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Nature of Cities and Nature in Cities

Prospects for Conservation and Design of Urban Nature in Human Habitat

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Abstract

Cities have scarcely been considered in the environmentalist agenda, except when they are invoked as examples of environmental degradation. This should change because human beings and their creations, of which cities might be the most prominent or obvious, are an inextricable part of the natural world. The way our species has distributed itself on the planet and how it will do so in the future has great implications for its impacts on the global environment, not all of which are gloom and doom. This chapter introduces a broader conception of nature in cities and nature of cities, inclusive of issues relevant to both the Global North and South. Cities certainly confront challenges owing to old and decrepit infrastructure, or needed infrastructure that remains unbuilt as cities expand with massive in-migration. Infrastructure of all types, including its social, ecological, and technological dimensions, provides services to urban residents but can also yield disservices, hazards, and risk. These features demand new thinking about services in cities, the role of nature, the meaning of conservation and possibility of restoration, as well as urban design that is appropriate for urban systems in the Global North and South. A broader concept of nature in cities, as well as a vision of the nature of cities, holds promise for justice, diversity, and sustainability of this future habitat for most of humanity.

Introduction: Cities and Their Changing Environments

The human imprint on the natural environment is massive, extending to nearly every piece of the Earth's land surface, oceans, and atmosphere (Vitousek et al. 1997; Kareiva et al. 2007). This impact is such that a new geologic epoch is under consideration—the Anthropocene—to reflect the pervasiveness of

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human influence on patterns and processes of the Earth system (Zalasiewicz et al. 2011; Ellis and Trachtenberg 2014). Humans have rapidly come to dominate all ecosystems (Boyden 2004; Ellis 2015) and the continued pressure of the extractive, manipulative, and productive activities of this keystone species portends severe consequences for Earth's species and nonhuman nature unless the trajectory is deliberately changed.

Of all ecosystems on Earth, cities arguably display the imprint of human design and intention to the greatest extent. Cities are places where human activities are concentrated, where the majority of the world's human population makes its home, and where the creative work of people is most evident (Grimm et al. 2008; Seto et al. 2012). Yet many cities in the Global South exhibit startling inequality, and many southern urban ecosystems are under tremendous stress (Baviskar, this volume; Swilling and Annecke 2012; Schindler 2017). Cities feature the infrastructures constructed for provision of food, water, shelter, energy supply, and transportation, and these constitute the form of an urban area. There is an unseen portion, such as the built infrastructure that is deliberately buried (e.g., sewers, electrical cables, or gas lines) as well as the social, political, and institutional components of society. Cities also feature urban nature. Encouraged or even designed, urban nature provides food or shade, or simply recreation and enjoyment. Preserved, produced, or "restored" (as in a remnant forest patch or a coastal wetland), as well as unrecognized or "accidental," urban nature persists or is reestablished by ecological and evolutionary processes in hidden places.

Cities are home to the majority of the world's population, and that proportion is projected to increase to 70% by 2050 and perhaps to near 90% by the end of this century (UN 2014). The history of urbanization, beginning 7,500 years ago with urban settlements in Mesopotamia (Redman 1999), has been a story of increasing perceived independence from nature, harnessing the benefits of technology and exploiting emerging hierarchies of wealth and power to replace the services once delivered by surrounding ecosystems—or the need to access them directly (Elmqvist et al. 2013b).

Cities have historically been dynamic centers of innovation and culture. At the same time, the emergence of impersonal and instrumental social relations in cities and the concomitant weakening of "traditional" social relations and institutions characteristic of agricultural communities has been met with trepidation in many societies. These changes in social order or social norms coupled with the obvious environmental problems accompanying a sudden rise in population density in rapidly urbanizing areas mean that cities are commonly perceived as dirty, dangerous, and centers of vice. Examples fitting both extreme images can be found among the world's cities. In fact, large cities have been shown to be centers of innovation out of proportion to their population (Bettencourt et al. 2007). Environmental conditions in many cities of the developed world have improved dramatically as industrial activities have relocated and governmental regulations on air and water quality have been

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implemented. A trend toward greening of these cities is reflected in the expansion of parklands and open space, "million tree" programs, and installation of "green infrastructure" projects (Tzoulas et al. 2007; Pataki et al. 2011; Hansen and Pauleit 2014). Yet in other parts of the world, particularly cities in decolonized societies, the extreme rapidity of urban expansion driven by massive migrations to cities by the rural poor and high intrinsic rates of increase in urban populations (Fox 2012) have outpaced the capacity of local governments to provide basic infrastructure (UN 2014). Such cities are suffering from air pollution, poor sanitation, and lack of clean water, among other stresses. The growth of urban populations without a concomitant expansion of infrastructure and services has indeed contributed to the production of dangerous and unhealthy urban environments.

The urban century—one in which we will see the movement of the vast majority of the Earth's human population to cities—coincides with other accelerating changes in the environment. Perhaps most urgent among these are climate change and increases in the frequency and severity of extreme events. The resulting collision course is one that presents opportunities and in which an ecologist's perspective—along with the perspectives of social scientists, planners, designers, engineers, and builders—has potential to move cities along a trajectory toward greater livability, resilience to extreme events, and sustainability (Childers et al. 2015; McPhearson et al. 2016). The ecologist who clings to an environmental protectionist view, however, presents a perspective in conflict with the needs of the twenty-first (urban) century. At the very least, protection of unaltered nature (if there is such a thing) involves trade-offs that may be untenable within urban centers and even suburban areas. Further, most urban ecosystems and urbanization processes are resource intensive; hence cities displace environmental problems to commodity frontiers and waste sinks, extending trade-offs beyond city boundaries to regional and global hinterlands.

An urban ecosystem includes all of the swatches of green that may be recognizable from an airplane window, here interchangeably termed green infrastructure or urban nature, but also the designed and built parts—the gray infrastructure—and the designers and builders themselves. This entire urban ecosystem is worthy of intentional care by urban residents and managers. It also is deserving of the attention of ecologists, environmentalists, designers, engineers, and others who are engaged in the process of envisioning, building, reforming, retrofitting, and managing the human habitat of the twenty-first century—the city.

We will explore the current and projected trends in urbanization and the issues those trends raise concerning equity, access, and services provided by cities in the Global North and South. The distinction between industrialized states in the North and developing countries in the South was made by the Independent Commission on International Development Issues (Brandt 1980). While we recognize the shortcomings of this distinction given the increasingly blurry boundaries between North and South, and the existence of many cities

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and neighborhoods that disrupt this neat classification, we retain it as a heuristic device reflecting an objective trend. In short, cities in the Global South persistently exhibit higher levels of inequality with regard to urban nature and services, as well as incomplete infrastructure systems that serve only a fraction of the population.

We review the causes of environmental degradation in cities, which are well understood. We then ask, what is the role of urban infrastructure and urban nature in providing services to people or protecting them from hazards? What are the prospects for managing unplanned-for risks of the future? Finally, we consider how the traditional views of conservation and restoration must be modified to apply to cities, by explicit acknowledgment of the importance of human design and human intention in the concept of urban nature. The concepts of diversity, justice, and sustainability are woven throughout the chapter.

Trends in Urban Development

The urban population is growing as the rural population stabilizes or even declines. The number of very large (>10 million) and large (5–10 million) cities is increasing globally, although cities of 1–5 million inhabitants have the fastest growth rate. An excellent special feature in *Science* illustrates some of these trends (Wigginton et al. 2016). As urban populations grow, the extent of urban areas grows even faster (Seto et al. 2012) so that more land is being transformed to urban uses than ever before. In 1950, 24% of the world's 233 countries were urbanized (i.e., the urban population was greater than the rural population) and only 8% had urban populations that were >75%. In 2014, these proportions increased to 63% and 33%, respectively; by 2050, over 80% of countries are projected to have more than half of their population living in cities, with about half of these countries being >75% urbanized.

Perhaps obvious, but still sobering, this grand transition to urban living will essentially be complete by the end of the century. When the vast majority of the world's population is concentrated in cities, urban land use will most likely occupy less than 5–10% of Earth's land surface, leaving vast areas sparsely populated (Brondizio and Le Tourneau 2016). Does this represent the most sustainable configuration for both Earth's ecosystems and its human population? Currently, the mean population density on Earth[1] is 97 individuals/km^2 and if all of these people were concentrated into cities occupying 5% of the land surface, mean urban population density would be 970 people/km^2—orders of magnitude lower than the world's densest cities and comparable to most U.S. cities today (Figure 6.1). Even with global population rising to 11 billion by the century's end as some of the highest projections suggest (Gerland

[1] Assuming population of 7.3 billion and land surface area of 150 million km^2, of which half is habitable.

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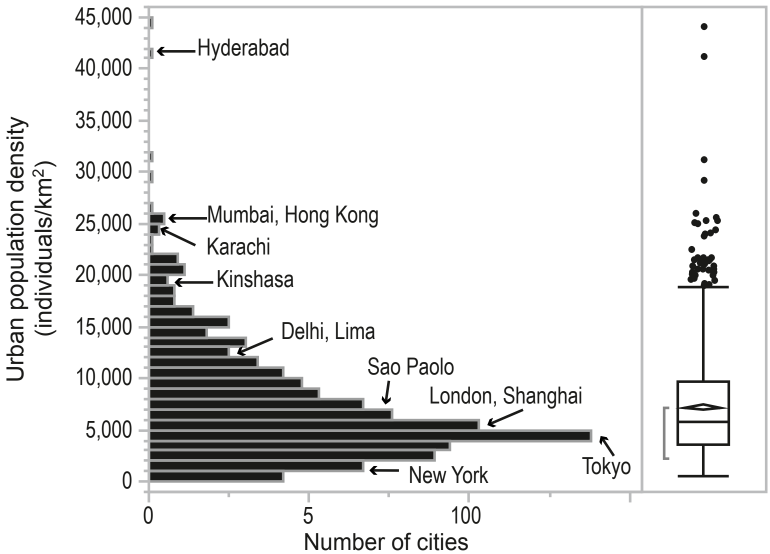

Figure 6.1 Frequency histogram of population density for the world's cities, showing several well-known cities. Data from Demographic 2016; city definitions were for large metropolitan regions including, in some cases, multiple cities. Standard box plot with mean, median, confidence intervals, and outliers is shown at right.

et al. 2014), if concentrated across the world's cities (we use the range 5–10% of the Earth's habitable land surface), population density would be ~725–1550 people/km^2. The world's cities today vary tremendously in their population size and density. Median urban population density is 5800 people/km^2, equivalent to the population density of Shanghai, China (Fig. 6.1), with a minimum of 500 people/km^2 in Knoxville, TN, U.S.A., and maximum of >44,000 people/km^2 in Dhaka, Bangladesh. Nevertheless, this arithmetic exercise illustrates that projections for city size and land area could feasibly accommodate the urban population surge, all else equal. Of course, all is not equal, a point we shall explore in more detail later.

A second important question is raised that is perhaps more central to the goals of this volume. What will the environment of cities, and the external ecosystems on which they depend, be like when the vast majority of the world's population lives in cities? Must expanding cities in previously rural countries experience the stages of environmental degradation and hazard seen in the early twentieth century in today's urbanized countries, or will they implement measures to improve local urban conditions? Will recent trends toward urban greening, urban agriculture, and open space preservation take hold in these developing cities, or will the simple provision of basic clean air, water, and sanitation overwhelm them? Will all urban populations have access to the external resources required to keep them functioning?

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How will cities vary in their dependence upon external ecosystems, and how distant will their reach extend? What measures can be taken to reduce this dependence while ensuring the adequate provision of services to urban populations? These questions have been asked and answered before, in part. For example, Asian cities in China, Korea, and Japan have traced evolutionary paths from poverty-related problems to pollution-related problems to consumption-related problems at different paces and points in the past decades of rapid urbanization (Bai and Imura 2000). As cities aspire to reach a more sustainable "ecocity" phase, Bai argues that strong leadership and planning can allow them to circumvent less desirable states (Bai and Imura 2000; Bai 2003). In contrast, for many cities in weaker economic regions, where meeting basic human needs in cities is still a priority concern, the question of how to accelerate transitions is urgent but not well understood. These examples serve to illustrate the wide variability in developmental challenges for cities of the Global North and South.

The foregoing discussion on density is relevant to these questions because the distribution of people among the world's cities and the distribution of those cities and their associated power and wealth is now heterogeneous, and the resulting inequality between and within large regions of the Earth (i.e., Global North and South) may persist or worsen. Today's transition to urban living is not experienced evenly across the globe, with trends favoring rapid urbanization in the Global South and fastest growth in African, Asian, and Latin American cities with less than one million inhabitants (UN 2014). North America, the Caribbean, and Europe are already >75% urban; most increases in the urban population are expected to occur in low-income and lower- to middle-income countries. For instance, low-income countries are now 30% urban and expected to become 40% urban, while lower- to middle-income countries that are now 39% urban will rise to 57% urban by 2050 (UN 2014). Most of these lower-income countries are in the Global South and many are in warmer climates, where problems of excess heat, inadequate sanitation, and vector-borne diseases already, and will increasingly, challenge public health.

Other trends associated with urbanization exacerbate problems of resource scarcity and environmental deterioration. One in particular is the proliferation of informal settlements in the world's fast-growing cities. The expansion of these settlements can be attributed to migration from rural areas by people seeking refuge from conflict and/or environmental degradation, and natural increase (i.e., births minus deaths) (Fox 2012; UN 2014). Informal settlements are commonly situated in peri-urban areas or hazard-prone areas, such as on steep slopes, or in stream or river floodplains. As a result, informal settlements are particularly vulnerable to global environmental change (Romero Lankao and Qin 2011). In addition to their disproportionate exposure to environmental hazards, residents of informal settlements typically lack access to resources (e.g., drinking water and electricity), services (e.g., waste collection and public transportation), and economic opportunity (Figure 6.2).

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Figure 6.2 Informal settlements, sometimes called slums, favelas, or shantytowns are a common feature of rapidly urbanizing regions in the Global South: (a) A town in Northern Mexico where residents have appropriated power by hooking in their own lines (photo by Nancy B. Grimm). (b) Favela da Rocinha, a shantytown built on a steep slope in Rio de Janeiro, Brazil (photo by Donatas Dabravolskas). (c) This stormwater "drain" in San Juan, Puerto Rico does not connect to a storm sewer system (representing inadequate infrastructure) and rapidly overflows during rainstorms (photo by Nancy B. Grimm). (d) An informal settlement in Marrakech, Morocco, with a discontinued sewer infrastructure project (photo by Seth Schindler).

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Today, there are thousands to tens of thousands of cities distributed widely across the habitable world that vary in population size, demographics, city age, urban growth rate, history, spatial extent, percentage open space, urban form, as well as in the sociocultural, geographical, ecological, and political environment in which they are evolving. As yet, there is no consistent or agreed-upon typology of cities, no "urban biome" (Pincetl 2015) that can be used to predict how cities might drive or respond to global environmental change. But we know that human activity drives environmental change and, under the current sociotechnical regime, the consumption and fossil-fuel burning that is concentrated in cities contributes to climate change. Collectively, cities are responsible for over two-thirds of greenhouse gas emissions, for example, although those in the Global North are vastly more prominent contributors. We can expect that as urbanizing countries continue to develop, they will have improved access to fuel and transportation and will consume greater amounts of meat, all of which are associated with increased intensity of fossil fuel burning. Cities also are important contributors to land degradation associated with food production and extraction of natural resources, given that they largely depend upon external ecosystems for these services.

Urban areas increasingly experience the impacts of global environmental change. Many of the most populous and rapidly growing cities worldwide are located in low-lying coastal areas and along river floodplains (Mansur et al. 2016). While affording the benefits of water delivery and access to transportation and trade, these regions are at increased risk from sea-level rise and coastal, riverine, and urban flooding, which are exacerbated by extreme weather-related events like typhoons or hurricanes, tsunamis, river flooding, and storm surges (De Sherbinin et al. 2007). Others are located in water-scarce regions, such as the North American West, where water must be appropriated—often from afar—and where extreme drought and heat events are substantial risks (IPCC 2012; Pachauri et al. 2014). Indeed, urbanization and climate change are on a collision course. Extreme events are the most immediate way that people experience climate change and urban areas are particularly vulnerable to such events, given their location, concentration of people, and increasingly complex and interdependent infrastructures (IPCC 2012). Infrastructure offers the possibility for protection from extreme events, but evidence suggests the vulnerability of outdated infrastructure (in the developed world) and the inadequacy or even absence of infrastructure (in the rapidly urbanizing world) to provide resilience in the face of an uncertain future climate. We assert that a resilient infrastructure is one that incorporates ecological, social, *and* technological elements. This concept of social-ecological-technological systems (SETS) (Grimm et al. 2016; Redman and Miller 2016) is foundational to a new sustainability research network focused on urban resilience to extreme events (McPhearson et al. 2016), recognizing the capacity of people and their institutions to not only harness and invent new technological solutions but to coproduce services with the natural environment.

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The Urban Social-Ecological-Technological System

The creation of an urban ecosystem is first and foremost about transforming land from what was there previously to a new system state (Grimm et al. 2017). The reasons for this transformation may be obvious, but should be stated: people need places to live and work (shelter), a means to get around (transportation), a steady supply of food and water, and energy sources to carry out their work and enjoy the comforts of modern life. Waste products need to be removed rapidly and efficiently and protection afforded from natural hazards. Such needs are met by infrastructure: the basic fabric of the urban built system (Ramaswami et al. 2016). These infrastructure systems have specific purposes, usually the provision of basic needs (e.g., water provisioning) or the solution to environmental challenges associated with concentrations of people (e.g., waste removal).

Initially, urbanization might involve pushing back nature, disrupting and degrading existing ecosystems, but cities continue to be ecosystems nevertheless (Golubiewski 2012), albeit dramatically transformed ecosystems. Sometimes nature is left in place or invited back in: some rivers, lakes, forest patches, or coastal wetlands may remain relatively unaltered; gardens and parks are planted with trees, shrubs, grass, and flowers; artificial ponds are created, and feeders are set out to attract birds. These components of the urban ecosystem continue to perform their functions (meaning: the ecological processes associated with their existence, such as primary production or pollination), perhaps less robustly than before, but blithely unconscious of human intent.

Together, the elements we think of as nature, the blue, green, and turquoise infrastructure (Childers et al. 2015), as well as the built environment and the beings who built and arranged it all, make up an urban SETS. Over time, urban SETS evolve and change, experiencing increases or decreases in human population, introductions of new technology, changes to urban form, continued loss or degradation of urban nature, or sometimes reversals of those trends through restoration of wild nature. Yet, there is a basic urban identity: the prevalence of built infrastructure; the concentration of people, their activity, and the products of their enterprise; the dependence upon external systems; and the production of wastes that are discharged to air, soil, and water and often transported to external ecosystems.

The Urban Environment: Benefits and Services

Cities provide for the basic needs of their inhabitants via built infrastructure (an expanded definition of infrastructure includes the knowledge systems and institutions responsible for decisions about infrastructure, as well as the biophysical underpinnings of the system). Ecosystem services, usually defined as the benefits derived by society from natural ecosystems, also contribute to human needs and well-being (Elmqvist et al. 2013a; Haase et al. 2014; Grimm

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et al. 2016). Does the alteration of the preexisting system during urbanization always mean that nature's services are lost or degraded? Are infrastructure services necessarily more or less valuable than nature's services? Can services from green infrastructure (nature-based or ecosystem-based services) replace the services of gray infrastructure, and if so, under what conditions? Because most literature on ecosystem services in cities primarily addresses the services derived from ecological functions of urban nature, such as parks and remnant patches (e.g., Gómez-Baggethun and Barton 2013; Haase et al. 2014; McPhearson et al. 2015; but see Grimm et al. 2016)), there are scant data available to compare the multiple values of services delivered between the built and nonbuilt, although such a comparison is a common means of valuation of nature's benefits (i.e., replacement value) (NRC 2004). A simple overview of services (Table 6.1) suggests that services from infrastructure and services from nature are interdependent and extend to scales much larger than the city itself, thus revealing its ecological footprint (Rees and Wackernagel 1996). Scholars of urban ecosystems are converging on ideas of ecosystem services in cities that recognize the following:

- Ecosystem services of urban nature are different from those of nonurban nature; they often are considered to be degraded.
- People are actively involved in the production, management, and extraction of ecosystem services from urban nature (Reyers et al. 2013; Andersson et al. 2014).
- Ecosystem services are often inequitably delivered.
- Built infrastructure provides services that in some cases substitute for local ecosystem services (i.e., shelter; see Table 6.1).
- Most ecosystem services in cities are the product of ecosystem processes that are modified by infrastructure and the built environment.
- Services in urban SETS are often dependent upon processes that take place far from the urban center where they are consumed.
- Urban residents are usually unaware of the prominent role external ecosystems play in providing the benefits that they enjoy in their cities.
- Protection of urban nature is challenged by the high cost of land in cities (a conformational and historical inertia), competing needs (multiple other urban problems), and a lack of connection with and understanding of the potential benefits of urban nature.

Making the conservationist case for nature preservation in cities based on their value in providing benefits to people is thus complicated by at least two issues. First is the broad perception that urban nature is degraded and that it is therefore unable to provide services. Although demonstrably oversimplified, until recently this has been a common view. The second challenge is the complexity of what constitutes "services" from urban nature and urban infrastructure, whether gray, green, or in between (Grimm et al. 2016), and whether they can substitute for one another. The service-providing elements listed in Table 6.1

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Table 6.1 A list of purposefully contrasting elements of built infrastructure and (nonurban) nature that provide some basic services, defined as benefits derived by people from either built infrastructure or nature. Service delivery to urban populations nearly always involves some combination of the two extremes. Note that all services ultimately are derived from nonurban ecosystems as the original source (e.g., water supply) or for raw materials to construct infrastructure. Most services from built infrastructure require large inputs of energy to construct, maintain, or operate.

Service	Built infrastructure	Nonurban nature
Water supply	Dams, wells, interbasin transfers (pipes, canals)	Streams, springs, rivers, lakes
Water delivery	Canals, pipes, plumbing	Streams, springs, rivers; gravity
Water quality assurance	Water treatment plants	Protected lakes and reservoirs, wetlands, rivers
Shelter	Housing, other buildings	Caves, trees*
Food provision	Food processing and storage plants, delivery systems	Farms, orchards, animal populations
Transportation	Roads, canals, public transit lines	Rivers, lakes, oceans,* land routes,* and human-powered or passive transport systems
Energy supply	Power grid, power plants, delivery systems	Fire and biofuel, sun,* wind*
Protection from flooding	Sea walls, river levees, drainage canals	Coastal wetlands, dunes, floodplains, natural terraces
Sanitation, waste removal and processing	Sewers, wastewater treatment plants, solid waste incinerators	Rivers,* soils*
Recreation and experience of nature	Parks, zoos, gyms, gardens, swimming pools, cinema, television, virtual reality	Forests, deserts, grasslands, rivers, lakes, streams, beaches, etc.

*minimally useable without built infrastructure

are purposefully contrasting; clearly, no one would propose that the use of rivers and soils should replace sewerage and wastewater treatment for sanitation. Yet, in some cities constructed wetlands (which contain elements of both built environment and nature and thus are hybrid green-gray infrastructure) are used to further purify water below wastewater treatment plants (Sanchez et al. 2016). In contrast, cities like New York are choosing (or at least debating) the restoration of coastal wetlands, dunes, and oyster beds (green infrastructure) for protection over sea walls (gray infrastructure) (Rosenzweig et al. 2011).

Nature-as-infrastructure should not be embraced as a second-best option for residents of informal settlements, and hence a justification for unequal exposure to environmental hazards. Nevertheless, there is a diverse range of ways in which informal settlements and their residents are related to infrastructure and integrated into the urban fabric (Bishop and Phillips 2014). In some instances, residents of informal settlements develop complex infrastructure systems incrementally on an ad hoc basis (Silver 2014) and informal yet visible and institutionalized systems mediate the relationship between formal and

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informal infrastructure systems (Demaria and Schindler 2016). Thus, as urban residents experiment with the materiality of the city and incrementally expand infrastructure systems in innovative ways (driven by need, availability of resources, and capacity), a complex urban landscape emerges. This landscape is characterized by the interconnection of hybrid infrastructure systems and uneven distribution of access, which combine core gray infrastructure systems with informal subsystems that in turn incorporate nonhuman nature in a range of ways (Björkman 2015). The planting of trees to provide shade, the development of community gardens and compost to support urban food production—even the installation of multiple, distributed, constructed wetlands to reduce discharge of pollutants—all may provide moderate solutions to problems of urban heat, food security, and waste disposal in absence of infrastructure development by local governments. In sum, a wide range of potential services is being discovered and increasingly promoted, albeit not necessarily by municipal authorities—as alternatives to the unifunctional, gray infrastructure approach.

The Urban Environment: Disservices, Hazards, and Risks

Urban nature provides quantifiable benefits to residents of the world's cities (Haase et al. 2014), as does built infrastructure. Both urban nature and built environment, however, can be associated with harmful outcomes to people. Design of infrastructure and urban nature must consider both benefits and costs in terms of human health and well-being as well as trade-offs and synergies between distinct classes of services (Bennett et al. 2009). In most cities of the Global North, air quality has dramatically improved over the past decades. Yet, despite careful planning, many growing Asian cities are struggling with air pollution resulting from expanding vehicle ownership and increased consumption of fossil fuels. Worsening air pollution continues to present a serious public health risk as industrialization fuels urban growth in other parts of the world.

Changes to the land surface also may have negative outcomes. For example, the coverage of large areas of land with heat-absorbing materials like asphalt and concrete, along with concentrated energy use in urban areas, can result in local climate change called the urban heat island that is far in excess of any increases in temperature yet experienced globally. The same impervious surfaces rapidly convey rainwater that falls on them, resulting in damaging floods. Even urban nature can be detrimental to human health and well-being: wetlands may attract insect pests, unmanaged streams and lakes can become polluted or eutrophic, unpoliced parks and open space may become dumping grounds or provide cover for criminals.

Often, it is the absence of human intervention that degrades urban nature, given that pollutants and waste produced in cities can become concentrated in areas that are not actively managed. Streams and rivers are integrators of the landscapes they drain, and lakes and wetlands as low places in the landscape

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receive the materials transported by streams and rivers. For example, Hale et al. (2014) report a dominant signal of residential landscape fertilization in stormwater of Phoenix, Arizona (U.S.A.) whereas Kaushal et al. (2008) show that leakage from sanitary sewers dominates the chemistry of stormwater in Baltimore, Maryland (U.S.A.). While entire cities can be subject to environmental hazards (Mansur et al. 2016), they are commonly borne disproportionately by the poor (Baviskar, this volume; Bullard 2000; Zeiderman 2016).

Sanitary solid waste disposal in the world's slums is haphazard at best, putting populations at risk of disease associated with inadequate sanitation (UN 2014). Complex informal systems of solid waste management have evolved in most cities in the Global South, as waste management has been somewhat of an afterthought for municipal officials who prioritize economic growth. Informal-sector waste workers tend to mediate the flow of recyclable material from small and inefficient formal-sector waste streams to formal and informal-sector recyclers. Informal-sector waste workers were historically not recognized by authorities in many cities, but their contribution to waste management was tacitly encouraged. This changed as the proportion of recyclable material in municipal solid waste increased over the course of a decade of increasing commodity prices. The result has been conflict over access to waste between large-scale, capital-intensive, waste-management firms and informal-sector waste workers (Demaria and Schindler 2016). The challenge is to integrate these systems in ways that ensure livelihoods for waste workers as well as sanitary and environmentally sustainable waste-management outcomes. Of course, sustainable outcomes with regard to solid waste are not assured in the Global North, given that some waste management consists of shipping the hazards elsewhere, often to poor regions.

Alteration of the natural environment and installation of infrastructure are sometimes intended to provide a measure of protection for urban residents against hazards. The service "protection from harm" is encompassed in a massive literature on disaster risk reduction. Hazards to which urban populations are exposed include natural hazards, such as storm surge or tidal flooding in coastal cities, riverine flooding, earthquakes, or fire; and anthropogenic hazards (either caused or exacerbated by human activity), such as urban flooding, water pollution, or contamination from wastes. In most cases, gray infrastructure is built to withstand all but the rarest of such events. Yet when these protections fail, the consequences can be severe. There is increasing interest in using urban nature to bolster or even replace the protective function of gray infrastructure through the use of what are called ecosystem-based approaches, nature-based solutions, or ecosystem-based adaptation (Royal Society 2014), and in the United States are generally encompassed by the preferred term green infrastructure. Green infrastructure includes stormwater retention features such as rain gardens, green roofs, bioswales, wetlands, and retention basins, but also street trees and parks maintained for aesthetic reasons.

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Risks to urbanites from hazards are increasing. Urbanization itself sometimes removes natural protective ecosystems, such as coastal wetlands. Exposure to coastal flooding under future climate scenarios without protective ecosystems is estimated to be double the exposure with such ecosystems left intact (Arkema et al. 2013). As the frequency and magnitude of extreme weather-related events increases (Munich RE 2017), our sense of security from infrastructure designed for a 1% probability event is likely misplaced. Under climate change, the future is uncertain (Milly et al. 2008; Miller et al. 2011) and a 1% event may actually happen as frequently as once in five or ten years. A recent study using proxy records for historical sea levels (to AD 800) shows that coastal floods that occurred once every 500 years in the past are now occurring once every 24 years in New York City (Reed et al. 2015). Thus, the capacity of extant urban infrastructure to provide protection against hazards that are increasing in frequency and/or magnitude is to some extent itself uncertain. Finally, hazard risk is increasing in some areas of the world because more people are settling in exposed places, and the rate of population increase in these areas is outstripping the capacity of local governments to provide services. Thus, there are both detriments and potential benefits to urban nature, the former usually arising from lack of management and the latter, which will be taken up in the final section of this chapter, representing a suite of potential solutions to the challenges of global environmental change.

Conservation and Restoration in Cities

Nature preservation, conservation, and restoration are the challenges that an environmentalist takes on. But what is it that we want to preserve or restore in cities? What is nature in cities? Do we include green infrastructure such as a green roof or a curb cut or a rain garden in this conception? Does our backyard qualify? Is the neighborhood park or a community garden worthy of preservation? Or are just the forest patches, remnant grasslands, unburied streams, or surviving wetlands eligible for the environmentalist's concern? In fact, the traditional nature protectionist doesn't even ask these questions; these pieces of urban nature are "fake nature" (Ross et al. 2015) and unworthy of preservation or restoration.

Cities are thought to have "novel nature" (Pincetl 2015) or "middle nature" (Tanner et al. 2014), concepts that recognize the idea that culture and nature are coevolving (Boyden 2004; Barthel et al. 2010). Much of urban nature fits the description of "designer ecosystems" proposed by Ross et al. (2015), reflecting the control that people as the designers exert and the extent to which they intentionally alter pattern and process. But some urban nature is "accidental"; that is, it arises independently of human intention (Palta et al. 2017). Examples include the grass and weed expansion in abandoned home lots (Ripplinger et al. 2016) and wetlands that have arisen in the once-dry channel of the Salt River in Phoenix as a result of increased outdoor water use and altered hydrodynamics

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in the river channel (Palta et al. 2017). Promoters of the intrinsic value of nature as a sole rationale for its preservation, "nature protectionists" (Miller et al. 2011), may have trouble with these concepts and may refuse to acknowledge urban nature as nature. A value inculcated in many conservation groups, and possibly in much of ecology, is that nature is virtuous and humanity profane (Ross et al. 2015), and that humans are a threat to nature. If this is so, how can urban nature, with only the occasional "accidental" escape from control by humanity, be thought of as nature?

When we ask these questions, it is instructive to think about how our species came to be so dominant on the planet. In a brilliant and fascinating conceptual treatise, Ellis (2015) argues that it is "sociocultural niche construction" and the long-term intertwined processes of human cultural evolution and engineering of the environment that underlie our species' transformation of the biosphere. He states: "It is no longer possible to understand, predict, or successfully manage ecological pattern, process, or change without understanding why and how humans reshape these over the long term" (Ellis 2015:287.) Whether one agrees with the mechanism or not, Ellis's admonition to incorporate an understanding of social and cultural drivers is most certainly relevant to the coevolution of society and urban nature (see also Boyden 2004), and is probably good advice for nonurban nature as well. We should target urban nature in our conservation efforts, both for its intrinsic value as nature and for its utility as a provider of services to urban residents. The intrinsic value of urban nature may be called into question, but as Hartig and Kahn (2016) note, we must both "experience nature in cities and experience cities as natural."

In an urban world, daily exposure to nature is reduced compared to that of early hunter-gatherers or even early agrarian societies. This reduction is particularly severe in the United States, where awareness of the perils of the so-called "nature-deficit disorder" (Louv 2008) has spurred the "No Child Left Inside" movement. Research shows a clear benefit to people's health and well-being from nature exposure. Opportunities for people to interact with nature can benefit their health through improvements in air quality, encouragement of physical activity, increased social interactions leading to a greater sense of community, and stress reduction with direct impacts on health and performance (Hartig et al. 2014). Even views of green space from classrooms have been shown to reduce stress and improve scholastic performance in high-school students (Li and Sullivan 2016). Recognizing this, many cities are working to both reduce urban sprawl and increase the amount of green space, two objectives that may at times conflict with one another. The challenges of "renaturing" cities (Hartig and Kahn 2016)—affording people greater opportunity to interact with nature—include not just enhancing the amount and quality of urban nature but ensuring access to it, a way for people to connect (Shanahan et al. 2015). Citizen science or "civic ecology" (Krasny and Tidball 2012) engages people in gardens, tree planting, or as friends of parks, resulting in positive outcomes from contact with nature as well as helping to change people's

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thinking about their relationships with nature. A study of community gardens in Stockholm has shown how people's interaction with ecological systems has evolved over many years, resulting in a "socioecological memory" that builds resilience (Barthel et al. 2010).

Management of urban nature has mostly focused on remnant ecosystems (which may be refuges for species that cannot survive in urban habitats), parks, and open space. This approach targets a small portion of the total urban land area and as a result, does not address the larger issue of the absence of nature from the fabric of cities and city residents' daily lives. To some extent individual landowners address this through their own decisions about local nature (i.e., in their gardens or yards), but a broader, landscape-scale management paradigm is seldom applied. Our understanding of the spatial and temporal scales of how ecosystem services are provided is underdeveloped (Andersson et al. 2014) and failure to understand the history of ecosystem service change may lead to inaccurate assessments of trade-offs (Tomscha and Gergel 2016). Recent work suggests that large tracts of undeveloped land are necessary to preserve ecosystem services while small, distributed bits of nature may be needed to ensure nature contact for urban residents (Stott et al. 2015). Does this necessarily apply, however, to all situations and all cities? For example, how urban nature can be woven into the too-rapidly developing fabric of explosive urban growth in Asia and Africa is an open question, but we have little to go on (McHale et al. 2013) with respect to cultural attitudes that shape ecosystem services, the kinds of designs that might be effective in these settings, the interactions between immigrants and the places in which they settle, and whether the governance structures exist to ensure the place of urban nature in an ever-expanding city.

The conservation of urban nature raises multiple issues of environmental equity and justice (see also Baviskar this volume). For example, the creation of extensive natural amenities can drive poor people from their neighborhoods as land prices increase or homes are demolished to make way for parks. The largest housing demolition in Delhi's history resulted in the displacement of approximately 150,000 people, whose community on the banks of the Yamuna River ostensibly posed an environmental hazard and was ultimately transformed into a park (Bhan 2009). In San Juan, Puerto Rico, proposed dredging of a long-abandoned canal and the creation of a wide riparian area will be put in place at the expense of several homes. This large riparian park could be a new, attractive amenity in a city at risk of gentrification. However, a local community organization has been working to ensure that the displaced homeowners will be relocated within their neighborhoods and that access to new housing and amenities will be restricted to current residents, mostly poor homeowners in eight neighborhoods that border the canal.

Across many cities, vegetative cover, which provides shade and respite from heat, habitat for birds, and other benefits, varies tremendously among neighborhoods. Hope et al. (2003) found that vegetation abundance was

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correlated with wealth in Phoenix, Arizona (U.S.A.); this relationship was recently supported for multiple neighborhoods in Southern California, where tree species' richness was significantly higher in wealthy than in less affluent neighborhoods (Avolio et al. 2014). Schwarz et al. (2015) went so far as to say the "trees grow on money" when they found support for the relationship between tree cover and income across seven U.S. cities.

Who benefits from the conservation of urban nature? The above studies suggest that in many cities it has been the wealthy—presumably people living in already clean, healthy neighborhoods with few other problems. The trend toward urban greening, it appears, is often unevenly applied. Further, the question must be asked, both at scales of individual cities as well as across the broader spectrum of world urbanization, whether conservation of urban nature can be given a high priority when confronted with the plethora of other issues with which the urban poor and the world's slums have to cope (Baviskar, this volume). We believe the answer lies in fully embracing the utilitarian view of urban nature, but even more importantly the view of social-ecological-technological coproduction of services as a means of building resilience to shocks and stresses. We address this in the next section on design.

Restoration has been conceptually challenging for ecologists confronted with altered ecosystems with no clear "natural" or "reference" analog. This is certainly the case for urban systems, and yet there continue to be efforts at restoration in cities. Efforts to restore streams, especially the excellent work of Australian stream ecologists and hydrologists (Walsh et al. 2005, 2012; Burns et al. 2012), involve the reduction of damaging peak flows that are a consequence of impervious surfaces in cities that are directly connected (through water flow) to streams. Yet, much of the literature on stream restoration concentrates on scarcely urbanized watersheds, since impervious areas over ~30% are considered too "far gone" to be restored. Note that most cities have >50% impervious cover, and many European cities are in the range of 70–80% impervious cover. While these restoration efforts should certainly continue, there also is reason to rethink the concept of restoration in highly altered urban environments. Instead, designing waterways with combinations of technological and ecological features specifically intended to be multifunctional (i.e., deliver multiple benefits)—that is, intentionally creating urban SETS infrastructure—may ultimately represent a more sustainable pathway (Ahern 2011; Larson et al. 2013).

Design of Urban Nature for Services and Resilience

> Imagine a city that is a part of nature, not apart from nature. —P. Mittenmeier[2]

The challenges facing cities of both Global North and South are massive, and against that backdrop, focusing on environmentalism—in the traditional

2 https://twitter.com/Conserve_WA/status/647100689756262402 (accessed Sept. 27, 2017).

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sense—can seem the height of hubris. Yet the strengthening of ecological elements in cities may be key to enhancing their chances of weathering these challenges. First, however, we have a long way to go in changing the attitudes and deeply embedded biases of ecologists, managers, and urban residents about what is nature and what is natural, in cities. Second, urban residents must be sensitized to the impact that their consumption patterns have on their regional and global hinterlands, that is, their role as drivers of global change. We need concerted efforts at environmental education that take on ecology in and beyond the city (Elser et al. 2003; Banks et al. 2005; Bestelmeyer et al. 2015) and civic ecology opportunities that engage citizens (Krasny and Tidball 2012), improving their environmental literacy, and perhaps moving them closer to stewardship that reconnects urbanites with the biosphere (Andersson et al. 2014). In both cities of the North and South, the interaction of residents, decision makers, and planners with regard to the design and promotion of urban nature's services holds potential to foster resilience and sustainability in the face of an uncertain future.

Designing Urban Nature in Northern Cities

It is probably no accident that the rise of interest in green infrastructure and nature-based solutions has occurred in cities of the United States and Europe, where transition from the industrial city to the sanitary city occurred during the last century (Grove 2009). These cities have enjoyed improved local environmental conditions including cleaner air, expanded and protected parks and open space, the best available wastewater treatment, and so on. Several cities are at the forefront of conceiving and implementing changes to institutions like zoning and park management, restoring urban streams, improving public transportation, offering bike lanes and pedestrian zones, and other positive trends for enhancing livability in cities. Initiatives like the World Wildlife Federation's Earth Hour City Challenge asks cities to reduce their emissions, and the Rockefeller Foundation's 100 Resilient Cities provides funds for cities to hire a Resilience Officer to implement changes in city structure to enhance resilience. There is much to be learned from Scandinavian cities, which consistently are at the top of the world's greenest and most eco-friendly and sustainable cities. Indeed, developing concepts of using coproduced ecosystem services from urban nature and its stewards to build urban resilience through the strengthening of people's connection to their local environment and promotion of ecological processes that underpin services emanate from urban ecology programs in Sweden (e.g., Andersson et al. 2014).

In many cities of the Global North, however, particularly where the transition to urban living occurred in the last century, urban infrastructure is aging and in need of replacement. A recent report in the United States gives infrastructure a failing grade for providing adequate protections for city populations (ASCE 2013). Furthermore, zoning and other protections are proving inadequate in

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the United States. In many flood-prone areas, new development has sprawled into flood plains, where federally funded levees and national flood insurance afford a false sense of security (for an analysis of recent flooding in Louisiana, see Colten 2016). Traditional risk-based engineering approaches to infrastructure design that focus on minimizing the risk of failure by investing in hard, structural, resistant elements—fail-safe designs—are inappropriate in the fast-changing environment of the Anthropocene. Instead, more ecologically based designs, which may be viewed as safe-to-fail (Ahern 2011), allow for some failure but minimize its consequences (Park et al. 2013). These designs should be appropriate to place, equitable (neither disproportionately benefiting nor putting at risk any particular segment of the population), and incorporate ecological as well as technological elements. For example, the combination of sea walls in highly built-up segments of a coastal city with restoration of marshes along less built-up coastlines may help to reduce the impacts of storm surge on neighborhoods.

Building resilience to climate extremes, that is, the capacity of SETS to experience and weather shocks from extreme climatic events without losing fundamental structure and function (Walker et al. 2004; Folke 2006), is urgently needed if we are to avoid, or even minimize, the debilitating impacts of such events in uncertain futures. This concept of resilience emphasizes multifunctional, diverse, participatory, and flexible solutions, which are best achieved by incorporating nature into design (Ahern 2011; Childers et al. 2014; Grimm et al. 2016).

Designing Urban Nature in Southern Cities

Rapidly growing cities in the Global South present serious social and ecological challenges, particularly as they attempt to meet basic needs for the urban poor and in doing so, exacerbate air and water pollution. The rapidity of urban growth has resulted in increasing flows of energy and material to sustain cities and this has strained local and regional ecosystems. Most cities in the Global South exhibit significant informal expansion, and in some cases municipal authorities have sought to connect informal settlements with formal infrastructure systems, while elsewhere they have sought to inhibit residents of informal settlements from accessing formal infrastructure systems. Regardless of whether municipal authorities decide to integrate or isolate informal settlements, the design of infrastructure and the extent to which it is resilient to future shocks and stresses is likely to differ from northern cities. Furthermore, it is important to note that there is no compelling reason to assume that solutions that have worked in the North can be effectively transplanted to the South (McHale et al. 2015).

There is an unequivocal necessity to enhance well-being and reduce environmental degradation in cities of the South. In developing regions, nearly one-third of urban residents live in informal settlements or slums, and in most

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of these cases the basic infrastructure for water delivery and waste removal is inadequate or absent (UN 2014). Small-scale, distributed, green infrastructure that fits the particular setting may be a cost-effective solution that improves resilience (Schäffler and Swilling 2013), certainly as opposed to the alternative, which is often the sluggish and uneven expansion of gray infrastructure. One problem, however, is that green infrastructure is typically not valued as infrastructure and its potential benefits in alleviating poverty, creating jobs, and ameliorating pollution are scarcely known (Schäffler and Swilling 2013). Instead, ecological elements are seen as a nuisance (if they are not managed) or a luxury (if they are) rather than as infrastructure. Thus, a reconceptualization of what constitutes viable infrastructure is needed.

The trajectory of urbanization in the Global South is unlikely to mirror the urban experience of North America and Europe (Roy 2009; McHale et al. 2013). This is in part because there is neither time nor resources to construct massive water treatment works, stormwater drainage systems, or wastewater treatment facilities. And, as we have seen in the case of Louisiana in the United States, a false sense of security can be associated with protective infrastructure constructed today based on traditional formulas of minimizing failure probability, given future increases in frequency and magnitude of extreme events. The urgency of the infrastructure needs in these situations argues strongly for the flexible, multifunctional, low-cost, replaceable, safe-to-fail type of options that ecosystem-based or hybrid solutions can potentially provide. In other words, planners are not faced with an either/or choice between gray and green infrastructure, but they should try to incorporate elements of each to develop unique hybrid and flexible systems that are city-specific and address localized contexts and challenges. Flexibility can be achieved through experimentation and continual monitoring and adjustment, as advocated by Ahern et al. (2014). In their transdisciplinary design and planning model, ecosystem services goals are stated and prioritized (decided by all stakeholders), an experiment is designed (which means a project is actually constructed), indicators and metrics are chosen to measure goals, monitoring is used to assess efficacy, and the process is iterated so that adjustments can be made when goals are not met. This kind of process is very similar to adaptive management used in natural resource management, but the design and construction of infrastructure has seldom involved all or even one or two of these steps. The pervasive view that infrastructure must conform to a standard design, usually gray or highly engineered and seemingly impervious to failure, must be reconsidered in favor of the more flexible alternatives that green infrastructure or urban nature can provide.

Personal Reflections

Schindler: Delhi's ecology is under tremendous strain and this generates hazards to which the poor are disproportionately exposed. The city and its ecology

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have changed tremendously since my first visit in 2006. Wasteland has become elite retail space, forests have become illicit landfills, landfills are slated to become parks. One colony I have visited regularly over the years is home to scavengers that collect recyclable material from an adjacent mountainous landfill. The houses are made of tarpaulins and wooden beams and, until recently, the lanes were dirt which meant that they became impassable during the monsoon season. The colony was long and thin, sandwiched between rows of two-storey brick buildings on one side, and a major road on the other. However, between the colony and the road there was a meager strip of greenery that provided residents with some space to momentarily escape from their cramped quarters and relax or play cricket. This space has been razed to make way for the construction of a metro station, and a massive incinerator now looms behind the brick houses. The community is being squeezed and its residents are losing a competition with the metro for space and with the incinerator for waste. For residents there is no escape from a localized ecology characterized by the absence of green space, leachate that flows out from the landfill toward the Yamuna River, and poor ambient air quality. Their exposure to environmental hazards is compounded by insecure livelihoods and lack of tenure security. Sadly, this sort of multifaceted vulnerability is all too common, and the livability of the future city depends on the emergence of novel human–environment interactions. Urban nature is diverse and can take many forms, but when conceived as more than a resource whose exploitation can facilitate economic growth, it has the potential to augment livelihoods and enhance well-being.

Grimm: I have lived in the Phoenix, Arizona metropolitan area for nearly forty years, although I grew up in the verdant eastern portion of the United States. As I drafted this paper, I was enjoying a mini-sabbatical in Stockholm, the home of the only urban national park in the world. Walking through those woods with their majestic, several hundred year-old oak trees, I marveled at the social structures and care in this socioecological system that have, over centuries, allowed these creatures to persist (Barthel et al. 2010). Phoenix seems to be a wholly designed and engineered city; even its flora is largely imported (Hope et al. 2003). Yet exposure, enjoyment, and recreation for its citizens and education about the desert environment are made possible by the recent formation of a community organization, the Central Arizona Conservation Alliance (CAZCA), dedicated to protection, education, research, and restoration of the Phoenix area desert mountain parks—a cluster of volcanic outcrops that have escaped the voracious sprawl of this desert metropolis primarily because of unsuitability for rapid housing development. CAZCA may function as the middle governance entity envisioned in Andersson et al. (2007), because it can coordinate the individual efforts of park managers, community groups, and conservation organizations and act as a representative in working to achieve protection goals through municipal and county governments. Indeed, a vision of county parks that ring the Phoenix metropolitan area with a hiking trail, the Maricopa Trail, passing through them uninterrupted, could emulate the urban national

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park of Stockholm. Instead of centuries-old oaks, the area features centuries-old giant cacti—saguaros—and other unique vegetation of the Sonoran Desert. This is urban nature on the wild end of the spectrum, but the necessity for social engagement among the four million inhabitants of the Phoenix metro area makes it urban nature all the same.

Conclusions

Our reflections capture threads woven through this chapter, contrasting the challenges associated with ensuring fundamental environmental rights in cities of the South and the continuing trend of reintroducing nature (and ensuring its conservation) in cities of the North. Both challenges benefit from a systems perspective that recognizes the interwoven SETS dimensions of cities, their infrastructure, and inhabitants. As the world's population has become increasingly urban, the distribution of wealth, urban density, and pathways of urban development have become extremely heterogeneous, leading to inevitable inequalities in the distribution of environmental problems both within and among the world's cities. Increasing risk from global environmental change adds further stress. Amplifying the benefits and services that can be provided by a SETS infrastructure, while reducing the hazards and disservices, is a key imperative for cities in the face of such changes. Design of a SETS infrastructure that incorporates urban nature appropriate to the setting is likely to be more flexible, multifunctional, replaceable, safe-to-fail, and cost-effective than the monumental gray infrastructure that characterizes urban development of past centuries. Both in terms of replacing the aging infrastructures of older cities and providing new infrastructures for rapidly urbanizing regions, multiple services and greater resilience may be expected from a SETS-sensitive design that incorporates urban nature.

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