7 Cities and Biodiversity: Hidden Connections Between the Built Form and Life

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Abstract

Urbanisation is perhaps the most crucial factor affecting the environment in the Anthropocene. Not only does urban development directly impact the biotic elements in the environment by causing changes in land cover and degradation of natural habitat, it also indirectly affects the living environment by altering abiotic components such as temperature, rainfall, soil conditions, humidity, etc. The biodiversity that exists within the contours of built environments emerges from the complex interactions between anthropogenic actions and the surrounding environment. While some floral and faunal species gain from human interventions, others decline in response to human-caused alterations to the habitat. The evolution of cities, and the biodiversity that they shape, is not only impacted by the geography and climate of the region, but is also affected by sociopolitical changes in the human communities that reside within the cities. Using a historical lens, and the examples of three Asian cities, this chapter examines how urban biodiversity evolved and was produced in different ecogeographic zones in the continent at different time periods. Drawing insights from these different patterns of urban biodiversity, the chapter explores the multitudinous ways in which cities and biodiversity have interacted over the years, the changing conceptualisations of urban biodiversity and the many challenges that face sustainable urban biodiversity.

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Whether one looks at the city morphologically or functionally, one cannot understand its development without taking in its relationship to earlier forms of cohabitation that go back to non-human species. One must remember not only the obvious homologies of the anthill and the beehive but also the nature of fixed seasonal habitations in protected sites, like the breeding grounds of many species of birds.— Lewis Mumford (Mumford 1956). The Natural History of Urbanization.

7.1 Urbanisation and The Evolution of Cities

Urbanisation is a process that shapes the structure, form, nature and function of cities. Defining this process has been a challenge because the criteria for what is urban vary across countries (Deuskar 2015). Researchers argue that there is no uniform or single process or pattern of urbanisation that has evolved over time. Smith and Lobo (2019) identify that the variation in the "spatial and social forms of cities, their size, functions, activities, and growth patterns" has made this difficult. Urbanisation is most often used to describe the transition of people, change in land use, economic activity and culture from a rural to urban setting (McGranahan and Satterthwaite 2014). While sociologists define urbanisation on the basis of demographical characteristics such as density, size and heterogeneity of population, anthropologists, historians and archaeologists find this limiting and define it with respect to the relationship of a city with its hinterland (Smith and Lobo 2019). Biologists, environmental scientists and ecologists define urbanisation from the perspective of changes in the environment and associated impacts. It is described as a growing threat to the Earth's ecosystems causing degradation of biodiversity and fragmentation of habitats and disturbing ecosystem services (Santangelo et al. 2018).

An urban ecological perspective of cities sees them as "emergent phenomena in which each component contributes to but does not control the form and behavior of the whole" (Alberti et al. 2003). Cities are seen as evolving from complex interactions between "human agents" (e.g. individuals, communities, the state, commerce) and "biophysical agents" (e.g. local geology, climate and other natural forces). Diverse development and land use patterns emerging from these interactions impact the ecosystems in and around the city, both directly and indirectly. Human health and well-being, in turn, is affected by these changes. More recent research explores how urbanisation affects species' evolution stemming from these changes to the environment (Johnson and Munshi-South 2017). As the Dutch biologist and ecologist Menno Schilthuizen puts it, "human actions are the world's single most influential ecological force," and the site of a lot of this change appears to be "the city's underbelly where the artificial and the natural meet and engage in ecological relations" (Schilthuizen 2018).

The phenomenon or rather the process of urbanisation can be traced to Neolithic times when the ancestor of a city, as described by Lewis Mumford, was a "tendency toward formal cohabitation and fixed residence" (Mumford 1956) in contrast to the peripatetic existence of hunters-gatherers in their quest for food and nomadic pastoralists. Mumford (1956) uses a natural history lens to discuss the history and evolution of cities. According to this perspective, early cities and urbanisation were characterised by a symbiotic relationship between human settlements and fertile agricultural land and pastures to cultivate food as well as rear animals. Urban growth was primarily along rivers to draw on these aquatic sources for food. Technological development, changes in transportation and the ability to store and process food, brought about by changes in access to, control of and transformation of energy sources, led to a shift from a symbiotic relationship to one of control over environmental resources. Security and protection from potential aggression led to another dimension of urbanisation: walled cities from as early as seventh to eighth millennium. Walled cities "retained some portion of the land within their walls for gardens and the harboring of animals for food in case of military siege."

As cities grew, urbanisation was accompanied by large-scale transformation of the environment. Paved surfaces and filling of water bodies to increase land availability changed the hydrology and microclimate of urban areas. There was a shift in the availability and choice of building materials: manufactured steel, cement, glass and composites taking over from materials sourced from the immediate local environment, e.g. stone, mud, wood, reed, bamboo, etc. Urbanisation therefore is seen as leading to transformation of the relationship of the city with its surroundings from a symbiotic one to a parasitic one and then to one of control leading to an intensive takeover of land and water resources of the surrounding areas to form an urban agglomeration rather than just a city, "the transformation of eopolis into megalopolis" (Mumford 1956).

As cities are growing, at various rates and in diverse ways across the planet, there is a sense of urgency to examine, understand and "manage" the process of urbanisation. There is increased recognition of how planetary processes such as global warming, biodiversity loss and threats to freshwater resources are inextricably linked with deepening socio-economic inequalities, threats to freedom, peace and justice (Steffen et al. 2015; Raworth 2012). This is pushing for a systemic and cohesive examination of how cities transform the environment, and how they in turn are transformed by the environment (Kondratyeva et al. 2020; Kowarik et al. 2020; Santangelo et al. 2018). Against this background, the present chapter attempts to understand the relationship between cities and biodiversity.

7.2 Urbanisation and Impacts on Biodiversity

Many studies have documented the varied effects of urbanisation on biodiversity. Urban development is regarded as one of the biggest threats to biodiversity, as it brings about fragmentation and loss of natural habitat. Scholars have pointed out that, unlike other anthropogenic drivers of habitat loss like logging and farming, the fallouts of urbanisation tend to be more permanent in nature (Stein et al. 2000) and that the impacts of urbanisation are not only due to the overall area effect but also because of the sprawl involved, i.e. the scattered and widespread nature of urban growth (Concepción et al. 2016). Urban expansion has direct and indirect effects on the ecosystem and biodiversity. Some of the direct impacts include vegetation loss and/or degradation, modified soil and microclimatic conditions and local extinction of species inhabiting the original natural habitat. The more indirect impacts are altered water and nutrient availability, increase in the abundance of non-native species and changes in herbivory and predation levels (Pickett and Cadenasso 2009). Urbanised regions often witness what is referred to as biotic homogenisation, wherein local native species are replaced by non-native species, resulting in a rich but homogenised urban diversity (McKinney 2006). The replacement of native organisms by non-native species in urbanised areas occurs due to two reasons: because (i) they are introduced through human activities intentionally or accidentally and (ii) human settlements offer environmental conditions that favour the establishment of non-native species (McKinney 2006). Novel, human-altered/human-created habitats often prove disadvantageous for native species, while they provide a competitive edge for non-native species (Byers 2002).

Organisms vary in their response to urbanisation and the changes it brings about both in the physical environment (e.g. presence of tall buildings as potential roosting sites, urban heat island effect, high alkalinity of urban soils) and the biotic environment (access to anthropogenic food resources, reduction in predation and competition levels, etc.). While some specialist/sensitive species (variously called non-synanthropes, avoiders or urbanophobes) show an avoidance response and disappear from urban habitats, some species (casual synanthropes, adapters, moderately urbanophilics) are able to adapt to urban settlements by utilising some elements of these habitats and natural resources (Johnston 2001). Yet others (exploiters, urbanophiles, full synanthropes) exploit the advantages offered by urban habitats to the extent that their numbers show high densities in urban areas and they become almost dependent on human food resources (Marzluff 2001). Highly urbanised ecosystems tend to have some common characteristics such as high human population densities, impervious sealed surface areas, built physical infrastructure, fragmented vegetation patches, soil alkalinity, average ambient temperatures and light and air pollution (Collins et al. 2000; Pickett et al. 2001), due to which cities in different regions tend be more similar to each other than to the environments that surround them (Savard et al. 2000; Clergeau et al. 2001). This homogenisation in the physical environment is also reflected in the biotic environment; species assemblages in cities are more similar to each other than to species communities in their surrounding areas (Clergeau et al. 2001; Blair 2001). Full synanthropes and exploiter species such as house mouse (*Mus musculus*), Norway rat (*Rattus norvegicus*), house gecko (*Hemidactylus mabouia*), house cricket (*Acheta domestica*), rock dove (*Columba livia*), peregrine falcon (*Falco peregrinus*), house sparrow (*Passer domesticus*), barn owl (*Tyto alba*) and chimney swift (*Chaetura pelagica*) attain their greatest densities in highly urbanised habitats, while the population sizes of casual synanthropes and adapter species like burrowing owl (*Athene cunicularia*), dandelion (*Taraxacum officinale*) and Chinese privet (*Ligustrum sinense*) peak in moderately urbanised or suburban environments (McKinney 2006).

The paradox of urbanisation is that it results in increased local biodiversity but reduced global biodiversity. This is because regional or local species richness in urbanised areas is augmented by the introduction of non-native or invasive species whereas the disappearance of locally endemic species diminishes global biodiversity (McKinney 2002; Kowarik 2011; Elmqvist et al. 2016). Specialisation in resource use, mobility and their interaction has been shown to affect species' adaptation to urbanisation, although different taxonomic groups varied in their responses (Concepción et al. 2015). For example, specialist and highly mobile plants increased in species richness in response to urbanisation, while the species richness of highly mobile specialist birds and butterflies showed decreases with increasing urbanisation levels (Concepción et al. 2015). Other studies also attest that animal taxonomic groups vary widely in their responses to urbanisation. While bird abundances generally increase in cities, often due to the increase in numbers of non-native species, bird diversity and richness tend to decrease (Chase and Walsh 2006; McKinney 2008; Shochat et al. 2010). Similarly arthropod abundance also increases (or shows no response) to urbanisation, while arthropod richness decreases (or shows no change) (Faeth et al. 2011). However, much of this data about species responses to urbanisation is drawn from studies conducted in temperate cities, which may therefore represent a skewed view of global urban biodiversity patterns. The few studies conducted in tropical cities show that species richness and abundances tend to decline in response to urbanisation, while the handful of studies conducted in cities with arid climates show that species abundances increase while species richness may increase or decrease due to urbanisation (Faeth et al. 2011). Clearly there is an urgent need for more studies in cities with different climates to achieve a more holistic understanding of urban biodiversity patterns and mechanisms.

7.3 Theorising Urbanisation-Biodiversity Interactions

Studies on ecological phenomena in urban environments reflect certain theoretical transitions in thought that occurred over the years, and it is useful to understand these conceptual phases to comprehend the current status of research in urban ecology. The initial set of studies on biodiversity in urban habitat patches compared species richness between various kinds of urban habitat patches and forest patches to understand differences between rural and urban ecosystems (Trepl 1995; Walbridge 1997), effect of patch size on species composition and richness (Klausnitzer 1993), invasion and extinction in urban ecosystems (Rebele 1994) and scale of variation in urban landscapes (Spence 1990; Blair and Launer 1997). These studies largely drew upon classical theories in ecology such as island biogeography theory (MacArthur and Wilson 1967), metapopulation theory (Hanski and Simberloff 1997) and intermediate disturbance hypothesis (Connell 1978) to use as frameworks to explain the processes occurring in urban ecosystems (Niemelä 1999). During this phase, environmental variables such as microclimatic factors, soil quality, rainfall, temperature and landscape factors were considered as the primary drivers for processes within urban ecosystems (Grimm et al. 2000). The second phase of studies in urban ecology is characterised by the emergence of the concept that human-induced impacts on the environment are long-standing and extensive and that urban ecosystems cannot be studied without considering human activities as an important driver for ecosystem dynamics. Vitousek et al. (1997), for example, state that "most aspects of the structure and functioning of Earth's ecosystems cannot be understood without accounting for the strong, often dominant influence of humanity." The "constellation" of studies (to use Mugerauer's (2010) term) in this phase variously acknowledge the role of human influence on ecosystem functioning and call for more extensive investigations into the way human beings interact with their environment, due to the inadequacy of classical ecological theory to capture all aspects of these interactions, and the need for a more integrative socioecological approach to address the coupling between anthropogenic components and environmental processes in urban ecosystems (Collins et al. 2000; Grimm et al. 2000; Pickett et al. 2001, 2008). The most recent phase of studies in urban ecology has pushed forwards the call for a more integrative socioecological approach in urban ecology to present urban ecosystems as coupled human-natural systems (CHANS approach—Liu et al. 2007) and focuses on the feedback mechanisms between human social process and the environment for a better understanding of eco-evolutionary dynamics and human-wildlife interactions in cities (Strohbach et al. 2014; Alberti et al. 2020; Des Roches et al. 2021).

While the large body of literature on urban ecology has addressed at length the role of human influences in driving biodiversity dynamics in urban ecosystems, there is relatively little work on how animal species may actuate urbanisation-biodiversity interactions. As described above, urban ecologists recognise that some species adapt well and even thrive in urban ecosystems, and based on the degree of adaptation displayed, they categorise such species as full or casual synanthropes (Johnston 2001). Ethologists refer to this phenomenon as synurbanisation and explain it in terms of the adjustments that animals make to alterations in their natural habitat (Luniak 2004). In contrast to this view that presents animals as "passive victims of changes in their habitats" (Radhakrishna and Sengupta 2020), animal studies scholars suggest that animals are *agents* in that they "actively engage with the environment" for improved chances of their survival and reproduction (Spinka and Wemelsfelder 2011; Špinka 2019). From this perspective, domestication is also interpreted as resulting from an act of animal agency; some animal species voluntarily moved towards human settlements for food or shelter and began to be utilised by humans for their domiciliary purposes (Budiansky 1992, 1994; Clutton-Brock

1994). A similar view of animal agency was proposed by Richard et al. (1989) when they characterised some Old World monkeys as "weed macaques" to explain their distributional spread and adaptive success. The authors suggested that these monkey species' dependence on human resources should not be seen as a "fall from grace" brought about by habitat destruction; instead it should be seen as an adaptive strategy that allows them to flourish near human settlements. "In short, like weed plants, weed macaques can be construed as human camp followers that may even occupy some habitats only because human disturbance is present" (Richard et al. 1989). Although scarce, ethological approaches that admit the notion of animal agency via observations on animal decision-making lend enormous insights into the dynamics of human-wildlife interactions in urban areas (Goulart et al. 2010; Beisner et al. 2015; Maibeche et al. 2015).

7.4 Socioecological Interactions in Cities

Geography, ecology, age and geopolitical position are some of the many factors that have influenced the evolution of cities and urban centres. Among the many biogeophysical factors that impact urban biodiversity, temporal dynamics is of particular import. Although well-accepted in the field of ecology, the importance of a temporal perspective is less acknowledged in studies on cities (Ramalho and Hobbs 2012). Urban biodiversity is shaped by the age of cities, as species diversity and abundance occur in response to climatic conditions, fragmentation intensities, disturbance regimes and the interactions of these various human and ecological elements. However, the rate of evolution of cities, urban sprawl and governance policies also crucially determine the continuing existence of biological communities in urban patches (Helm et al. 2006; Luck et al. 2009; Blaustein 2013). In the following sections, we examine three Asian cities from different ecoregions, at different periods of their history, to illustrate the uniqueness and universality that is involved in urbanisation processes worldwide and the nature of urban biodiversity generated by these processes. The rationale behind the selection of these particular cities was their diversity in geography, climate, age and ecology.

7.4.1 Ancient Jerusalem: Biodiversity Shaped by Religion and Geography

The earliest archaeological evidence of Jerusalem as an urban centre points to between 4500 and 3500 BCE (Slavik 2001). Present-day Jerusalem is characterised by the old "walled" city and the more "modern" new city that was built after 1948 (Slavik 2001). The natural systems from which the urban centre of Jerusalem emerged and grew are defined by mountainous regions with valleys and ridges on either side of the watershed line between the Mediterranean and the Dead Sea. The significant difference in precipitation across the city as well as exposure to the sun shapes the natural landscape of the city. The area around the watershed line forms a relatively narrow strip around which the ancient city of Jerusalem developed. This was a relatively protected area with natural springs serving as a good source of water for the population. The geology of the area dominated by diverse limestone formations was conducive for agriculture and yielded the prized building stones used in the city's construction (Avnimelech 1966). These geological and hydrological factors shape the quality of the soils in the area which in turn influences the natural biodiversity, as well as what is cultivated and how the latter modifies the native biodiversity.

Historical political events and ancient Jewish traditions have played a unique role in shaping the flora of Jerusalem; the biodiversity of the ancient (and the modern) city is a product of the intersecting forces of geography, geology and religion. Drawing from literary and archaeological sources, Shemesh (2018) found that during the Second Temple period between 560 BCE and 70 CE, the natural and cultivated vegetation within and around the city was strictly regulated by religious practices. In the inner urban space, "special ecological regulations" permitted only the growth of roses and cinnamon trees since they were fragrant, enhancing the religious and spiritual significance of ancient Jerusalem. Agriculture (local crops included vines, figs, olives and palm trees) was only practised in the hinterland outside the city, and the uncultivated area outside the city walls supported natural vegetation characteristic of the region (e.g. trees such as oak, pines, almond and hawthorns and several shrub and bush species). These species were harvested for heating, cooking and building and the areas used as grazing grounds for sheep (Shemesh 2018). Human processes thus influenced the growth, abundance and diversity of floral and, indirectly, faunal species. The study also showed that this biodiversity was significantly transformed by the Great Revolt (66–70 CE) when the Romans uprooted trees, cleared the agricultural land and destroyed the local vegetation. Cinnamon and acacia trees disappeared from the landscape.

Palynological studies from Jerusalem provide evidence of the role of palace gardens in influencing the city's biodiversity between the seventh and fourth centuries BCE. For instance, Persian rulers during that period imported tree species into the palace gardens of Ramat Rahel from other parts of their empire. This also led to introduction of the shrubby citron tree into the region. Other imported trees grown in the gardens were the cedar, birch and Persian walnut. Native fruit trees and ornamentals that were grown include the fig, grape, olive, willow, poplar, myrtle and water lily (Langgut et al. 2013). This study indicates the nature of biodiversity in Jerusalem during that period and also provides a glimpse into ways by which native flora was adapted and finally disseminated throughout the world. Creation of water features such as garden pools brought in aquatic plant diversity. Local and exotic shrub and tree species, ornamental plants and aquatic plants shaped the biodiversity of the area.

The building materials used and architectural style also shaped the urban ecosystems. Jerusalem stone used for construction (various types of limestone, dolomite and dolomitic limestone) characterises most parts of the old and new city. This stone was quarried from the surrounding limestone and dolomite hills. Centuries-old stone walls with their nooks and crannies, reservoirs and rooftops have interacted with natural systems in very dense areas and transformed into habitats for diverse local and migratory fauna and flora. This includes wet habitats, mature trees, nesting sites, refuge for molluscs, reptiles, insects and mammals. The most notable example is how the stones of the Western Wall provide close to 88 nesting spaces housing the migratory common swift nesting communities for over 2500 years (SPNI 2013). Historically the walls of the old city "constituted the point of encounter between nature and the city." But with the development of the new city, these walls are considered to have fragmented habitats and passage of wildlife and flora (City of Jerusalem's Biodiversity Report 2013).

A large part of modern Jerusalem is built on land that was used for agriculture until the nineteenth century. Vineyards, orchards and olive groves, which characterised the hinterland of the Second Temple period, are found in private and public gardens, open spaces around the city as well as monasteries. Rapid and dense urban development in the new city has displaced natural habitats and agricultural land, fragmented wildlife habitats leading to reduction in their population and eliminated several ecological corridors permanently (ICLEI 2017). On the other hand, a mosaic of new public and private green spaces in the form of orchards, groves, parks, gardens and agricultural sites have also been created leading to formation of new habitats in the built environment for diverse floral and faunal species. Conflicts of the twentieth century have created separation fences leading to physical fragmentation of the city that impacts ecosystem functions. For example, the enclosure of habitats of large mammal populations reduces the chances of their survival. Other human-natural systems interactions that are exerting selection pressure and shaping the city include efforts at mainstreaming biodiversity governance into urban planning, periodic urban nature infrastructure surveys that provide information needed to plan effectively and the active role of citizen groups in conserving open spaces (City Biodiversity Report 2013).

Human activities that have transformed the Jerusalem landscape for over close to 5000 years include nomadic pastoralism, settled agriculture, traditional orchard and grove farming, religious traditions, Jerusalem's place as a pilgrim centre for the Abrahamic religions, invasions by the Roman and Persian empires, modern agriculture practices, changing patterns of urban planning, several years of conflict and strong collective actions by citizen groups and civil society to conserve its biodiversity. Varying degrees of selection pressure have been created by grazing, traditional agriculture, planting forests of select species of trees, construction of roads and other infrastructure and, more recently, artificial lighting at night (Amichai and Kronfeld-Schon 2019). The modern city of Jerusalem has been shaped through interactions with the natural systems over centuries that have altered the hydrology, temperature and microclimate of the area, created transitions and gradients between the old and new city and with the hinterland and contributed to the emergence of the current urban socioecological system.

7.4.2 Modern Bengaluru: Colonial Production of Biodiversity

Bengaluru, a megacity in southern India, is the largest city in the country (741 km^2) and the third most populous (about seven million in 2007) (Sudhira et al. 2007). Built in 1537 by Kempe Gowda, a chieftain from the Yelahanka Nadu Prabhu dynasty, as a fortress town, Bengaluru has gone through many transformations in structure and governance over its history. Captured by British troops led by Lord Cornwallis in 1791, the city saw the development of a new Civil and Military Station (the cantonment town) just outside the old city area in 1809. Following India's independence in 1947, the two urban settlements were merged into a single urban centre, and what is now considered the city of Bengaluru, in 1949 (Sudhira et al. 2007; Kamath 2008; Pani et al. 2010).

Bengaluru is often referred to as the Garden City, due to large green spaces within the city (now fast disappearing) and its many public parks (Nagendra and Gopal 2011). Yet, the history of Bengaluru establishes that this urban biodiversity was to large extent produced and created by various regimes that built and governed the city. The British Cantonment was established in 1809 as separate from the old city (pete), in the plains towards the east, and historical maps from 1791 depict this area as largely open and semiarid, with intermittent scrub vegetation and a smattering of tall trees (Nagendra 2016). Narrative accounts from travelers who passed through the region then describe the area as open, treeless and stark (Buchanan 1807). Over the next few decades, persistent greening efforts by the administrators of the cantonment transformed this landscape. Importance was placed on the cultivation of home gardens, and British sepoys received small parcels of land for cultivation. With a focus on garnering income from their home gardens, British soldiers tended to grow fruit-bearing trees, while the officers' bungalows displayed a profusion of ornamental trees and plants (Rees 1891; Arthur 1847). In 1865, the picture that emerges of the cantonment is of considerable greenery in the home gardens and campuses of educational institutions, but "little or no jungle" outside of these private spaces (Ellis 1865). The efforts to intensively plant trees in areas "populated by British officers" continued apace, and a map of Bengaluru in 1885 "depicts trees distributed widely across the cantonment, and in lesser density across the native pete areas as well" (Nagendra 2016).

Planted vegetation in the pete and the cantonment subscribed to the differing aesthetics of the resident populations. According to Nagendra (2016), "while sacrality and productivity were the lens through which nature seems to have been viewed in the pete, recreation played a major role in shaping the cantonment's view of nature." For example, while the trees in the old city were largely native fruiting trees and sacred plants like jackfruit, mangoes, tamarind, coconut and tulsi, most of the trees planted in the public parks and along roads were exotic trees, chosen for their large flowering canopies and seasonal blooming (Issar 1998). The *Casuarina* tree, introduced primarily as a fuelwood, was grown so extensively that it "visibly altered the landscape in some parts" (Rice 1878). The wildlife populations in Bengaluru also reflected the differing biodiversities of the pete and the cantonment. While the deciduous forests around the old city harboured elephants, tigers, leopards and bear, the grasslands around the cantonment abounded in blackbuck populations, bustards and snipes (Pollock 1894). The landscape of the new cantonment area was remade not only through the assiduous planting of trees and shrubs but also by the construction of new reservoirs to meet the needs of the new immigrants and the draining of existing lakes to accommodate their recreational requirements (Nair 2005; Unnikrishnan and Nagendra 2014; Nagendra 2016). While much of the wildlife around the city and the cantonment was decimated due to hunting practices of the colonial era, the ecologically fragile grasslands around the cantonment area also disappeared over the course of that era, in response to the demands of the built environment as well as the recently planted exotic and invasive flora. Within the cantonment, the presence of smaller wildlife and domestic animals like large fruit bats, snakes, monkeys and cattle prevailed by adapting to the new habitats (Hoole 1844; Arthur 1847).

The legacy of this colonial production of biodiversity makes its presence felt to this day in contemporary Bengaluru. Over the years since the colonial era, more lakes have been drained and the lake beds converted to sports stadiums, markets, golf club, football grounds and bus stations. Small remnant grassland patches on the outskirts of the city and their fauna are threatened with destruction to make way for a film city. Amidst these changes, some wildlife like the bonnet monkey, the slender loris and fruit bats continue to persist in the ever-decreasing green patches within Bengaluru city. The existing green patches and the fauna and flora within the city are a reminder of how biodiversity can be created and destroyed due to the constantly changing goals of urbanisation.

7.4.3 Contemporary Singapore: A Biodiversity Paradox

Singapore, an island city-state in Southeast Asia, is a highly developed nation, with 392 species of birds, over 50% vegetation cover and a score of 80 out of 100 on the City Biodiversity Index. Contemporary Singapore is often held up as an example of exemplary urban biodiversity. However, with its high population density (over five million in total land area of 714 km^2), rapid rate of urban development and extensive loss of forest cover (the city lost more than 99% of its original lowland tropical rainforest within a century of its founding in 1819), the city appeared as a poor case prognosis for biodiversity even a few decades ago (Corlett 1992). Singapore's remarkable attempts to recover the loss of its native fauna and flora and overcome the effects of fragmented landscapes within the city not only offer insights into the resilience of urban biodiversity but also speak of the success of focused governance efforts. Post-independence in the 1960s, urban ecosystem development was included as a national developmental goal to promote the nation as a Garden City (Blaustein 2013). The strategies for this were multipronged: (i) 22 nature areas were set up that sustain about "255 hard coral species, 50 species of intertidal sea anemones, more than 2000 species of native vascular plants, 57 mammal species, 364 bird species, 301 butterfly species, and over 400 spider species"; (ii) the quality of nature parks were improved by adding other green patches to them as buffer parks; (iii) diverse microhabitats were inserted into nature sites to improve the complexity of the habitat and attract higher species diversity; (iv) diversified land management techniques were employed such as avoiding insecticides, reusing leaf litter, changing concretised canals to naturalised waterways to encourage growth of greenery along the sides; (v) making incremental additions to green habitat patches to improve their attractiveness to wildlife; (vi) planning interventions that accommodate urban developmental goals alongside urban greenery; (vii) designing structural barriers that maintain distance between people and wildlife yet permit visual access to biodiverse landscapes; (viii) establishing landscape connectivity measures that permit movement of fauna between fragmented landscapes, such as the tree-top overpasses, overhead bridges and underpasses below elevated highways; and (ix) implementing environmental education programmes that increase citizens' awareness of and value for urban biodiversity (Chan and Toh 2017; Tan 2017; An et al. 2020; Low 2020; NParks 2020; Jain et al. 2020; Hwang and Jain 2021).

Going forward, Singapore needs to balance the constructed biodiversity, which dominates the urban landscape, with trying to retain native species and accommodating rapid economic growth. Yu and Makoto (2017) point out that the biodiversity conservation approaches adopted by Singapore are characterised by manicured landscapes and green corridors which have been modelled on urban biodiversity planning in temperate regions. This approach has also changed the relationship of the people of Singapore with nature. While most of them support nature conservation, they identify it as manicured landscapes which have a lower conservation potential as shown from comparative biodiversity surveys (Yu and Makoto 2017). Any efforts at regenerating native biodiversity needs to consider this aspect. Moreover as tropical biodiversity has very different habitat requirements and adapts differently from temperate biodiversity, sustaining the constructed biodiversity may be a challenge as climate uncertainties increase. The historical top-down approach to urban biodiversity conservation is also raising some challenges for Singapore's future conservation efforts due to increasing inequalities and demands for more democratic governance (Hamel 2020). A more balanced, democratic, less top-down governance approach is recommended to promote urbanisation that benefits both human and natural systems.

7.5 The Urbanisation Benefits for Biodiversity

Research and discourse around urban biodiversity interactions is largely focused on the impacts of pollution on natural systems, effects of invasive species on native biodiversity, erosion of biodiversity and human-wildlife conflict. It is only more recently that some studies have begun to highlight other dimensions of human-nature interactions in urban environments such as understanding the emergence of novel ecosystems and examining human activity as a driver of evolution (Alberti et al. 2003; Johnson and Munshi-South 2017) wherein some species "are actually adapting to habitats that were originally created by humans for humans" (Schilthuizen 2018). Some researchers like Johnson and Munshi-South (2017)

Pathways		*Importance in the city when the city is surrounded by...*	
		Agriculture/ plantations	**Wildlands**
1. Provide release from pressures faced in the surrounding landscape	Interspecific interactions (predation, competition, herbivory, and parasitism)	Low	High
	Prey abundance	Low	High
	Net primary productivity (arid)	High	Low
	Net primary productivity (temperate)	Low	High
	Chemical inputs	High	Low
	Length of growing season	High	High
	Human food subsides	High	High
2. Increase regional habitat heterogeneity	Habitat heterogeneity	High	Variable
	Rare habitats	High	Variable
3. Provide stopover locations for migratory species	Stopover habitat	High	Low
4. Contribute to species genetic diversity and preadaptation to climate change	Genetic diversity and pre adaptation to climate change	High	Variable
5. Enable and bolster intensive engagement and stewardship	Opportunities for engagement in biodiversity conservation	High	Low

Fig. 7.1 Benefits provided by cities to various species (Source: Spotswood et al. 2021)

consider that "urbanization represents the best and largest-scale unintended evolution experiment." Cities and urban areas thus offer opportunities to understand the nuances of the mechanisms that are driving evolution.

Spotswood et al. (2021) draw upon examples from various locations to illustrate what they call the "biological deserts fallacy." As discussed earlier in this chapter (Sect. 7.2), rather than seeing urbanisation only as destroying native biodiversity, it is useful to recognise that urban areas can also provide benefits, support various species and create novel ecosystems. The study identifies five primary categories of benefits (Fig. 7.1). The examples used illustrate that urban biodiversity interactions in cities can lead to increase in abundance of some species by making conducive habitats available; create refuges during periods of food or water stress for animals living outside the urban areas; provide habitats that serve to release threats from predators of some species thus promoting greater survival of the latter; provide easy access to food for some species through vegetable gardens and availability of waste;

serve as stopovers for migratory birds due to presence of urban parks, forested areas and water features; and support species through diverse and heterogenous habitats such as rooftops, windows, various kinds of green spaces, empty lots, gardens, water features, etc. While considering the benefits of cities to species, it is important to understand that urbanisation-biodiversity interactions are highly species-specific. The emergent effect on species is context specific: characteristics of the species, the actions of the urban system and the nature and responses of the surrounding environment together influence the adaptation of the species to urbanised habitats. This is important to understand in the context of urban planning and biodiversity conservation.

Urban conservation biology studies on the impact of urbanisation on native species of an area provide evidence of cities supporting both biodiversity and people. For example, Aronson et al. (2014) found that while cities retained most of their native species, the abundance of the plants reduced by 75% and that of the birds by 92% compared to their pre-urban density. The authors also point out that "retaining these connections requires sustainable urban planning, conservation and education focused on each city's unique natural resources." Anthropogenic features such as land cover and city age were found to be greater determinants of the density of species in the cities studied compared to geography, climate and topography.

The role of human systems as drivers of "microevolutionary change" through application of selection pressures, particularly in urbanised environments, is well-documented. However it is only recently that evidence points to significant evolutionary change occurring over a short time scale (Alberti 2015). While evolution was considered to be too slow a process to study in the context of urbanisation, more and more evidence is emerging that evolution can be rapid. Studies are reporting observable evolutionary change even in two generations (Johnson and Munshi-South 2017). It is also being recognised that urbanisation is a unique anthropogenic activity and studies on evolutionary processes in non-urban environments are distinct and may not be relevant for understanding these processes in urban areas. More recent studies present evidence of urbanisation affecting both adaptive (natural and sexual selection) and nonadaptive (genetic drift and gene flow) evolutionary processes in diverse organisms (microbes, plants, insects, fish, mammals and birds) (Johnson and Munshi-South 2017; Alberti et al. 2017).

Alberti et al. (2017) report more than 1600 cases of distinct "signatures" of phenotypic changes across species (animals, plants, fungi and microorganisms). Based on an analysis of drivers of change, it was found that the changes were higher and faster in urbanising compared to non-urbanising and natural systems. The study also found that the strongest drivers were interactions between organisms and humans or with other organisms brought into the city by humans (Alberti et al. 2017; Schilthuizen 2018). Urban ecologists are also reporting evidence of a convergence of species of soil microbes, plants and animals across cities and natural areas in various continents: similar species of these organisms playing similar roles are being reported in various cities (Schilthuizen 2018).

Globalisation and advances in communication technology facilitate rapid spread between cities of innovations and technology in transportation, infrastructure construction, architecture, building materials, urban planning, etc. These provide the selection pressure for evolutionary changes in species leading to better adaptation by some to the new conditions and disappearance of others who are not able to adapt. While, in non-human-dominated ecosystems, evolution is driven by natural drivers, in cities evolutionary change appears to be driven by human decisions and interactions. This extract from Menno Schilthuizen's book *Darwin Comes to Town* (2018) summarises the role of human-natural systems interactions in cities well:

> *We build cities full of novel structures made of glass and steel. We irrigate, pollute, and dam waterways; mow, spray, and fertilize fields. We pump greenhouse gases into the air that alter the climate; we release non-native plants and animals, and harvest fish, game, and trees for our food and other needs. Every non-human life form on earth will come across humans, either directly or indirectly. And, mostly, such encounters are not inconsequential for the organism in question…So what does nature do when it meets challenges and opportunities? It evolves. If at all possible, it changes and adapts. The greater the pressure, the faster and more pervasive it does so.*

7.6 Sustainable Urban Biodiversity and Its Challenges

Urbanisation has been with us since Neolithic times, but what is new is the scale, rate and intensity of the process. As centres of economic growth, cities and urban areas are becoming more and more powerful drivers of environmental change. Urban processes of the present and future and urban living are being seen as "shaping planetary dynamics" (UN Habitat 2020). Asian and African cities are projected to be at the epicentre of urban growth. Studies report that 96% of urban growth is projected to take place in Asia and Africa with the level of urbanisation in Asia set to increase from 37.5% in 2000 to 59.2% in 2035. At a country level, India, China and Nigeria are projected to account for 35% of the increase in global urban population by 2035 (UN Habitat 2020).

Asia has cities at various stages of urbanisation. While Singapore, Seoul, most cities in Japan and larger cities in China are witnessing a slowing of population growth, smaller cities in China and cities in other Asian countries including India are exploding with increasing in-migration from rural areas. Comparisons of today's Asian cities with cities of the Global North note that they exhibit much higher densities. This is attributed to geographical constraints (e.g. Tokyo, Hong Kong and Mumbai), rates of infrastructure development not being proportionate to rate of spatial expansion and population growth. Some of the main challenges that emerge from this include affordable housing, increased densification of cities, rising water and sanitation needs, solid waste management, transportation and, underpinning all this, high energy demands which are predominantly met by fossil fuels (Yue-man 2011; UNESCAP 2013). Other features characteristic of modern Asian cities are incentives for economic growth through creation of special economic zones, industrial corridors where infrastructure is provided and labour and environmental regulations are relaxed. This results in a spillover into pressure on land and water resources which transcends the administrative boundaries of cities and has regional impacts. Apart from cities drawing on resources from their immediate surroundings, studies report that multiple urban areas may also depend on the same regions for their resource requirements. This has implications for urban planning which needs to go beyond city to regional planning taking cognisance of the finitude of resources and limits of planetary boundaries (Seitzinger et al. 2012).

It is projected that by 2025 half the world's expansion in urban land will occur in Asia, primarily in largely rural countries. Studies on impact of urbanisation in 41 tropical countries document significant increase in pressure on resources in rural areas as a result of rise in deforestation accompanying changes in land use and land cover (Hughes 2017). Resource extraction, waste disposal and changes in land use and land cover from and in these surrounding areas can lead to fragmentation, erosion and loss of habitats of living species in these areas (ADB 2014). As discussed in Sect. 7.4 and 7.5 the urbanisation-biodiversity relationships and interactions are complex and multidimensional. The interactions lead to transformations both within and beyond the city. In some cases, as discussed earlier, cities see a rise in species richness and abundance of non-native species including habitats conducive for species considered invasive. At the same time, it has potential impacts on species dispersal as a result of habitat fragmentation. In this context an important distinction is made by Güneralp and Seto (2013): impact on biodiversity is determined not just by size of urban areas but also by the spatial configuration and heterogeneity in urban land use. As demand for land increases, it is accompanied by deforestation with implications for biodiversity loss, release of greenhouse gases, changes in rainfall patterns and effect on ground and surface water resources. Urbanisation is also accompanied by contamination of water bodies by wastes from cities, providing conditions for thriving of potentially invasive species. Compared to cities of the Global North, a large part of the urban areas in Asia, particularly South and Southeast Asia, fall within biodiversity hotspots. This not only drives a direct loss in biodiversity in areas where land use and land cover undergoes changes, but it also potentially impacts biodiversity in surrounding areas and in the region as a whole.

Emphasis on the need for urban planning that integrates biodiversity conservation and regeneration is widely being called for by civil society, citizen groups, the scientific community, UN agencies and international NGOs such as ICLEI—Local Governments for Sustainability as well as UN agencies (UN 2019; ICLEI). Exemplars of these are presented from Asian cities considered as well-planned and managed (e.g. Singapore, Seoul), in the form of creating new green spaces, maintenance and regeneration of existing urban green spaces, promoting food forests, home and kitchen gardens, living roofs, etc. While they enhance urban biodiversity and cause evapotranspiration-based cooling of the urban heat islands, they can be a serious challenge in cities where density of population is increasing and there are serious spatial constraints on land. Mega coastal cities like Mumbai, Dhaka, Singapore and others are particularly vulnerable in this regard. Projected sea-level rise, effects of intense monsoons and unpredictable extreme weather events add to the challenges of these cities (UN Habitat 2012).

A number of approaches and solutions are being proposed to find ways to integrate ecological principles into urban planning, e.g. nature-based solutions in some cities in China, Vietnam, Laos and India (Lechner et al. 2020; ICLEI) and maintaining provision of ecosystem services within cities (Hughes 2017). In Kochi, Panjim and Mangaluru which are non-metro cities in India, projects are underway with a focus on improving ecosystem services through urban forestry and wetland restoration efforts and mainstreaming biodiversity conservation in urban policy and planning (ICLEI—INTERACT-Bio). Some critics argue that most of the urban planning and management in Asian cities is top-down, and does not recognise or accommodate ground realities -, "way of life" of most people and communities in the city and the unique identity of each city; an identity built by historical, cultural and ecological diversity. The technology focus and requirements of many of these plans are complex and cost intensive which deepens the inequalities in most Asian cities. Lack of adequate public consultation of the plans makes them incompatible with the culture, values and priorities of local communities (UN Habitat 2012).

The future of urbanisation in Asian cities has significant implications for biodiversity regeneration and sustainability. Urban planning, approaches to land use, architectural styles and construction practices will all need to be aligned to the geography, climate and deeply unequal socio-economic-ecological realities of each city and region. A democratic, participatory and bottom-up approach to planning is almost an imperative to ensure that these realities are incorporated in the planning and actions in these urban areas. Above all, there cannot be a uniform "model" of addressing urban biodiversity interactions. It has to emerge from the sociocultural and ecological understanding of the place.

Building socioecological resilience of the linked human-natural system in urban centres for a climate-uncertain future needs adaptive capacity. In thinking and planning for the future of human-natural systems and their resilience, two points merit particular consideration—some of the changes that human systems are creating in this process of urbanisation are irreversible and, the adaptations by life on Earth to this "selection pressure" and its impact for the future of life on the planet.

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