Chapter

Urban Ecosystem: An Interaction of Biological and Physical Components

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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 are crucial for improving and maintaining urban environmental health. This chapter emphasizes the most important issues associated with 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 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 occur 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 with their non-urban counterparts, which are comprised by 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

Research on Green infrastructure (GI) started to gain more momentum from 2010 by becoming a motor theme of urban sustainability assessment for the first time, which is strongly linked to issues such as climate change adaptation and mitigation, microclimate regulation, and ecosystem services [7], suggesting that urban green infrastructure is essential for achieving sustainability [8]. Regarding the 'green infrastructure' sub-themes, analysis of the thematic networks shows that more attention has been paid to the health and well-being impacts during this period. It is also worth noting that in this period green infrastructure is closely related to conservation which is another motor theme.

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 enormous ecosystem services from nature to people and to protect biodiversity [9]. In urban landscapes, a GI may have different kind of components including green roofs, bioswales, parks, protected areas like urban forests, road verges and other types of soil-based, which are widely emerging across the world [10].

The "Green Infrastructure" has the ability to perform several function in the same spatial area. In contrast to gray (or conventional) infrastructure which usually have 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 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 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

Cities are expected to grow rapidly in the coming decades, therefore, it is important to understand urban ecosystem services and their values by city planners and policymakers [12]. Many aspects of human wellbeing and economic activities rely on ecosystem processes, from food security which is rely on maintaining soil fertility to filtering clean air and water 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 urban level

At urban level, ESs contribute in several ways to human wellbeing. They ensure a better quality of life in cities by providing a wide range of benefits such as air and water purification, local climate regulation, carbon sequestration and storage, water and food provision, higher physical and psychological wellbeing, esthetic appreciation and inspiration for culture, art, and design [14–17].

Several classifications of ESs have been provided, including; I) Millennium Ecosystem Assessment (MA) [18], II) The Economics of Ecosystems and Biodiversity (TEEB) [19], III) The Common International Classification of ES (CICES) [20], IV) and the Mapping and Assessment of Ecosystems and their Services (MAES)—Urban ecosystems, 4th report [21].

The MAES Urban only considers those ESs which are relevant to and occur in urban ecosystems, defined as socio-ecological systems composed of green infrastructure and built infrastructure [21]. The ES classification according to the MAES-Urban ecosystems is limited to only 11 out of the 21 ESs. According to the MAES Urban, freshwater and food are the main provisioning services in cities; noise reduction, air quality regulation, moderation of extreme events, regulation of water flows, local climate regulation, climate sequestration and storage, and pollination are the main regulating services; and finally, recreation, mental and physical health, and esthetic appreciation and inspiration are the main cultural services [22].

Supporting services despite being left out of both the MAES Urban and the CICES, are, namely habitats for species and maintenance of genetic diversity. These kinds of ESs are defined as intermediate ESs. Even if ESs do not produce direct benefits to human wellbeing [23], through a cascade model the linkages between intermediate ESs and final ESs can be put in evidence by investigating their indirect contribution to human wellbeing (e.g., urban parks create habitat for pollinators, which in turn provide pollination, beneficial to society) [24]. Moreover, several studies claim that urban parks constitute biodiversity hotspots and thus provide habitats for wildlife [25]. Since the interaction with biodiversity is among the activities of park visitors [26], the provision of habitats for species in urban contexts does contribute directly to human wellbeing.

1.4 Biodiversity

Urban development threatens some elements of biodiversity, yet urban areas often contain significant biodiversity, including threatened species [27].

Biodiversity loss has become a major global issue, and the current rates of species decline are unprecedented [28]. Among the different species, vertebrates, particularly mammals and birds have more attention for scientists and publics [29, 30], whereas insects were routinely underrepresented in biodiversity and conservation studies in spite of their paramount importance to the overall functioning and stability of ecosystems worldwide [31, 32]. The drivers of this decline is mainly point to habitat change as the main driver of insect declines, a factor equally implicated in global bird and mammal declines [33, 34]. Next on the list is pollution (25.8%) followed by a variety of biological factors (17.6%), whereas few studies (6.9%) indicate climate change as triggering the losses [35].

1.4.1 Biological factors

Urban development is a major threat to conservation [36]. Animals including mammals, insects, and birds are among the urban wildlife that need attention for conservation. Thus, ecological and life history traits can predict species' responses to urbanization. In new environment which totally differ from their natural habitat, they have to move and disperse in order to maintain their species development through colonization. Different species have different ability of disperse. Species with strong dispersal capacity have more probability to colonize novel environments. For example, in birds, behavioral flexibility, nest type, brain size, migration, and environmental tolerance have all been suggested to be important in allowing successful colonization of urban areas [37, 38].

Specialized species are more at risk of extinction, because they are most susceptible to habitat changes and lack of host plants while generalist species are more adaptable to environmental change, have behavioral plasticity, climatic adaptability, and broader range of host plants, food, and shelter requirements. Moreover, the generalist species are able to survive under different conditions and often colonies vacant niches and new urbanized environments. Many invasive plant and animal species have cascading effects on ecosystem, which have pervasive impacts against a number of species communities. For instance, invasive plants have negative effects on the abundance and diversity of different species especially insect species. In South Africa, a predatory fish (rainbow trout) which has economic and recreational benefit, causes the reduction in the distribution of a threatened dragonfly (*Ecchlorolestes peringueyi*) [35].

1.4.2 Habitat change

Over the past centuries, human activities such as industrialization, agricultural intensification for food production, deforestation in tropical countries, and urbanization (in the last decades) have boosted the susceptibility of specialist pollinators to land-use changes (involving loss of floral resources, nesting and hibernation sites), appears to be a determining factor in the decline of many bumblebees and wild bees. Urbanization, causing the disappearance of many habitat specialists and their replacement with a few generalists adapted to the artificial human environment [39].

1.4.3 Pollution

Pollution is the second major driver of insects decline and other species in urban areas. The factors caused environmental pollution include fertilizers and synthetic pesticides used in agricultural production, sewage (sanitary, industrial and storm sewers) and landfill leachates from urbanized areas and industrial chemicals from factories and mining sites [39].

Exposure to pesticides occur mostly in agricultural settings. However, the neonicotinoid residues have been detected from multi-floral honey collected from *Apis mellifera* hive in many countries (for example, France, Poland, the USA). A recent study reported that Neonicotinoid like Clothianidin and thiacloprid frequently detected in honeys from urban habitats, highlighting the urgent consideration of pesticide use in urban domestic pesticides, sport and amenity contexts, given potential exposure of bees and other pollinators. These, pesticides have also been demonstrated to cause and chronic toxicity to bees [40]. Fipronil, a comparatively new and widely used urban insecticide were found in runoff waters in California and were considered responsible in exerting acute toxicity to arthropods, chironomids, and other aquatic invertebrates even at very low concentrations [41, 42]. The use of modern urban insecticides such as imidacloprid, bifenthin, and fipronil also causes toxicological effects to black tiger shrimp (*Penaeus monodon*) and other crustaceans [43]. Moreover, many other kind of insecticides have a high toxicity on aquatic insects, crustaceans, and fish survival which can cause to a significant reduction in their abundance. This is even more evident for aquatic environments, where pesticide residues from agricultural and urban runoff are the major cause of biodiversity declines [44, 45].

In Germany, over the 27 years of study, about 80% of the flying insect biomass losses was caused by increases in pesticide application [46]. In a study in Paris, urbanization made a dramatic decline (−89%) of the bird species called "House Sparrows" [47].

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 [48]. Among them, heat waves, drought, and flooding are the three most important stresses having huge multi-lateral impacts [49].

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

In the recent years, climate phenomena (mainly heat-related) have become severe on agricultural crops, infrastructure and human health which have complex interactions with the urban/rural habitat. Urban heat island is one of the most climatological effects of man's modification of the atmospheric environment. The heat-related phenomena are related with heat waves and drought which produce negative effects as heat-related illness and heat-related mortality [50–52]. Moreover, long-term exposure to heat-related stresses could trigger certain types of diseases, for example; respiratory, gastrointestinal, caused by low humidity, high temperatures and lack of water for personal hygiene and household cleaning [53].

1.4.4.2 Urbanization and sponge city concept

The Sponge City concept refers to the man-made changes which positively affect the urban climate. In 2014, the concept of the 'Sponge City' established, which will be used to tackle urban surface-water flooding and related urban water management issues, such as purification of urban runoff, attenuation of peak run-off and water conservation. The concept is being developed to make use of 'blue' and 'green' spaces in the urban environment for stormwater management and control [54].

It 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. It is envisaged that related practices will enhance natural ecosystems and provide more esthetically pleasing space for the people that live and work in urban environments, in addition enabling nature-based solutions to improve urban habitats for birds and other organisms. The Sponge City concept and related guidelines and practices will provide multiple opportunities to integrate ideas from eco-hydrology, climate change impact assessment and planning, and consideration of long-term social and environmental well-being, within the urban land-use planning process [55].

1.4.4.3 Global warming and insect's decline

Global warming stimulates the decline of many beneficial insects, for example, wild bees and butterfly. In some cases, global warming has increased their population and geographical distribution in the northern part of Europe. However, due to the climate change and warming trend, the world's insect population are declining approximately 50%. Likewise, the insect populations which are adapted to the cold climate have declined (e.g. dragonflies, stoneflies and bumblebees), and negatively impacted the population of some pollinators in Mediterranean regions [35].

1.5 Connectivity

The term "Connectivity" is considered as a proxy for biodiversity or a measure of biodiversity potential [56], which contribute to habitat fragmentation alleviation and in turn genetic diversity. To improve connectivity and later ES, linking between parks and other green structures together with green corridor is proposed to be pragmatic approach, which enhance both structural and functional connectivity. Structural and functional connectivity are the two elements of connectivity. Structural connectivity may serve as useful indicators of functional connectivity and guide green space planning [57]. The graph theory approach is a useful tool to analyze connectivity, which takes both intra-patch and inter-patch connectivity into account, it is one of the most robust metrics to prioritize habitat patches to support decision making [58].

1.5.1 Connectivity indices

Connectivity is represented by groups of habitat patches (i.e., *nodes*) and the links that connect paired nodes, including the movement between them. The links encode information about the physical distances among patches and can represent structural, potential, or functional connection [59]. Different connectivity indices have been used, such as the number of existing links between patches (NL) and the number of components (NC) representing the number of groups of patches which are connected. A higher NL and a lower NC denote better connectivity. The term *component* considers a set of nodes (i.e., habitat patches) connected by links and thus defines a group of patches with possible migration within the system. An isolated patch is itself a component [58].

One of the more sophisticated indices is the integral index of connectivity (IIC), which was proposed by Pascual-Hortal and Saura [58]. The IIC allows not only estimating the current "degree of connectivity" within a landscape, but it also offers a relative ranking of patches by their contribution to overall landscape connectivity [58]. This relative ranking is considered to be the most useful tool in the decision process for planners [60–62]. The importance of each patch in overall connectivity (IIC) was assessed based on the difference (delta, d) in the IIC value when that patch was excluded from the entire system. The rank of dIIC values for each patch ranged from 0 to 1, with a higher value indicating greater importance of the patch for connectivity of the analyzed landscape [58]. Moreover, the dIIC index enables distinguishing three fractions, which additively yield the overall value. The first fraction includes the intra-patch connectivity component (*intra*), which is based on the assumption that connectivity exists within the patch. Two fractions compose the inter-patch connectivity component: *flux*, which indicates whether the node is directly connected to other nodes, and *connector*, which indicates whether a node serves as a stepping stone and contributes to the connection between other nodes [63].

1.6 Urban microbiome

The term microbiomes refers to a complex communities of bacteria, fungi, viruses and micro-eukaryotes and are an integral part of human and natural ecosystems [64, 65]. In terms of environment, soil microbial communities are a key factor in biochemical process which support plant growth and other ecosystem services of GI features [66, 67]. In urban level, the first assessment of subsurface microbial communities in a truly urban site was investigated in 1992 [68].

Microbial biogeography is controlled primarily by "edaphic variables" [69]. As, in urban areas, the soil physical (moisture and texture) and chemical properties (pH, solid minerals, and organic matter) can influence microorganism communities [70, 71]. Moreover, microbial diversity has a positive correlation with human population density (as a proxy of anthropogenic activity) [72], which always companies with the increase in species richness of some taxonomic group [73], although this relationship is still unknown.

Understanding the anthropogenic impacts on soil ecosystems is crucial because some on its impacts like exposure to petroleum products, heavy metals, salt, animal feces, pesticides, fertilizers, and garbage in urban runoff can shift abundances of bacteria within the Technosol microbiome [74–76].

Different urban soil types and their locations show that the Phyla Acidobacteria and Actinobacteria, are the most dominant soil bacteria [77]. On the other side, the most abundant fungi are related to the genera Glomus and Rhizophagus. Many of identified taxa are associated with key ecosystem services involving nitrogen cycling, biodegradation, and decomposition [78].

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 [79]. 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 [80].

Growing the world's population accelerate 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 urban environmental, considering the implementation of surveillance programs, discovering the genetic characterization and functional diversity of microbes in the cities [81, 82].

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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