem. Urban areas are composed of natural and constructed systems. In a city, an ecological process including immigration and dispersal agents often occur in habitat patches, which are connected by corridors. Urban ecosystems have different physical and chemical properties, which highly influence species distribution, ecosystems functioning, and provide ample ecosystem services, representing sustainable tourism, saving energy, increasing the biodiversity, reducing environmental costs and providing health benefits for residents. Nowadays, however, urban development threatens human health and some elements of biodiversity, which is mainly caused by climate change especially urban heat island, environmental pollution, and habitat fragmentation. Green corridor is proposed to be pragmatic approach in connectedness of different groups of habitat structures and in turn genetic diversity. Subsurface microbial communities are also associated with major biochemical process which support plant growth and ensure key ecosystem services involving nitrogen cycling, biodegradation, and decomposition.

In an increasing urbanized world, adopting sustainable practices for communities are crucial for improving and maintaining urban environmental health. This could be helpful to guide urban planning for the purposes of improving urban biodiversity or bioremediation as a guide for future GI management. To do this, researchers from different disciplines, both in national and international collaborations can address many environmental issues and consequently human well-being in cities. To explore next, multidisciplinary, interdisciplinary, transdisciplinary projects are required to untangle the current challenges associated with biodiversity, ecosystem services, and climate change in urban areas.

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