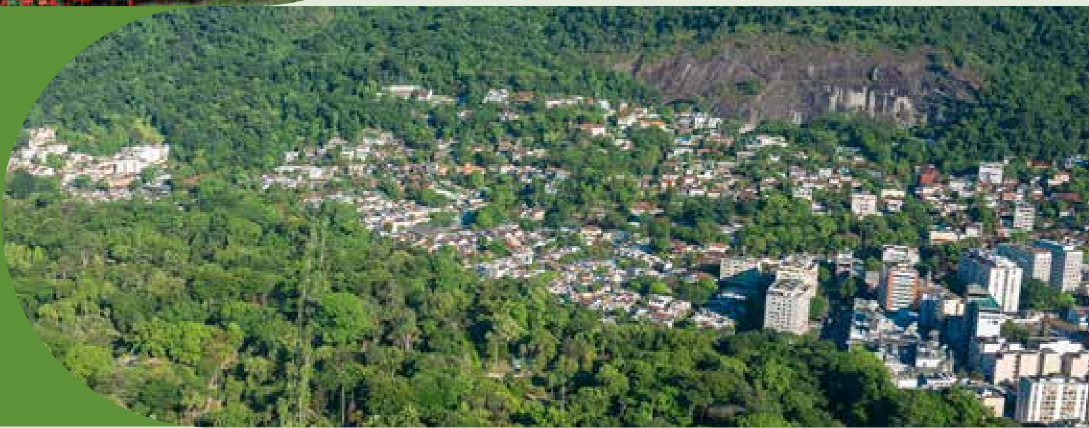
Urban Nature and Biodiversity for Cities

POLICY BRIEF

September 2021



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Acknowledgments

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Lotus flowers and Finches. Photo: kool99


Bird's eye view of Shanghai. Photo: URF

1. Introduction

This is the urban century; over half of humanity now lives in cities and more than 70 percent are expected to do so by 2050 (Liu et al. 2020; UN DESA 2018). An estimated 60 percent of urban areas that will exist in 2050 have not yet been built (United Nations 2013). Thus, the design of future cities—and the evolution of today's—will determine the health and well-being of billions of people (Ramaswami et al. 2016; Munro and Grierson 2018; Vidal et al. 2020). At the same time, the coming decades are predicted to witness the most dramatic reduction in biodiversity since the dinosaurs went extinct 65 million years ago (IPBES 2019a). The rapid growth in human populations in cities and their use of land, water, timber, and energy—often on biodiversity-rich terrain—are a major driver of these losses (Elmqvist et al. 2013).

Today, cities are hubs of social interchange, economic vitality, and innovation. Yet the pace and scale of global transformation in where and how people live pose threats to biodiversity and nature that demand serious attention. Against this backdrop, urban leaders have a significant opportunity and responsibility to safeguard the well-being of their constituents and the natural systems on which they depend. In today's complex world, it is natural—and sometimes necessary—to compartmentalize sectors and realms of experience. Thus, urban planning traditionally occurs without much consideration of biodiversity and nature. Similarly, conservation planning often ignores cities as places with little to no biodiversity. There are multiple advantages to recognizing both the many societal benefits of nature in cities and the ways in which cities and urban cultures can support biodiversity. It is therefore imperative that cities are designed in ways that maintain the provision of ecosystem services and that national and international conservation plans consider urban centers. (World Bank Group, 2021).

This report presents the scientific basis for why and how incorporating biodiversity and nature into urban design is crucial for achieving sustainability, livability, resilience, and equity in cities and beyond. After defining key terms and concepts (remainder of section 1), this report examines what is at stake regarding urban nature and biodiversity (section 2), explores what urban leaders can do to promote them (section 3), and offers some practical tools and approaches for incorporating urban nature and biodiversity into urban decision-making (section 4).

1.1. What is urban biodiversity? What is urban nature?

Urban biodiversity is the *variety and abundance* of life in a city (Puppim de Oliveira et al. 2014). *Urban nature* refers to all life in a city, including expansive and relatively wild green and blue spaces, as well as gardens, green roofs, street trees, birds, and butterflies (Turini and Knop 2015). Different elements of *urban nature* can be home to different types and amounts of *biodiversity*. For example, a city park with forested trails, a stream, and a pond may be rich in urban biodiversity because it is home to many types and large numbers of trees, birds, frogs, fish, and beneficial microbes. In contrast, another nearby city park that features sports fields and picnic areas is also an example of urban nature but supports little biodiversity. Another way to think of this is that *urban nature* defines the extent of the geographic space, while *urban biodiversity* refers to specific attributes of that space, such as the species richness or abundance of individuals (see **box 1** for definitions of other important terms).

1.2. Why do urban biodiversity and urban nature matter to people?

Natural features (e.g., mountains, rivers, lakes, coastlines, forests, wetlands, trees, birds, and bees) help create a unique, thriving region that draws and retains residents

Box 1 GLOSSARY OF TERMS

While terms such as *nature, green and blue space*, and *biodiversity* may be used interchangeably in colloquial settings, each has a distinct definition. The precise definitions given here are those used in this report; they integrate meanings associated with the terms in the literature (see sample references).

Blue space: Areas that feature surface water prominently, such as ocean beaches or cliffs, wetlands, lakes, and rivers and their surroundings (Nutsford et al. 2016).

Ecological planning: A type of landscape design that is cognizant of biodiversity and nature. In urban contexts, it is planning that recognizes the mutual dependencies of people, nature, and biodiversity for livability and well-being. It entails smart use of nature-based solutions to urban problems; the blending of "gray" and "green" solutions to create sustainable cities; and investing in nature to attract talent and further investment so as to yield competitiveness and vitality (Steiner et al. 1988).

Ecosystem disservices: The negative impacts of nature on people, such as allergic reactions from pollen, diminished air quality from emissions of some plants, and disease spread by some wildlife. Good management of urban nature can maximize the desired benefits that contribute to human health and well-being while minimizing negative impacts (von Döhren and Haase 2015).

Ecosystem services: The benefits people obtain from nature, such as provision of food, timber, flood protection, climate stability, mental and physical health, recreational opportunity, beauty, and cultural, intellectual, and spiritual stimulation (Guerry et al. 2017). A related, broader term is "nature's contributions to people" (Díaz et al. 2018; IPBES 2019a).

Green infrastructure: Elements of nature infused in urban design that serve utilitarian needs of cities, such as flood protection, water infiltration and purification, noise reduction, and cooling (Fairbrass et al. 2017).

Green space: Relatively extensive areas with vegetation; in urban settings, this includes parks, botanical or zoological gardens, community gardens, allotment areas, cemeteries, and golf courses (Jansson and Polasky 2010).

Natural capital accounting: An accounting framework that quantifies stocks and flows of natural capital for a given region in a given time period (e.g., the amount of standing forest in Costa Rica or Germany in 2020 and the flow of benefits therefrom). The accounts may report values in biophysical or monetary terms. The UN System of Environmental Economic Accounting (SEEA) is the most well-known natural capital accounting approach (Ruijs, van der Heide, and van den Berg 2018). UN SEEA has adopted gross ecosystem product (GEP) as a metric for (1) revealing the contribution of ecosystems to society; (2) guiding investments in conserving and restoring ecosystems; and (3) evaluating such investments and tracking progress (Ouyang et al. 2020).

Nature-based solutions: Targeted investments in nature aimed at solving particular problems. Such solutions generally support human well-being by maintaining a comfortable and secure physical environment, with protection from flooding, extreme heat, and other climate risks. They also provide additional ecosystem services beyond those targeted, often referred to as co-benefits (van den Bosch and Sang 2017).

One Health: A collaborative, multisectoral, and transdisciplinary approach—working at the local, regional, national, and global levels—that seeks to achieve optimal health outcomes by recognizing the interconnection between people, animals, plants, and their shared environment (CDC 2018).

Urban biodiversity: The variety and abundance of life in a city. It is most commonly and simply measured in terms of ecosystem types and extents (e.g., lakes, grasslands, wetlands, and forests) and in terms of the types and abundances of plant and animal species within them (Puppim de Oliveira et al. 2014).

Urban ecosystem services: Those benefits generated by urban nature and biodiversity, and not those generated by nature outside of a city, such as provision of safe drinking water, from which the city also benefits (Hamel et al., forthcoming).

Urban nature: The totality of plant, animal, fungal, and microbial life in a city, including expansive and relatively wild green and blue spaces, as well as small elements of more domesticated life embodied in gardens, natural roofs, street trees, and flowering shrubs (Bratman, Hamilton, and Daily 2012).

and visitors alike (World Bank 2019). Urban biodiversity and urban nature influence the well-being of city-dwellers and the livability of cities via multiple pathways (Keeler et al. 2019). Benefits provided to people by urban nature and biodiversity and are often referred to as *urban ecosystem services*. The Millennium Ecosystem Assessment framework divides ecosystem services into four categories: provisioning services (products obtained from ecosystems), regulating services (benefits obtained from regulation of ecosystem processes), cultural services (nonmaterial benefits obtained from ecosystems), and supporting services (services necessary for the production of all other services) (Millennium Ecosystem Assessment 2005). The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) has refined these concepts, emphasizing the central, pervasive role that culture plays in human-nature connections and operationalizing the role of indigenous and local knowledge in understanding nature's contributions to people (Díaz et al. 2018; IPBES 2019a).

Recognizing these diverse and vital benefits can help solve multifaceted urban problems, reduce risk and expenditures, address inequity, improve the livability of cities, and yield multiple advantages from one intervention (see **box 2** on nature-based climate adaptation in cities). Street trees, rivers, and wetlands cool the air and can play a significant role in the mitigation of urban heat islands (Tan, Lau, and Ng 2016; Rosenzweig, Solecki, and Slosberg 2006; Loughner et al. 2012). Urban green spaces can increase the livability of cities by alleviating the urban heat island effect by 2°C during the day and up to 12°C at night (Zhang et al. 2017; Raj et al. 2020). Vegetated areas included with pavement and rooftops allow water to penetrate into the ground, reducing flooding and downstream pollution and increasing the recharge of precious groundwater (Ishimatsu et al. 2017; Chan et al. 2018; Zhang et al. 2020). Coral reefs, mangroves, seagrass beds, and beaches protect coastal cities from erosion and flooding (Kuehler, Hathaway, and Tirpak 2017). Parks and other natural areas promote recreation, exercise, inspiration, and social connection, enhancing mental and physical health (Bratman et al. 2019; McCormack et al. 2010; Sturm and Cohen 2014). Urban nature can also help mitigate climate change by storing and sequestering carbon. For example, urban forests across the US state of California were found to store 2 percent of the total carbon of California forests and sequester 12 percent of the total annual carbon sequestered by forests in California (McPherson et al. 2013).

Monetary valuation of urban ecosystem services is complex but can be done transparently and rigorously and can help inform decisions. Proximity to urban nature can increase property values; forests, large parks, and the percentage of green space in a 500 m radius positively influenced apartment prices in a study of over 9,000 real estate transactions in Poland (Czembrowski and Kronenberg 2016). At a broader geographic scale, an examination of over 85,000 transactions across Europe also showed a positive effect of forests, parks, and water on real estate prices (Wüstemann and Kolbe 2015). More generally, a meta-analysis of the economic value of green and blue spaces for recreation and health benefits, conducted using studies in the US and Europe, suggests that people value access to green and blue spaces and are willing to pay to improve such local environments to gain the health benefits of undertaking leisure activities in them (Lynch, Spencer, and Tudor Edwards 2020). Finally, a study in France showed that adding green and blue spaces leads cities to become more compact, increases population densities, raises real estate values, and changes demographic distribution patterns (Roebeling et al. 2017).

While a focus on the ecosystem services provided by urban nature and urban biodiversity can be useful to municipal decision makers, it is important to recognize the other values they offer. An emphasis on measurable ecosystem services should not undervalue other aspects of biodiversity, such as the intangible ways that urban biodiversity can improve lives and the intrinsic, cultural, and spiritual values of biodiversity. Urban species and spaces can play an important role in linking city-dwellers to nature and can instill pro-environment behavior (Cox and Gaston 2016, Zhang, Goodale, and Chen 2014). Many cities become famous or known for their relationships with certain species. For example, the return of the pelican to New Orleans (in the US state of Louisiana) after the BP oil spill marked a huge turning point for the city. For many people, biodiversity—in cities and outside of them—has intrinsic value irrespective of any utilitarian benefits derived from it (Oksanen 1997).

Box 2 CASE STUDY

Nature-based climate adaptation in cities

Cities are responsible for over 70 percent of global climate emissions, primarily from transportation and built infrastructure within cities and from the production of goods consumed by urban residents (UN-Habitat 2011). Cities are also where some of the most extreme impacts of climate change will be felt. Increased frequency and/or severity of extreme events—such as heat waves, floods (from storms and rising seas), droughts, fires and smoke, and storms—will stress urban communities and systems.

Recent research has estimated that without migration, 1–3 billion people will soon live outside of the climatic niche in which human society developed (Xu et al. 2020). Moreover, if sea levels rise as projected, the homes of up to 340 million people may be below projected annual flood levels by 2050 (Kulp and Strauss 2019). Climate change will likely spur major migrations of people to cities from the hottest and driest regions that can no longer support lives and livelihoods. If current trends continue, 140 million climate refugees in Sub-Saharan Africa, South Asia, and Latin America are expected to move within the borders of their own countries by 2050 (World Bank 2018), most of them to cities and informal settlements, where they will remain particularly vulnerable to extreme weather.

These grim statistics do not have to be the future. Taking action today can reduce the number of people forced to move by 80 percent; critical actions include reducing emissions, building climate migration into development planning, and further understanding climate migration (World Bank 2018; Adger et al. 2020. Of course, cities can play a leading role in the mitigation of greenhouse gas emissions by using renewable energy, limiting industrial emissions, bolstering public transport, and more. However, cities can also make strides toward climate adaptation and mitigation by promoting urban nature and biodiversity. This case study provides three brief examples of the many urban areas undertaking such work.

Battambang, Cambodia. Photo: URF

▲ Battambang, Cambodia, is working to build climate change resilience while planning for a doubling of its population by 2030. Unplanned development of this riverside town has combined with climate change risk to make the region vulnerable to both flooding and drought. As part of an Asian Development Bank project, representatives from different government agencies and key sectors are working together to map expected climate extremes, understand vulnerabilities, and develop adaptation measures. Nature-based adaptation solutions include rehabilitation of a canal system for flood control and associated co-benefits, and development of a multi-use zone with natural drainage infrastructure, which incorporates housing for the current residents of informal settlements around wetlands that flood each year (ADB 2016).

▼ In Barcelona, Spain, a collection of ecological planning strategies is being deployed to achieve key objectives, including climate adaptation. For example, the city's Green Infrastructure and Biodiversity Plan envisions a city where "nature and urbanity interact and enhance one another" and where citizens benefit from the city's natural heritage (City of Barcelona 2013). This plan, together with the city's "Trees Masterplan" (City of Barcelona 2016), the "Urban Green Corridors Program," the protection of peri-urban forest, and the creation of dunes on heavily used urban beaches, offers nature-based solutions that serve multiple purposes: providing cooling through shade and evapotranspiration; increasing the amount, quality, and connectivity of green space; and protecting people and valuable resources against sea-level rise (Oppla n.d.).

Park Güelll, Barcelona, Spain. Photo: Vladislav Zolotov

Box 2 CASE STUDY

Nature-based climate adaptation in cities (cont.)

Moreover, the ongoing, gradual transformation of urban forest is designed to promote arboreal biodiversity; it focuses on a rich array of species, with no single species to make up more than 15 percent of the total number of street trees. This approach, which is being achieved gradually, is meant to reduce pest and disease risk, eliminate use of pesticides and fertilizer, and reduce water use by avoiding large monocultures and focusing on native species best suited to future climate. The approach has been successful so far, not only in biophysical terms but also in social distributive justice terms, as it has benefited vulnerable populations in particular (Baró et al. 2019; Climate ADAPT 2016).

▼ The County of San Mateo, located in the heart of Silicon Valley in the US state of California, has used a conceptual framework to guide urban ecological planning (described in section 3.3) to explore how alternative options for adapting to sea-level rise—such as use of coastal, tidal, and riverine habitat restoration—might deliver a variety of ecosystem service benefits.[1] After exploring vulnerability to sea-level rise, the county drew on stakeholder engagement and local scientific expertise to create two alternative scenarios of nature-based adaptation for each of five regions in the county. One scenario focused on current and planned projects to restore coastal habitats, such as marshes and beaches, and the other included additional nature-based adaptation strategies, such as horizontal levees and beach creation; the suitability of nature-based adaptation strategies was in both cases determined by rigorous science (Beagle et al. 2019). The team compared both strategies to an entirely engineered solution using InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), a software suite used to compare changes in ecosystem services with changes in management, policy, climate, etc. (see **box 13** for more information). The two nature-based scenarios resulted in five to seven times more marshland area than the engineered solution, in turn yielding five to six times more carbon storage and sequestration and five to seven times greater retention of runoff. The county has distributed fact sheets with this information to leaders throughout the region and is working to build a toolkit to help inform specific adaptation choices.[2]

San Mateo, California, United States. Photo: SpVVK

These three locales—as well as the many others linked together by similar efforts, such as C40, Eurocities, Local Governments for Sustainability (ICLEI), and the Resilient Cities Network—can provide inspiration for other cities implementing the framework laid out in section 3.3. Cities can and must be part of the solution to climate change or they will bear significant costs. Nature-based solutions can play a role in adaptation and mitigation. Using the best available science and tools can help urban leaders envision, compare, and create a positive future. Scaling up this type of work and sharing lessons across cities, the C40 network of cities already reports approximately 10,000 actions as part of climate adaptation and mitigation strategies (C40 Cities 2020).

1 Sea Change San Mateo County, "Nature-Based Shoreline Protection Strategies," https://seachangesmc.org/current-efforts/nature-based-shoreline-protection-strategies/.

2 For a sample fact sheet, see Sea Change San Mateo County, "San Mateo OLU." https://seachangesmc.org/wp-content/uploads/2020/06/San-Mateo-OLU-Factsheet.pdf.

1.3. How do biodiversity and nature outside the city impact the quality of life in the city?

Nature and biodiversity in peri-urban and rural areas also provide crucial benefits to urban residents. Conversely, unchecked urban sprawl into outlying areas can impact the residents of the city center in a multitude of ways. Cities can help maintain biodiversity by serving as key nodes between connected ecosystems in the landscape's surrounding cities (The Nature Conservancy 2018). Cities rely on resources coming from outside of their city borders, with nearby agricultural lands providing food, timber, fuel, and fiber (Folke et al. 1997; Rainham, Cantwell, and Jason 2013). Many cities, like New York, Beijing, Nairobi, Cape Town, and Quito, depend on water from source areas some tens or hundreds of kilometers away (Kauffman et al. 2014; Goldman-Benner et al. 2012; Hunink and Droogers et al. 2015; see **box 3** on upstream investments to secure water supply). Some cities rely on far-away ecosystems to maintain healthy air quality; for example, Beijing relies on Inner Mongolia (Ouyang et al. 2016). Similarly, countless cities rely on nature that exists outside of their borders to provide recreation and beauty, such as the natural wonders outside of San José (Costa Rica), Salt Lake City (United States), and Nairobi (Kenya), to name just a few. Lastly, much of the scenic beauty and character of some cities, such as Vancouver (Canada) and Taipei (Taiwan), comes from natural features that exist outside of their municipal borders.

Stanley Park, Vancouver, Canada/© Michael Wels

Box 3 CASE STUDY

Upstream investments to secure water supply

Miyun, Beijing, China.
Photo: Bonandbon Dw | Dreamstime.com

In the mid-1990s, New York City made one of the most famous investments in ecosystem service provision in recent history: it invested about US$1.5 billion in a variety of watershed protection actions and policies, including a payment for upstream property holders designed to improve drinking water quality for 10 million consumers, rather than spending the estimated US$6–8 billion needed for building a water filtration plant (this figure excludes annual operating and maintenance costs) (Chichilnisky and Heal 1998; Daily and Ellison 2002). The experiment continues successfully today.

Worldwide, watershed degradation compromises the water supply of nearly a billion people, with tremendous economic and health consequences (McDonald and Shemie 2014; Herrera et al. 2017; Salzman et al. 2018). Given rapidly growing populations, increasing human impacts in upstream watersheds, and climate change, water security for cities is a growing concern for governments, corporations, and residents.

The New York City investment is currently one of many such experiments underway in major cities across the world (Bremer et al. 2016; Vogl et al. 2017; Zheng et al. 2013; Li et al. 2015). These efforts typically involve a reciprocal watershed agreement, through which downstream water users and other parties (e.g., municipal water companies, conservation and human development organizations) pay for upstream changes in land cover and use in order to achieve certain objectives. In biophysical terms, the objectives may include maintenance or enhancement of water quality, regular water flows (for dry-season supply and flood control), groundwater recharge, and terrestrial and aquatic biodiversity. Other benefits are also anticipated, such as carbon storage and sequestration, crop pollination, and pest control (Goldman-Benner et al. 2012). In socioeconomic terms, the objectives also include sustainable improvements in human livelihoods and well-being.

Investments may include protection of native vegetation, restoration of degraded lands, improved agricultural practices, and shifting of some farmers into other livelihoods, through training and other support. The investments target the twofold goal of improving upstream livelihoods and downstream water security. Investments are targeted across landscapes to yield the highest return, subject to stakeholder preferences. A great deal of stakeholder input feeds into the analysis of options. Monitoring programs can ensure that these investments lead to measurable improvements in a variety of objectives, including water quality, biodiversity, livelihood options and security, and access to nature by urban residents through weekend recreation (as in the Catskills-Delaware watershed serving New York City and the Miyun Watershed serving Beijing, for example). The overall effort also involves advancing standards in biophysical modeling (much of it through InVEST), financing, governance, and monitoring.

Since New York City's investment proved successful, the model has spread widely across Latin America, where there are now over 50 funds in different stages of establishment in major cities. The model is also spreading rapidly across China (Zheng et al. 2016) and is being tested in Africa and other regions (Salzman et al. 2018). Further progress could be made upon the emergence of flexible yet durable institutions that could help guide the growth of cities and management of the natural capital and land stewards they depend on for green and inclusive development.

2. What is at stake?

2.1. How can urbanization affect biodiversity?

Across the planet, three-quarters of the land surface has been transformed by human interventions, two-thirds of the oceans are under severe threat, and over 85 percent of wetlands have been destroyed. The average abundance of nonhuman species in their native home regions has declined by more than 20 percent, and approximately 1 million species face imminent extinction (IPBES 2019b).

Against this backdrop, urbanization can have significant negative impacts on global biodiversity. Some 60 percent of urban areas that will likely exist in 2050 have yet to be built (United Nations 2013). Between 1985 and 2015, urban land cover grew by almost 10,000 km^2 each year (Liu et al. 2020). From 1992 to 2000, 190,000 km^2 of natural habitat was lost to urban growth, and an additional 290,000 km^2 will be at risk by 2030 (The Nature Conservancy 2018).

Better planning of urban growth, management of protected areas near cities, integration of habitat for biodiversity within cities, and use of nature-based solutions to urban problems can all help reverse the negative impacts of cities on biodiversity (The Nature Conservancy 2018). In some cities, providing habitat is key to the local and even global survival of plants and animals on the brink of extinction. Examples include the signature Presidio manzanita plant and Mission blue butterfly in San Francisco (United States), and migratory birds along the coastline of China, which is a crucial part of the West Pacific Flyway. Of the global Key Biodiversity Areas (IUCN 2016), 300 are at least 50 percent urbanized, showing the importance of designing urban areas for long-term biodiversity conservation (The Nature Conservancy 2018).

Some species thrive in urban habitats. For example, birds with broader environmental tolerances are more likely to make cities their homes (Bonier et al. 2007). Birds with bigger brains are also more likely to thrive in urban environments (Maklakov et al. 2011). In many cases, urban development leads to the replacement of native species with non-native species that are well adapted to urban environments globally. This shift leads to biotic homogenization threatens to reduce the biological uniqueness of local ecosystems (Blair 2001). For plants, birds, and butterflies along urban gradients, the number of non-native species increases toward centers of urbanization while the number of native species decreases (Kowarik 1995; Blair and Launer 1997).

It is worth noting here that this report focuses on localized biophysical linkages between a city and its hinterlands. However, cities also exert massive environmental pressures on the entirety of the globe by driving resource extraction and land conversion in far-away places through global trade. These impacts that are moderated through economic drivers have profound effects (e.g., Mirabella and Allacker 2017, Świąder et al. 2020).

2.2. How can urban sprawl undermine the well-being of city dwellers?

Urban sprawl can affect human well-being in numerous ways. Globally, nearly a billion people depend on watersheds that have degraded capacity to deliver safe, reliable water, where city investments in restoration and protection upstream could yield high returns (Herrera et al. 2017; Salzman et al. 2018). Like water supplies, urban food supplies come from places now threatened by degradation and urban sprawl (Hatab et al. 2019). That is because historically, cities were typically founded in places of exceptionally fertile land. Unchecked urban sprawl into outlying areas not only endangers the provision of water and food; it also threatens access to rural and natural landscapes for mental and physical health, recreation, and cultural benefits, thereby undermining the well-being of urban economies and residents.

A quantitative analysis of the change in ecosystem service value was recently conducted for Montreal (Canada) and surrounding areas. This study found a nearly 25 percent decrease in the value of ecosystem services provided by the landscape from 1966 to 2010—from $1.026 billion CAD per year to $791 million CAD per year. The most significant declines were driven by losses in air quality, water purification, habitat for biodiversity, and recreation opportunities (Dupras and Alam 2014). **Box 3** provides further examples.

2.3. What are the risks of urban development without consideration of urban biodiversity and nature?

The vast range in quality of life within and across the world's cities today helps in visualizing what is at stake in failing to consider urban biodiversity and nature. Rapid urbanization can result in informal settlements that imperil the health and well-being of both people and nature—which are tightly connected, as the One Health approach maintains. Incorporating nature-based solutions into problem-solving in informal settlements can offer a way forward for urban development that takes nature and biodiversity into account (see **box 4** on revitalizing informal settlements and their environments).

In many cities, children grow up and adults live with almost no contact with nature. The implications of this situation are profound, ranging from elevated mental health risks (Lederbogen et al. 2011), to compromised immune function (Roslund et al. 2020), to loss of intergenerational understanding of humans' intimate interdependencies with nature. Urban living is associated with heightened risk of cardiovascular and respiratory disease and of a suite of mental disorders, including depression, anxiety, stress, loneliness, and schizophrenia (Hartig et al. 2014; Kondo et al. 2018). Of course, many factors contribute to these risks, but a growing body of research demonstrates causal links between experiences of nature and human health (Soga and Gaston 2016). In line with these findings, new policy and management approaches seek to connect investments in parks to investments in health (see **box 5** on investing in nature for health). Furthermore, human beings are host to many microbial symbionts, together forming a single "holobiont" (Margulis and Fester 1991) that is interdependent with biodiversity in the environment. People likely require contact with diverse microbial habitats to live healthy lives, and urbanization may disrupt these vital symbiotic relationships (Mills et al. 2019).

Although increasingly hidden, the dependence of urban people on nature remains utterly fundamental not only in health but in other dimensions as well, including security in water, food, and climate (Ouyang et al. 2016; Keeler et al. 2019). Destroying the nature that remains in and around cities imperils drinking water, healthy diets and food systems, security from flooding and heat stress, and the core human experiences nature stimulates—creativity, connection, and freedom. Our current trajectory will take us into a future ever more depleted of nature, with escalating risks, shocks, and costs (Rockström et al. 2009; IPBES 2019a; see **box 2** on nature-based climate adaptation in cities). Indeed, the coronavirus pandemic, which follows decades of intensifying disasters wrought through land conversion and climate change, is both a warning that highlights the tight interconnections of people and nature and an opportunity to shift trajectory.

Solutions to urban problems will necessarily come from a range of interventions that include gray (or built) infrastructure, green (or natural) infrastructure, and hybrids of the two. Urban development that defaults to gray infrastructure risks inefficient use of resources and lost opportunities for synergies. A city choosing to manage stormwater, for example, could construct drains for urban flood protection; or it could build a park that could both store floodwaters when needed and provide recreational opportunities that increase health and well-being, contribute to urban cooling by mitigating heat islands, offer carbon storage and sequestration to mitigate climate change, and serve as a habitat for biodiversity.

Box 4 CASE STUDY

The RISE (Revitalizing Informal Settlements and their Environments) project

Much of the rapid urbanization expected to occur by 2050 will be in Asia and Africa, where many of the new urban dwellers will live in informal settlements on the edges of towns and cities. At present, close to 1 billion people live in slum conditions, and by 2030 this number is expected to swell to 2 billion (World Bank 2018).

The RISE (Revitalizing Informal Settlements and their Environments) project is a prime example of a program deploying nature-based solutions in informal settlements. RISE is a randomized control trial of a water-sensitive green engineering intervention to improve health and environments in informal settlements. The goal is to demonstrate how a novel, nature-based approach can lessen environmental contamination by improving sanitation and access to clean water and by reducing stormwater impacts.

Taking these steps will improve human health in informal settlements, especially for children, who are profoundly affected by poor sanitation. The intervention, which is funded under the Our Planet Our Health program of the Wellcome Trust, will also reduce exposure of inhabitants to flooding hazards.

Four major environmental improvements are being sought through the RISE program:

1. Better-managed hydrology to reduce the impacts of flooding and to enhance climate change resilience
2. Reductions in mosquito vectors associated with poor sanitation, poor drainage, and limited hard waste solutions
3. Improvements in thermal conditions to provide resilience to projected rising temperatures, which compromise human health and productivity
4. Reductions in anthropogenic noise and an increase in audible biodiversity, which are associated with improved human well-being

RISE is being undertaken in Fiji, Suva, and Makassar, Indonesia. The ultimate aim is to scale up a set of demonstrably effective solutions that can improve the lives and environments of informal settlement residents globally. For more information, see the RISE program website at https://www.rise-program.org/.

Batua in Makassar, South Sulawesi, Indonesia, before (left) and after (right) the RISE intervention.

Source: Kerrie Burge, RISE Program, Monash University

Box 5 CASE STUDY

Investing in nature for health

Bycicle path in Bogota, Colombia.
Photo: Working In Media

A large and growing body of research has shown that nature experience is associated with both mental health and physical health (Bowler et al. 2010; Hartig et al. 2014; van den Berg et al. 2015; Ohly et al. 2016; Ives et al. 2017; White et al. 2017). Given the relative scarcity of urban nature, much of this research has focused on linkages between access to nature and the well-being of populations in urban settings (Roe et al. 2013; Wheeler et al. 2015; Mitchell et al. 2015; Dadvand et al. 2016; van den Berg et al. 2016). As urbanization increases globally, living habits tend toward reduced regular contact with outdoor nature and increased time spent indoors, looking at screens and performing sedentary activities (Hofferth 2009; Atkin et al. 2013). Recognition of the intimate connections between access to nature and the mental and physical health of urban residents can highlight new pathways for investment in health.

Investing in urban nature and parks can improve the health of the surrounding community by increasing physical activity, social cohesion, and stress relief. Cities, health care organizations, and nongovernmental organizations (NGOs) around the world are increasingly recognizing the One Health concept and leveraging the connections between nature and health to target investments in local green and blue infrastructure for upstream health prevention.

Projects often have a primary focus on programming to improve community health. For example, Camden and Islington in the United Kingdom initiated a two-year program in 2019 to reshape the management of urban green spaces to tackle health challenges. The program aims to develop close links between health providers and parks, test innovative opportunities in the active use of green space for health, and create equitable engagement and access to parks. The program also develops infrastructure for health-focused green spaces.[3]

The UK has also launched investments in improving the quantity and quality of urban green spaces. For example, the National Health Service (NHS) Forest project invests in creating green spaces around health care sites such as hospitals and clinics, with the aim of leveraging health benefits of nature for patients, staff, and the surrounding community. The project is active in nearly 200 sites across the UK. The project started in 2009 and is funded by charitable trusts, individual donations, and businesses and is coordinated by a charity. NHS Forest has planted over 65,000 trees, helped develop therapeutic gardens, and improved access to green spaces.[4]

In Phoenix, Arizona (US), the Vitalyst Health Foundation provided a US$125,000 grant to the Arizona Community Tree Council in 2019 to implement a Park Rx program in medically underserved communities and improve the quality of and access to local parks.[5] Together with city authorities and stakeholder groups, the Arizona Community Tree Council plants trees, provides amenities such as benches, and removes barriers to park access, while also encouraging health care professionals to prescribe time in parks for their patients (Warren 2019).

Health and well-being are recognized as key benefits of urban green spaces, and there are positive examples from cities around the world in which this link is leveraged to create, maintain, and promote urban nature for human health. There is clearly room for improvement, as financing urban green spaces is a continuous struggle and the multitude of health benefits are still being uncovered.

[3] Beyond Greenspace, "Making the Most of Green Space for People's Health: Case Study Parks for Health Camden and Islington," https://beyondgreenspace.files.wordpress.com/2020/06/ci-parks-case-study-final.pdf.

[4] See the NHS Forest website at https://nhsforest.org/.

[5] Vitalyst Health Foundation, "2019 Innovation and Medical Assistance Grants," http://vitalysthealth.org/grants-2019/.

3. What can urban leaders do?

Chongqing Wenfeng Forest Park overlooking the Wushan Yangtze River Bridge, Photo: © Jingaiping | Dreamstime.com

Melding the arenas of urban planning and nature conservation yields a powerful vision for sustainable, livable, equitable cities of the future. Simultaneously, cities have an important role to play in protecting biodiversity and nature. Mapping, measuring, and valuing the benefits provided to people by urban nature can help cities deploy limited resources efficiently, thoughtfully design with nature, and generate multiple benefits from urban nature. Mapping also reveals the distribution of those benefits to different populations, informing policies that improve equity (see **box 6** on equity in urban nature for biodiversity, ecosystem services, and people).

Initiatives to include urban nature in planning, to foster biodiversity within cities, and to share knowledge and experience across cities are beginning to take hold. For example, in the US, the Forest Service has an urban forest program,[6] and the NGO American Forests has recently emphasized urban forestry, specifically working to reduce inequities in the distribution of trees in US cities.[7] The Biophilic Cities Network connects cities, scholars, and advocates to build better understanding of the ways in which nature in cities contributes to the lives of urban residents.[8] The international platform Nature of Cities connects people across the globe who are interested in the design and creation of better cities for all.[9] The Cities with Nature program of ICLEI is another example of an international network for sharing best practices across cities.[10]

6 US Forest Service, "Urban Wildlife," https://www.fs.fed.us/research/urban/wildlife.php.
7 American Forests, "Tree Equity in American Cities," *https://www.americanforests.org/our-work/urban-forestry/*.
8 Biophilic cities network, *https://www.biophiliccities.org*.
9 Nature of Cities, *https://www.thenatureofcities.com*.
10 ICLEI Cities with Nature, *https://www.citieswithnature.org*.

Box 6

Equity in urban nature for biodiversity, ecosystem services, and people

Cities around the globe, in both developed and developing nations, are challenged by inequitable distribution of both material and natural wealth. While the economic inequalities in cities have been well-documented for decades (Akyelken 2020), researchers and practitioners are only now beginning to fully appreciate the unequal distribution of urban nature, biodiversity, and ecosystem services across cities (Jennings et al. 2012; Lin et al. 2015).

Wealthy neighborhoods have much higher density of urban green and blue spaces than impoverished neighborhoods, where many individuals and populations live with insufficient access to nature (Rigolon et al. 2018a, 2018b), which has been demonstrated to have negative effects on human health, both physical and mental (Beyer et al. 2014; Jennings et al. 2016). Furthermore, reduced access to green space inhibits educational growth in schoolchildren (Browning and Rigolon 2019).

A recent analysis found strong linkages between historic practices of "redlining" in the United States and the intensity of the urban heat island effect: neighborhoods that were subject to racial discrimination in the past and present have higher surface temperatures (Hoffman et al. 2020). Perhaps more surprising, however, is recent evidence that racially discriminatory practices in cities affect not only human inhabitants of those cities, but also the ecology and evolutionary history of other urban species (Schell et al. 2020). For example, the existence of only small, isolated patches of green space in under-resourced communities makes it more likely that ecological drift (stochastic processes) will cause populations to go locally extinct or that genetic drift (stochastic processes) will lead to deleterious mutations due to lack of sufficient outbreeding opportunities.

Some ecosystem service analyses address the equity in distribution of green spaces and their benefits. For example, approaches to modeling urban cooling and access to nature and its impacts on physical and mental health aim not only to maximize net benefits but also to spread them across the entirety of the city. Further work to understand how changes in climate and urban planning might decrease or exacerbate inequity in the distribution of urban ecosystem services is a critical research frontier.

Many of the metrics of urban biodiversity discussed here do not explicitly account for the distribution of species across the city and the ways in which that distribution may impact people. Unfortunately, some of the actions most advantageous for urban biodiversity may further entrench existing inequities. Actions such as increasing the size of existing green spaces, which is undoubtedly good for biodiversity, may further exacerbate inequities in human access to urban nature, biodiversity, and ecosystem services.

As the community of scientists and practitioners works to advance the science and tools related to equity and urban biodiversity and nature, decision-makers must remain cognizant of how different strategies or tactics will exacerbate or alleviate inequalities in their city (Schell et al. 2020).

3.1. What is ecological planning?

Ecological planning in cities is urban design with nature. It is planning that is cognizant of biodiversity and nature—both within and outside urban boundaries—and the ways in which a city impacts and depends upon them. It is planning that recognizes that the well-being of city residents is affected by biodiversity and nature. It is smart use of nature-based solutions to urban problems and the blending of gray and green solutions to create sustainable cities. Ecological planning guides smart urbanization that limits sprawl and directs new development to places with minimal impacts on biodiversity and ecosystem services, while also meeting a city's development goals. It can be done at the scale of a region, a metropolitan area, an urban core, a neighborhood, a district, or a parcel of land.

Both within and beyond cities, ecological planning guides decisions based on an understanding of nature and people as interlinked elements of an ecological system (Ndubisi 2014). Ecological design and planning use nature as an inspiration and blend nature and culture, science, and art to improve the well-being of all (Steiner, Thompson, and Carbonell 2016). Ecological planning is closely connected to landscape urbanism, a theory of urban design that flexibly integrates built, natural, and social infrastructure (Waldheim 2006).

Ecological planning refers to the broad *strategy* of incorporating biodiversity and nature into urban planning. Various *tactics* can be used in the service of ecological planning to better incorporate nature into the city, depending on the decision context and strategy. Some important examples of tactics include the following:

- **Improve existing green spaces for local biodiversity (Beninde, Veith, and Hochkirch 2015).**
- **Identify habitats that used to exist in the city and restore them (Blaustein 2013).**
- **Enrich and/or reintroduce native plant and animal species (Burghardt, Tallamy, and Shriver 2009).**
- **Plant native plants in parks, roadsides, and gardens (Tallamy 2009).**
- **Encourage urban gardening for food security, food for pollinators, and mental health and other benefits (Langmeyer et al. 2016; Soga et al. 2017).**
- **Connect fragmented ecosystems by expanding green spaces near one another, particularly by adding corridors of vegetation or other forms of connectivity (Beninde, Veith, and Hochkirch 2015).**
- **Expand tree canopy using native species (Shackleton et al. 2015).**
- **Build tunnels or overpasses to enable movement of animals throughout the city, particularly across roads or other linear features (Riley et al. 2014; Teixeira et al. 2013).**
- **Add parks and other green spaces to the city (Beninde, Veith, and Hochkirch 2015).**
- **Use nature-based solutions when possible for stormwater and flood management (Ishimatsu et al. 2017).**
- **Use transdisciplinary collaborations between urban planners, engineers, and ecologists to design stormwater and flood management plans (World Bank 2019).**

These sorts of actions and many others could be undertaken, depending on the specific ecological and socioeconomic setting of the city. Further information about many of these actions can be found in the Convention on Biological Diversity's Cities and Biodiversity Outlook (Secretariat of the Convention on Biological Diversity 2012) and in guides to nature-based solutions, such as the World Banks's flagship report on green and gray infrastructure (Browder et al. 2019) and its guide to implementing nature-based flood solutions (World Bank 2017).

All of the tactics above are useful for ecological planning, but often they are not particularly useful without bigger-picture planning, or a strategy that helps explain the broader context—one that asks what species we are trying to support, what problems we are trying to solve, and what groups could benefit most from urban nature. Bigger-picture planning also helps target the tactics to the places where investment will provide the biggest returns for accomplishing the stated goals (e.g., enhancing particular elements of biodiversity, nature, and/or ecosystem services for key beneficiaries). The rest of this document can help identify appropriate strategies and tactics for protecting and enhancing urban nature and biodiversity.

3.2. How can ecological planning help protect nature and biodiversity?

Better ecological planning can help reverse the negative impacts of cities on biodiversity. To be effective, ecological planning is nested within urban planning. A recent UN report (UN Environment 2018) describes five key principles of building better cities: (1) density (minimizing sprawl while maintaining sufficient green space), (2) diversity of use and income, (3) design (walkability, traffic safety, tree cover), (4) distance to transit, and (5) destination access (sustainable transportation) (UN-Habitat 2018). Principles (1) and (3) are intimately tied to ecological planning. Attention to these approaches and principles can guide targeted investments to secure cities' livability, sustainability, resilience, and equity, today and into the future. Cape Town (South Africa) is an example of a city that has successfully integrated ecological planning into its broader urban planning efforts—to the benefit of local biodiversity (see **box 7** on Cape Town's biodiversity).

Box 7 CASE STUDY

Cape Town's biodiversity


Orange-breasted Sunbird on Table Mountain, South Africa.
Photo: TheUntravelledWorld

Cape Town is situated in one of Earth's most biodiverse regions. Not only does Cape Town have disproportionately high levels of species richness, but also it has an extremely high rate of endemism, with 190 plant species and over 100 animal species found only in Cape Town (Helme and Tinder-Smith 2006; Cape Nature 2011; Holmes et al. 2012).

Cape Town is not the only city with significant biodiversity—but where it stands out is how well it has protected that biodiversity within its municipal borders. The city prides itself on maintaining high levels of biodiversity, perhaps best demonstrated by its recent victory in the City Nature Championship, where residents of Cape Town recorded the most species of any city globally (City Nature Challenge 2021),[11] recording 50 percent more species than the second-place city.

Cape Town's success in maintaining biodiversity within its city limits can be traced to its thorough evaluation and incorporation of biodiversity in four key steps: (1) monitoring biodiversity, (2) assessing threats, (3) reducing threats, and (4) assessing efficacy of programs.

First, Cape Town has an extensive biodiversity monitoring system that was put into place in the early 2000s (Rebelo et al. 2011). This program draws on ongoing monitoring efforts and proposes new protected areas of vegetation within the city called Critical Biodiversity Areas.[12] These areas are defined based on field studies of where unique vegetation types are located, how much of each type is protected, and what the national and international guidelines are for protecting habitat. Crucially, this program is constantly evolving, with frequent updates to the initial assessment (e.g., Benn 2008).

Second, Cape Town has developed a holistic assessment of the threats posed to its biodiversity. It has identified nine unique drivers of biodiversity loss in Cape Town: urbanization, invasive species, agriculture, fire, mowing, overexploitation, pollution, hydrology, and crime (City of Cape Town 2018). This identification of threats reveals linkages between urban planning and biodiversity conservation in domains whose relevance might not otherwise be clear. For example, Cape Town perceives crime as a risk to biodiversity because some people may view elements of natural habitat as unkempt, likely to promote crime, and thus undesirable. However, it is these very elements that are key to preserving biodiversity. It is therefore necessary to balance these concerns in the broader urban planning process.

Next, the city of Cape Town uses information about biodiversity and threats to biodiversity to inform urban ecological planning. The BioNet and other supporting biodiversity assessments are used alongside other sources to inform decisions across all arenas of urban planning. Because BioNet is explicitly incorporated into the Spatial Development Framework for Cape Town (ICLEI 2012), it ensures that biodiversity and nature are not left out of key urban planning decisions.

Lastly, the city has made concrete recommendations on how to conduct continued monitoring of biodiversity post-intervention (City of Cape Town 2018). Though the Spatial Development Framework for Cape Town does not explicitly include scenario assessment, the data collected, the process used, and the types of decisions informed are consistent with the conceptual framework to guide urban ecological planning laid out in section 3.3. This approach has allowed Cape Town to make significant gains in the conservation of urban nature and biodiversity. For example, from 2008 to 2018 the amount of protected area expanded by 10,000 hectares, and the management assessment score of these sites increased from around 33 percent to around 75 percent in this time period (City of Cape Town 2018).

[11] City Nature Challenge 2021, "2019 Leaderboard" (accessed September 20, 2020), https://citynaturechallenge.org/leaderboard-2019/
[12] South Africa National Biodiversity Institute, "City of Cape Town's Biodiversity Observation Network," http://bgis.sanbi.org/capetown/bionetwork.asp.

3.3. Conceptual framework to guide urban ecological planning

A general framework for decision-making is essential to guide urban ecological planning. This section briefly outlines an overall process by which municipal leaders can most successfully incorporate information about biodiversity and nature into urban decision-making. This is not a new framework, but rather a suggestion for how the consideration of nature and biodiversity can be part of standard planning processes. It aligns with more specific frameworks for nature-based solutions for flood protection, such as the World Bank (2017) guide on nature-based flood protection, the World Wildlife Fund (WWF 2016) Green Guide, and The Nature Conservancy (2021) Blue Guide. The framework describes three steps to developing a *strategy*, or the bigger-picture overview, for urban ecological planning. Step 1 and Step 3 are common elements of any planning process; but Step 2 needs more explanation; hence section 4 below details tools and approaches for accomplishing Step 2 in the context of bringing urban biodiversity and nature into decisions. Section 4 also provides guidance for how to use and evaluate specific *tactics* (individual development of management actions) to achieve the overarching *strategy*.

STEP 1

Build the foundation: Identify stakeholders, goals, specific questions, and information needs

In this first step, municipal leaders establish the outlines of the ecological planning process, including goals and objectives, specific questions being asked, team members, stakeholders/advisors, timeline, and work plan. The team identifies the scale and scope of the ecological planning process and engages with key stakeholders and community voices to ensure broad participation. When planning an assessment of urban biodiversity and urban nature, it is critical to think about the goals; clear articulation of the goals determines key aspects of the assessment and planning. Careful inclusion of appropriate stakeholders in goal-setting can help illuminate diverse visions and values, and ensure support for the process and its ultimate outcomes (Reed 2008; Haddaway et al. 2017).

Different types of questions and decisions call for different types of information (Hamel et al., forthcoming). In some cases, coarse information that provides qualitative results is sufficient. In others, more detailed, quantitative assessments are required. When the goal of an assessment of urban biodiversity and nature is communication and capacity building, and the team aims to educate constituents and build support for the general concept of using nature-based solutions, qualitative results are often sufficient. For example, in the case of a proposed park designed to address flooding (by storing temporary floodwater) and offer other co-benefits (such as opportunities for recreation, carbon storage and sequestration, and the mitigation of urban heat), a simple list of benefits provided by habitat types could help build support from local taxpayers and other stakeholders. If, however, decision-makers are trying to determine whether a park or a built infrastructure solution is a more cost-effective form of flood control, scenario exploration is likely necessary, and in this case a more detailed analysis would be in order. And when specific design questions are being asked about a park—such as, how big it would need to be to provide the desired level of flood protection—quantitative analysis of detailed data is critical.

In this step, leaders also identify useful data sources and experts within their network and compile available data about urban biodiversity and nature. These data come from a range of sources, including satellite imagery, local government databases, conservation organizations, local zoos and botanic gardens, and community members. Incorporating traditional cultural knowledge through an integrated stakeholder process is key to ensuring that diverse community voices and values are considered.

Some ***key questions*** that might be asked in this step include the following:

- Whose voices do we need to hear?
- What is our shared vision for the future of our city/district/neighborhood, and what roles might urban biodiversity and nature play in that future?
- What is our shared vision for urban biodiversity and urban nature?
- How might ecological planning move our city/district/neighborhood forward?
- What data, expertise, and other resources do we need to achieve our goals? How can we work with groups within our city or broader network to acquire them?
- To what climate, social, or health issues might nature provide solutions?
- What scale of questions are we asking? (**Box 9** specifically addresses this question.)
- What are we trying to achieve, and what metrics will we use to assess and monitor success?

Some ***key outputs*** from this step include the following:

- An expert team, a strategic, inclusive vision, and a work plan
- Clear questions for the ecological planning process at hand
- Metrics and indicators with which to assess success
- Compilations or assessments of relevant data and other resources
- A clearly articulated goal for proposed nature-based solutions
- Participation and realistic expectations of local residents and stakeholders

STEP 2

Analyze and compare: Articulate possible alternatives and evaluate likely outcomes against stated goals

With clear goals in hand, stakeholders, communities, and leaders next articulate the baseline of biodiversity and ecosystem services in the region as well as possible alternative development plans for their area of interest. By using the *tactics* described above, decision-makers can generate scenarios of potential futures for their city by adding, rearranging, or rethinking the management of green and blue spaces. These scenarios might translate alternative visions or policy options into possible future maps of the city, district, or neighborhood. Ideally, the team translates the stated goals and objectives into alternative future maps with different maps representing different visions and policies.

Next, the team uses the baseline and alternative future scenarios to compare the likely outcomes of each alternative with respect to the chosen metrics. With the original project objectives in mind, the team digs into the data and uses qualitative or quantitative models or other projections to understand how policies, management choices, or investments change nature, biodiversity, and the flows of ecosystem services to people in the city. An example of this approach in Guangzhou, China is detailed in **box 8**. Section 4 details useful tools, such as a modified version of the Singapore Index and InVEST, that can help identify potential changes in biodiversity and ecosystem services associated with different decisions; with that information, decision-makers can weigh trade-offs and better understand possible impacts on the distribution of benefits to different stakeholders in the city (see **box 6** on equity in urban nature for biodiversity, ecosystem services, and people).

Some ***key questions*** that might be asked in this step include the following:

- What is the baseline of biodiversity in the region of interest today?
- What ecosystem services are provided where?
- Are ecosystem services distributed equitably in our city? If not, what demographic groups currently benefit from urban nature, and how might this situation shift in the future?
- What are some possible alternative futures for our city, district, or neighborhood?
- How and where can we best invest in urban nature to achieve our stated goals?
- How do environmental or societal changes affect biodiversity and the provision of benefits to people?

Some ***key outputs*** include the following:

- Current maps of biodiversity, ecosystem types, and ecosystem services
- Original species diversity, and ecosystem types and services
- Alternative future maps of the area of interest
- Maps and summary tables reflecting agreed-upon metrics of urban nature, urban biodiversity, and urban ecosystem services compared across alternatives

Box 8 CASE STUDY

Understanding the value of the Haizhu wetland in Guangzhou, China

The Haizhu Wetland. Photo: The World Bank

Guangzhou, China belongs to one of the world's largest metro areas, the Guangdong-Hong Kong-Macao Greater Bay Area, with a population of 72 million in 2019. The Haizhu wetland in Guangzhou occupies 11 km^2; it is the largest wetland located in the downtown core of a Chinese megacity. The Haizhu wetland is locally known as the "Green Heart" of the city. It provides many services to residents. For example, it is highly accessible from the Central Business District and other densely populated areas, making it a key component of greenspace access for locals. Indeed, the wetland received over 60 million visitors from 2012-2020. It is also an important area supporting biodiversity in the city, with 177 bird species (compared to 72 bird species locally, outside the wetland) and 325 documented insect species (compared to 66 outside).

In 2020, the World Bank partnered with the local planning agency in Guangzhou and the Natural Capital Project to explore some of the important benefits provided by the wetland to people. The goal was to quantify key benefits provided by the wetland—in biophysical, monetary, and other metrics—to make those benefits explicit to decision-makers and help protect the wetland from future development. To do so, the team mapped and modeled four services provided by the wetland: climate change mitigation (carbon storage and sequestration), urban cooling, access to nature for recreation, and improvements in health (through both mental health and physical health pathways). The team then calculated the provision of those same services in a future in which the wetland was replaced by dense residential development. This allowed for the calculation of the marginal value of the examined ecosystem services. Such values are measured in biophysical (e.g., degrees of cooling), monetary (e.g., energy savings), and other metrics of value (e.g., mortality risk).

The marginal value provided to Guangzhou by the Haizhu wetland via the examined ecosystem services is at least **$146.8 million USD** over the next 30 years, in addition to reduced mortality risk and increased workplace productivity in the surrounding landscape. Including additional ecosystem services that were beyond the scope of this analysis, such as water purification and flood mitigation, would most certainly add to this reported value. Understanding the ecosystem services provided by the Haizhu wetland enables city officials and urban planners to make ecologically-informed decisions about urban development in Guangzhou.

This approach represents a substantial leap in valuing urban ecosystem services to inform ecological planning by articulating the marginal values of urban green spaces. The team used a combination of existing and prototype Urban InVEST models to assess the marginal values of the Haizhu wetland. InVEST is a free and open-source software suite that has been used in over 185 countries globally; it leverages geospatial data inputs alongside known ecological processes to predict the provision of ecosystem services from land and seascapes (Sharp et al., 2020, Hamel et al. in press). This is one of the first applications of Urban InVEST. This approach is globally generalizable; software, tools, data, and workflows are available to make it easier and more efficient to understand the services provided by urban nature and to use that understanding to inform urban planning decisions across China and throughout the world.

Source: World Bank Report on Guangzhou Sustainable Urban Cooling Options, forthcoming.

STEP 3

Synthesize and inform: Summarize results, inform decisions, and iterate

The first step builds the foundation, laying out goals of the specific ecological planning enterprise to be undertaken. The second step creates alternative future scenarios and evaluates what those scenarios might mean for progress against the objectives. This final step builds on the previous two to synthesize results in decision-relevant ways, inform decisions, and plant the seeds of implementation.

This process involves learning as a group and equips municipal leaders with the tools they need to incorporate urban nature and biodiversity into urban design. The team has been working with key stakeholders throughout the process, but this is when the final results are delivered and discussed. With target audiences in mind, the team packages and presents the results in compelling ways to key stakeholders.

Of course, information about urban nature and biodiversity and their value to people (both monetary and nonmonetary) is only one of many types of information used to make decisions about urban land use and development. A good synthesis of the work done throughout these steps can help bring the diverse values and beneficiaries of urban biodiversity and nature to the fore and thus allow for decision-making that best serves both nature and people in the city.

Iteration and evaluation—of both the results and the process itself—are important throughout the course of this work. Building in evaluation and iteration from start to finish ensures that both the process and the end results have good support and accomplish stated objectives. Throughout, it is essential to build in a diversity of knowledge sources and to value the cultural and traditional knowledge available through local collaborators.

Some ***key questions*** asked in this step include the following:

- How do we present results in a way that is most accessible to stakeholders and other important audiences?
- What worked well, and how can we improve? How thoroughly did we consider urban nature and urban biodiversity in our decision process? Are we content with the likely impacts of our decisions on urban nature and biodiversity?
- What are the next steps to get to implementation of the plan?

Some ***key outputs*** from this step include the following:

- Interactive maps of urban nature and biodiversity, simple diagrams showing projected changes in urban nature, and local workshops to communicate the city's vision for the future
- An updated version of the desired future and a process for how to derive plans to reach that future
- An interpretation guidebook for nature education

The process focuses on getting to a plan. Of course, additional actions are necessary to fund, implement, monitor, and review activities consistent with that plan. ICLEI's guidance for biodiversity action plans for cities lays out a broader, five-step process from initiation to monitoring and review (ICLEI 2015).

Box 9 CASE STUDY

At what scales can ecological planning provide answers to urban leaders?

Ecological planning is a useful concept that can operate at many different scales and levels of specificity, to (1) guide the development of the city as a whole—often in relation to other cities, (2) identify areas for investment in urban nature and biodiversity, and create zonation schemes across the city, and (3) inform specific land use decisions within the city.

1. Scale beyond urban borders. The broadest planning scale looks at a city as a whole and/or at multiple cities, or seeks to meet national or international targets. Questions at this scale help urban leaders gain inspiration from peer cities to guide the development trajectory of the whole city. Questions at this scale can also help lenders and NGOs prioritize investments in particular cities—or help those cities argue for such investments. For example:

- Does our city have globally significant levels of biodiversity either within the city or in the hinterlands? What are current levels of protection for biodiversity in our city and the surrounding areas? Are there functional corridors connecting urban nature to nature outside the city?
- Is our city one that would significantly benefit from upstream or upwind investments in ecosystem restoration to improve water or air quality? (See **box 3** on upstream investments to secure water supply.)
- Which cities have pioneered approaches that my city could adopt? (See **box 10** on how to identify peer cities to guide ecological planning.)
- What can our city do to meet biodiversity targets set by national and international agreements (e.g., UN Sustainable Development Goals, EU Biodiversity Strategy)?

These questions are being asked principally by city governments and planners, in consultation with national governments and international organizations to guide urban design at the highest levels.

2. Scale of city as a whole. The next planning scale is smaller, focusing on the city as a whole. Questions at this scale can be used to prioritize investment in urban biodiversity and nature and to create zoning plans within a city. These questions help explore opportunities and challenges in the city, such as stormwater management or resilience to intensifying temperature extremes. Illustrative questions include the following:

- Where in the city do we see significant levels of urban biodiversity?
- Where does urban nature provide the most benefits to people in this city?
- Where are more trees, wetlands, or other surface waters needed in the core urban area to moderate temperature?
- Where do parks and other forms of open space most benefit the health of urban residents? How might we articulate these values and find new funding sources for urban green spaces? (See **box 5** on investing in nature for health.)
- How can we improve equity in the delivery of nature's benefits to residents? (See **box 6** on equity in urban nature for biodiversity, ecosystem services, and people.)
- What parts of the city provide the greatest potential for both biodiversity and flood protection services?
- How might nature-based solutions improve the well-being of the most vulnerable in my city? (See **box 4** on the RISE project.)
- What urban plans, strategies, or policies should urban nature and urban biodiversity be incorporated into (e.g., a city master plan, stormwater management plan, zoning plans, etc.)?

These questions are being asked by city governments, planners, utilities, NGOs, environmental justice groups, and public-private partnerships.

3. Scale of individual parcels within the city. The third planning scale addresses local assessments that can inform particular land use decisions within a city. Asking and answering questions at this scale takes place daily, and cumulatively shapes the future of cities. Better answering these sorts of questions could transform the evolution of cities:

- What benefits do urban residents get from this natural area within the city, and does it make sense to maintain it as is?
- Considering a broad range of stakeholders—including commercial businesses, schools, and community groups—what use of a particular parcel will best satisfy diverse objectives?
- In light of the coronavirus pandemic and shelter-in-place orders, how can we best serve neighborhoods with poor access to parks for physical activity and mental health: through increasing the number and size of local parks, improving transportation to more distant parks, or providing programs that targets those with greatest need? (See **box 11** on health risks related to urbanization.)
- What types of management (or tactics) might greatly enhance urban biodiversity in this landscape (e.g., increasing tree cover and diversity, removing harmful invasive species, restoring natural vegetation, adding connectivity and/or corridors for key species)?

These questions might be asked by private landowners, city governments, community associations, development agencies, or public-private partnerships.

Box 10

How to identify peer cities to guide ecological planning

While every city faces a unique set of challenges and opportunities, it is possible to identify groups of peer cities—those sharing certain commonalities and potential policy solutions that relate to the biological, geological, social, and governance context—by means of a simple typology. This typology can help highlight policy choices related to the allocation of urban green and blue space, or other actions related to promoting urban biodiversity and ecosystem services. Its components reflect information that is commonly used by indexes of urban biodiversity, including city age, size, and population density; economic profile; equity in allocation of resources; baseline levels of biodiversity; and amounts of green and blue space. Cities may relate to one another in some or all of these metrics. This typology can be used alongside the steps outlined in section 3 to (1) help identify goals, (2) identify potential policies or future scenarios, and (3) evaluate the success of the decision-making process and its outcomes.

	Possible metrics	How might this metric influence decisions related to urban nature?
Environmental conditions	▪ Climate ▪ Topography ▪ Elevation ▪ Proximity to coastline ▪ Presence of rivers, lakes, wetlands, etc.	▪ Warmer cities may be more cognizant of urban heat island effects. ▪ Coastal cities or cities with large bodies of water may be more concerned with flood mitigation. ▪ Mountainous cities are likely to see dramatic shifts in biodiversity with climate change and the upward migration of species.
Age	▪ Age of city ▪ Time since reaching 100,000 people ▪ Time since reaching half of current population	▪ Older cities have more established infrastructure. ▪ Older cities likely have more entrenched zoning schemes. ▪ Younger cities may be more flexible in reallocating land.
Size and density	▪ Area of city ▪ Population size ▪ Population density	▪ Larger cities can support more green space and biodiversity. ▪ Denser cities are expected to have less green space. ▪ More populous cities are likely to need to more green space to meet citizens' demands for nature.
Economic conditions	▪ Gross domestic product (GDP) ▪ GDP per capita ▪ Economic breakdown by sector (manufacturing vs. services vs. technology) ▪ GEP (gross ecosystem product)	▪ More affluent cities may have more tax revenue to allocate to urban nature (e.g., the establishment and upkeep of urban parks, bioswales, street trees, etc.). ▪ Cities with a higher proportion of their economy in manufacturing sectors may have less land to allocate to nature because of the footprint of factories. They may also face unique challenges with regards to local pollution. ▪ Cities can track and communicate the benefits of nature to society. ▪ Cities with high dependence on outside sources of water or other benefits can target financial investments in securing those ecosystems and the livelihoods of their stewards. ▪ Cities providing sustainably produced natural products can command higher prices for them and receive other credit for their commitment to sustainability.
Equity within city	▪ Heterogeneity by neighborhood in household median income ▪ Heterogeneity by neighborhood in distance to nearest green space	▪ Cities with more uneven distribution of household income and wealth may have a longer history of inequality to actively overcome. ▪ Urban residents in informal settlements or poor neighborhoods may have particularly strong dependence on urban nature, because of vulnerability to hazards and lack of built infrastructure providing safe water, cooking fuel, or cooling. They may also experience greater disservices, such as exposure to insect and animal pests. ▪ Cities with less equal access to green spaces across neighborhoods may have to do more to ensure future green spaces are allocated equitably across neighborhoods.

Box 10

How to identify peer cities to guide ecological planning (cont.)

	Possible metrics	How might this metric influence decisions related to urban nature?
Baseline biodiversity	▪ Maximum species richness ▪ Number of unique ecosystems ▪ Extent of Key Biodiversity Areas in the city	▪ Cities in biodiversity hotspots (high species richness) are expected to have higher levels of biodiversity; peer cities in hotspots might strive for similar levels of biodiversity (e.g., by increasing the amount and quality of urban green space). ▪ Cities with lots of different types of ecosystems within their boundaries should have higher levels of biodiversity.
Existing green and blue space	▪ Amount of city area dedicated to nature ▪ Historical patterns in amount of green space per year	▪ Cities with lots of green space may have less need or desire to allocate additional land to urban nature. ▪ Cities on a trajectory of decreasing green space with time are especially vulnerable to further loss of urban nature.

Understanding where a city falls along these seven spectra can help decision-makers seek peer cities for inspiration. For example, Copenhagen and Stockholm have similar ages (close to 1,000 years old and around 800 years old, respectively), sizes (180 km^2 and 188 km^2), economies (US$78,000 and US$75,000 GDP per capita), and underlying biodiversity pools (204 bird species versus 181 bird species [Map of Life 2020]), though Copenhagen lags behind Stockholm in green space as a share of area (25 percent compared to 31 percent). Similarly, Bogota might look to Rio de Janeiro as a peer, since the two share similar levels of biodiversity (718 bird species and 612 bird species, respectively [Map of Life 2020]) and are similar in age (both over 400 years old), area (685 km^2 and 485 km^2), and population (7.41 million and 6.32 million).

Green-billed Tingua, Bogota, Colombia. Photo: dalomo84

Toucan and Macaw, Rio de Janeiro, Brazil. Photo: agustavop

Box 11

Zoonotic and vector-borne disease health risks of urbanization

Vector control . Photo: Muhammad Gunawansyah

Connections between nature, biodiversity, and cities bring numerous benefits, detailed throughout this report. However, careful consideration of disease risks associated with urbanization can inform wise ecological planning that prioritizes the health of human populations and the ecosystems on which they depend.

The COVID-19 global pandemic is a dramatic example of the importance of understanding, mitigating, and responding to zoonotic disease emergence in an increasingly urbanized and globalized world. Zoonotic diseases are caused by pathogens (e.g., bacteria, viruses, fungi, and other eucaryotic parasites) transmitted between other animals and people; they comprise the majority of known infectious illnesses in people (Wolfe et al. 2007).

While the COVID-19 pandemic has often been referred to as "unprecedented," the history of humanity is marked by pandemics (Huremović 2019). Some of these—such as the spread of yellow fever and malaria to the Americas via the slave trade—have profoundly altered the course of civilizations (Athni et al. 2021). The ongoing threat of emerging diseases, together with increasing urban-wildlife interfaces, underscores the importance of evidence-based ecological planning in the shaping and reshaping of healthy, vibrant cities for the future.

Before the dawn of agriculture, people living in low-density groups were likely relatively free of virulent epidemic disease (Inhorn and Brown 1990). Only when critical community sizes and densities were reached did zoonotic diseases, such as smallpox, influenza, and measles, seriously affect people; these are thought to have evolved from monkeypox, avian flu, and canine distemper, respectively (Fenner et al. 1974). Measles could not persist in human populations until there were cities of about 200,000 to 500,000 people (Black 1975).

In early urban centers, it was not only the density of human populations but also the conditions in those centers that enabled infectious disease to thrive. For example, poor sanitation and health infrastructure were likely the primary drivers of the first instances of plague outbreaks in early urban centers. The earliest known example of plague caused the collapse of an early European mega-settlement more than 5,000 years ago. Compact housing arrangements and amassed food storage, alongside high densities of animals (including rats and fleas), created ideal conditions for the disease that continued to spread across Eurasia through various trade routes (Rascovan et al. 2019).

From this and other historical examples, several key factors driving zoonotic and vector-borne health risks emerge: (1) human population of sufficient size and density; (2) lack of

Zoonotic and vector-borne disease health risks of urbanization (cont.)

sanitation and health services; (3) heightened population mobility and speed of transport; (4) agricultural intensification, declines in large wildlife, and associated rise of rodents; and (5) contact with animals and human-wildlife-environment interfaces (Daily and Ehrlich 1996). Each of these drivers is increasingly exacerbated by urbanization. The majority of global population growth (resulting, in large part, from internal migration) is expected to occur in urban centers in developing countries where access to adequate health infrastructure may be comparatively limited (World Bank 2018). Increased density will also raise the risk of disease transmission, especially in growing peri-urban slums (Waldman 2015). People in informal settlements often have limited access not only to health services, but also to sanitation infrastructure such as insect screening, drinking water treatment, plumbing, and wastewater treatment, all of which limit the spread of disease.

Mobility of people is also key to disease transmission. For example, mobile phone data have shown that human movements are an important component of the transmission of malaria (Wesolowski et al. 2012). The COVID-19 pandemic demonstrated how rapidly an emerging pathogen can spread in today's interconnected world; local disease outbreaks can now become global with breathtaking speed. In addition, long-term resettlements from conflict and natural disaster can increase the spread of diseases with longer latency periods (Institute of Medicine and National Research Council 2010).

Contact with animals is a significant factor for zoonotic risk, and a variety of human-wildlife-environment interfaces represent critical points for transmission. Industrial agriculture, wildlife trade, wet markets, and research laboratories are some examples of these interfaces that require careful management and safety protocols to mitigate health risks. Habitat degradation is also widening human-wildlife-environment interfaces. Landscape-scale changes—including agricultural intensification, loss of large wildlife, promotion of rodents (Dirzo et al. 2014; Young et al. 2014), and urbanization—result in the expansion of ecotones, transition zones between ecological systems. Ecotones host diverse wildlife-human interactions that increase the risk of emerging infectious diseases (Despommier et al. 2006). For example, bats are a well-known source of zoonoses, including the Ebola, Nipah, Hendra, and SARS-CoV-2 viruses (Letko et al. 2020). Habitat fragmentation and destruction that often accompany urbanization can force bats and other animals to shift their behavior from feeding in more remote, natural ecosystems to feeding in agricultural lands, urban parks, and developed areas, greatly increasing the risk of disease transmission (Plowright et al. 2011; Wacharapluesadee et al. 2018).

The compounding of various risk factors necessitates cross-sectoral solutions. The One Health approach offers insight for urban planning. It recognizes that human health is intimately connected to the health of other animals and the environment and calls on experts across disciplines to integrate their approaches to public health crises (CDC 2018). The One Health approach is urgently needed and is now gaining some traction around the world.

4. Practical tools for analyzing and comparing biodiversity and ecosystem services to support decisions

All three steps above are equally essential to ensuring positive outcomes, as is the follow-up monitoring described more fully in other frameworks.[13] The remainder of this section, however, addresses Step 2—analyzing and comparing biodiversity and ecosystem services to support decisions. Goal-setting and stakeholder engagement (Step 1) and synthesizing information and iterating with decision-makers and communities (Step 3) are already integral parts of urban planning and municipal governance. Of course, they will need to be done anew as part of an ecological planning enterprise, but the tools and approaches are not novel (Yiftachel 1989; Malbert 1998). It is the analysis of urban nature and biodiversity (Step 2), and the necessary tools and approaches for carrying it out, that represent a significant impediment to ecological planning in current practice. This section outlines how to evaluate the efficacy of various tactics used to determine which management actions are most useful in achieving the strategy or goals outlined in Step 1.

Many different types of tools are useful when analyzing and comparing biodiversity and ecosystem services in cities. Almost all mapping requires a geographic information system (GIS). Both licensed tools (ArcGIS) and free and open-source tools (QGIS) are available for manipulating spatial information. The Global Platform for Sustainable Cities (GPSC) describes natural asset and biodiversity valuation in cities and outlines some useful tools (GPSC 2019).

Just as urban planners often have to manage many potentially competing aims in designing metropolitan areas (Levy 2016), ecological planning often requires the consideration of many different forms of nature, biodiversity, and ecosystem services that may or may not be aligned (Anderson et al. 2009; Nelson et al. 2009). Many frameworks have been put forward to evaluate how well a city is currently supporting nature, biodiversity, ecosystem services, and in turn people (Hansen and Pauleit 2014; Woodruff and BenDor 2016). These frameworks focus on evaluating cities against criteria such as (1) the demographics of the city, (2) the amount of nature protected within the city, (3) the levels of urban biodiversity, (4) the provisioning of ecosystem services in and for the city, and (5) local governmental structures and policies put forth to ensure continued protection of nature (Chan et al. 2014). To allow for specificity, this section focuses on two important tools for understanding biodiversity and ecosystem services in cities: the Singapore Index and InVEST, described in detail in **box 12** and **box 13**, respectively.

Expansion of the Singapore Index to enable its use in the evaluation of current patterns and predicted future trends in urban nature, biodiversity, and ecosystem services will enhance its utility in planning and ensure that it is useful in Step 2. Additional metrics of urban nature, biodiversity, and ecosystem services can be incorporated to complement the set of metrics already included in the Singapore Index. Urban nature, urban biodiversity, and urban ecosystem services are all key themes for understanding both the baseline and likely future states of nature in the city. Important metrics and tools for assessing each of these themes is discussed in turn below.

[13] See for example Daily et al. (2009); ICLEI (2015). See also the online course offered by edX., "Introduction to the Natural Capital Project Approach," https://www.edx.org/course/introduction-to-the-natural-capital-project-approach.

Box 12

The Singapore Index

Cape Town, South Africa. Photo: Vera Shestak

The Singapore Index (Chan et al. 2014) is a self-assessment tool for cities that generates a profile of the city's key information, including location, physical features, demographics, economic indicators, biodiversity features, and the administrations responsible for urban nature. Based on this profile, cities evaluate their performance on a number of metrics in four categories: (1) the availability of urban nature (such as amount of green space, configuration of green and blue space, etc.), (2) biodiversity (such as bird species richness, plant species richness, proportion of invasive species, etc.), (3) ecosystem services (such as water regulation, climate regulation, etc.) and (4) administration of nature (such as funding to programs, number of policies in place, etc.). The index tracks 23 indicators spread across these four categories, each of which is scored between 0 and 4, with clear quantitative metrics associated with each of the five possible values for each indicator. More detail on how each section is scored is given in section 4.2. Each city merits an annual score (out of a possible 92) and is expected to recalculate the index annually to track its progress (Centre for Liveable Cities 2015).

The Singapore Index has been applied in 50 cities globally to track current levels of urban biodiversity, nature, and ecosystem services. In at least 36 of these cases, it was the city's municipal government that applied the metrics directly, while in the remaining cases academics or NGOs carried out the analysis for a given city. The application of the Singapore Index has been widespread and varied, with cities from all continents and many nations taking part. A full list of cities that have applied the Singapore Index to date can be found on the interactive web viewer at www.tinyurl.com/SI-Cities.

4.1. Urban nature

The amount and spatial distribution of area dedicated to urban green and blue spaces forms the backbone of any city's plan for conserving urban biodiversity and ecosystem services. There are two metrics that can best measure the baseline of urban nature. First, cities can evaluate the percentage of their landscape that is currently dedicated to green and/or blue space. Second, planners can assess what proportion of this space is permanently protected through legislation or zoning. A city's green and blue spaces are easily assessed over time, using GIS software and data from satellites such as MODIS or Landsat (Kabisch et al. 2016), while public records indicate the amount that is protected by statutes (Girault 2017). Creating scenarios for green and blue space is a simple matter in theory and entails coding areas as urban nature or protected natural areas specifically within a GIS.

In some cases, leaders will not want to go beyond this level of documentation and quantification of urban nature. In other cases, they will want to explore the distribution of urban nature throughout the city (both at the baseline and in alternative scenarios). Understanding what metrics to use to monitor the configuration of urban nature depends on whether the endpoints of interest are ecosystem services or biodiversity or both.

The distribution of green and blue spaces throughout a city is important for planners to consider as they think about equity in the delivery of services to different communities within the city. Some urban ecosystem services provided by urban green space, such as climate mitigation through carbon storage and sequestration, benefit people who are far away from that green space. Others, such as urban cooling services, benefit only nearby people. Consideration of the equitable distribution of urban green spaces and the services they provide to people is critical.

To maintain healthy levels of biodiversity within a city, it is not enough simply to have areas of dedicated green and blue space; species must be able to move between these areas in order to maintain healthy populations—that is, there must be connectivity. Decision-makers can consider three metrics in the evaluation of how well green spaces within a city are connected and thus how well they might support urban biodiversity: (1) the perimeter-to-area ratio, (2) the average distance between green and/or blue spaces, and (3) the permeability of the urban matrix.

The perimeter-to-area metric measures how intact urban nature is: cities with large contiguous patches have much lower ratios of perimeter to area, and cities with many small, isolated patches have higher average ratios (Cook 2002; Hunsaker, Carpenter, and Messer 1990). Again, this metric is easily calculable through Landsat or MODIS images and can easily be recalculated for potential scenarios of change.

The perimeter-to-area metric, however, ignores the spatial arrangement of the patches relative to one another, which necessitates the inclusion of additional connectivity metrics. The first is the average distance between green spaces, calculated as the mean of all possible pairwise distances between parks. This is again calculable under current conditions from satellite imagery, and recalculable with scenarios of change by simply adding or removing more green space (Brown 2008; Davis and Glick 1978; MacArthur and Wilson 1967).

The third and final connectivity metric builds in the recognition that urban biodiversity may not only exist in urban green and blue spaces, but may live in, and move throughout, the entirety of the city (Kowarik 2011; Werner 2011). Those cities with more natural elements throughout are more likely to prove beneficial for the maintenance and movement of biodiversity. Thus, the final metric is the permeability of the urban matrix. This value theoretically ranges between 0 and 1 (but in reality will be much closer to 0) and is calculated as the proportion of each pixel that is classified as photosynthetic vegetation. This metric is responsive to increasing density of street trees, addition of green infrastructure, and similar initiatives. Calculating how this metric will change under future scenarios is more complicated, as it can include both site-specific development plans, such as the addition of green infrastructure in a particular place, and more flexible plans, such as doubling the number of urban street trees in flexible locations. Once these policy positions are translated to maps, however, calculation of future matrix permeability is readily achievable.

Unfortunately, increases in these connectivity metrics that are good for biodiversity can feed into dynamics that increase inequities in the distribution of urban nature and its benefits. To counter unequal distribution of green space, some cities (e.g., New York) and nongovernmental organizations have set goals for every resident to be within a 10-minute walk from a park.[14] The EU has outlined methodologies for exploring and comparing 10-minute-walk access to parks across European cities (Poelman 2016). Many small parks distributed evenly throughout a city will lead to lower connectivity for wildlife, highlighting the need for clearly articulated goals, scenario planning, and careful balancing of trade-offs when considering the appropriate level and distribution of urban nature for a particular city.

Beyond the amount of green and blue space and the connectivity between them, one further aspect of urban nature is important to urban biodiversity: vertical complexity. More vertical complexity in available habitats tends to lead to higher levels of biodiversity (Davies and Asner 2014). Vertical complexity is best measured with two metrics. The first is simply the mean canopy height of urban nature, with a preference for taller trees, indicating older and more mature urban green spaces (Newbold et al. 2015). The second is the inter-quartile range of canopy height across urban green spaces. This metric captures a key point: while mature, tall trees will be generally beneficial, grasslands, shrublands, and other habitats are also key. Hence attention must be paid to the diversity of vertical structure (Goetz et al. 2007). Present-day values for these variables can be derived from LIDAR imagery, and future scenario scores can be generated based on proposed policy interventions (e.g., introduction of mowing and expansion of woodland area). It should be noted that increasing vertical complexity is only one way to manage land use intensity, and cities could also seek to reduce the chemical inputs (e.g., fertilizers, pesticides) that are applied to parcels of urban nature.

[14] NYC Parks, "Walk to a Park Initiative," https://www.nycgovparks.org/planning-and-building/planning/walk-to-a-park; Trust for Public Lands, "10 Minute walk," https://www.tpl.org/10minutewalk.

4.2. Urban biodiversity

The Singapore Index (**box 12**) contains a number of classical metrics of biodiversity. These metrics focus on the number of species, with an emphasis on iconic groups such as birds and butterflies. They typically rely on estimates of species richness, as well as the change in richness through time (Chan et al. 2014). While helpful in many cases, these metrics leave out two key aspects of biodiversity: (1) the abundance of animals or representation of ecosystems (Pereira et al. 2013), and (2) the representation of less iconic taxa (Donaldson et al. 2016). This section suggests building upon and/or expanding the metrics in the Singapore Index for maximum decision-making utility. It proposes methods for assessing these metrics in the absence of high-quality data and suggests how they can be extrapolated into future scenarios of change.

The first two new metrics (beyond those used by the Singapore Index) are associated with the diversity of plants within a city's boundaries. Plants are one of the easier taxonomic groups to sample, especially with repeated visits through time; it is feasible to calculate the following metrics using local plant surveys conducted by the government, universities, or NGOs (see the supplement to Aronson et al. [2014]). If that is not possible, the procedure described below for quantifying total species richness can be applied for plants as well. Surveys should enumerate the total number of plant species as well as the proportion of those species that are invasive (Gulezian and Nyberg 2010). While invasive species are problematic at all trophic levels, the links between overall levels of biodiversity and the level of non-native species in an urban or suburban area are the clearest and most well-resolved (Burghardt, Tallamy, and Shriver 2009; Burghardt et al. 2010).

Birds are often used as indicators of animal biodiversity at large (Butchart et al. 2010). Not only does the species richness of birds tend to correlate well with total species richness, but also the plethora of data available for birds enables much more nuanced consideration of bird biodiversity than would be possible for other taxa (Donaldson et al. 2016). Therefore, three additional metrics can be used to indicate avian biodiversity: total species richness, total abundance, and the evenness of the bird community (evenness refers to how similar the population sizes of each bird species are relative to one another). Comprehensively these three metrics ensure that policies (1) promote a large number of species, (2) encourage healthy populations of those species, and (3) do not overly preference common species over rare species. The use of these three complementary metrics is possible because of frequent, widespread point counts for birds that already cover many cities. Programs such as the Breeding Bird Survey or Farmland Bird Survey provide a framework that other cities currently lacking such coverage can follow (Pardieck et al. 2019; Sauer et al. 2017). The recording of both species richness and abundance, alongside known absences of species, allows for a much fuller understanding of bird biodiversity than the diversity of other taxa.

For taxa other than birds and plants, high-quality biodiversity data can be difficult to find (Donaldson et al. 2016). However, the rise of popular citizen science platforms such as iNaturalist or the Global Biodiversity Information Facility (GBIF) can fill a key void. It is important to note that the most popular citizen science platform for reporting species occurrences varies by country, and individual cities should use data coming from those platforms that are most robust in their regions. These platforms record the latitude, longitude, time of sample, and identity of all species in their database (GBIF 2017). From this, city managers can conduct annual surveys of how many vertebrate and invertebrate species are found within their city each year. It is important to note that some statistical considerations will make the analyses much more robust (Haque et al. 2018; Pardo et al. 2013). For example, relying on a three-year moving average of total species richness, rather than individual annual snapshots, will lend robustness to the analysis. Moreover, it is important to standardize the total number of observations used to calculate species richness for each year, as the increasing popularity of such services has also led to rapid increases in the number of individual organisms recorded and can make present species richness look artificially high relative to years past.

The meta-analysis from Beninde, Veith, and Hochkirch (2015) allows for the extension of static indexes to include projections of how biodiversity is likely to change with alterations to urban green space or other natural elements, such as street trees. This meta-analysis compiles data from 75 global cities and examines how the number of species in a given city is affected by the level of urban nature in that city. It found that species richness increases significantly as a function of the amount of green space, the vertical structure of green space, the area of water bodies in a green space, and the presence of biological corridors between green spaces. This finding allows for the projection of how species richness will likely change under various scenarios considered in Step 2 above.

Biodiversity can be represented not only by the number of species in a city, but also by the abundance and evenness of those species. Similarly, biodiversity can also be characterized at other levels of biological organization (Miraldo et al. 2016). At present, data limitations prevent meaningful evaluation of genetic diversity, but at a larger scale it is possible to incorporate ecosystem diversity into urban development plans. For example, it is feasible to integrate metrics of how well cities are protecting the ecoregions contained within their boundaries. Ecoregions are zones that represent distinct habitat types (Bailey 2004) and contain distinct groupings of species (Smith et al. 2018). Stratifying conservation plans to protect land across all the ecoregions within a city can help ensure that all species within that city are being protected, not just those in the dominant ecoregion. Such calculations can be carried out using global maps (Dinerstein et al. 2017; Olson et al. 2001) or more finely tuned maps for the country or region.

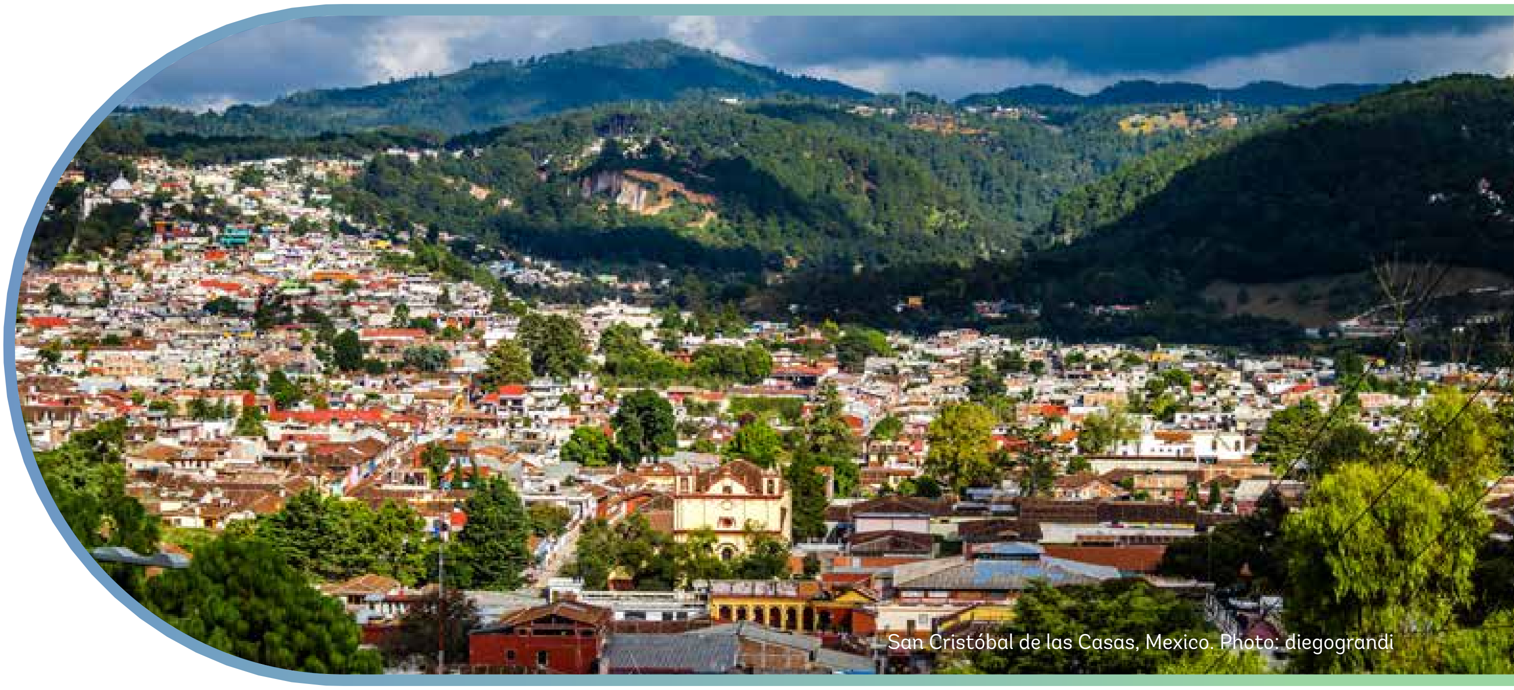
4.3. Urban ecosystem services

The Singapore Index (**box 12**) includes four metrics representing ecosystem services. Two metrics represent regulating services (water quantity and climate) and two metrics represent a cultural service (recreation and education). The four metrics are (1) regulation of quantity of water, (2) climate regulation—carbon storage and cooling effects of vegetation, (3) recreation and education—area of parks with natural areas, and (4) recreation and education—number of visits per child below 16 years to parks with natural areas per year. Some practical complements to the Singapore Index will allow urban leaders to make decisions informed by understanding of ecosystem services and how they can contribute to the well-being of a city and its residents.

There are a number of tools that are available to help assess the provision of ecosystem services, though relatively few have been used in urban environments. See De Groot et al. (2018); Bagstad et al. (2013); Hamel et al. (forthcoming); and the Ecosystems Knowledge Network tool;[15] see also **box 13** on InVEST tools.

When using information about biodiversity and ecosystem services to inform decisions, it is helpful to use the three steps outlined in section 3.3. In consultation with key stakeholders, the team members decide early on in the process what services are important for their context and what metrics they think are useful to compare across the outcomes of the alternative future scenarios. A key choice is in the services to model. For example, urban cooling is of critical importance in Phoenix, Arizona, in the United States, but less so in a high-elevation city such as Bogotá, Colombia.

[15] Ecosystems Knowledge Network, "Welcome to Tool Assessor" (accessed June 2, 2021), https://ecosystemsknowledge.net/tool.



San Cristóbal de las Casas, Mexico. Photo: diegograndi

Box 13

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs)

InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) is a collection of software models that use spatial data and analysis to value the goods and services from nature. It helps explore how changes in ecosystems can lead to changes in the flows of many different benefits to people (Sharp et al. 2019; Chaplin-Kramer et al. 2019; Hamel et al., forthcoming). InVEST is free and open source, designed to work at any scale and in any location globally, and can be used to model multiple ecosystem services.

The multiservice, modular design of InVEST provides an effective tool for balancing the environmental and economic goals of diverse decision-makers. InVEST models use geographic information systems (GIS) in which maps are both the inputs and outputs. InVEST can return results in biophysical metrics (e.g., degrees of urban cooling), economic metrics (e.g., avoided cooling costs, and other social metrics (e.g., changes in mortality/morbidity). The models allow for diverse spatial resolutions, enabling users to ask and answer questions at local, regional, or global scales. InVEST has been available for more than a decade and has users in over 185 countries worldwide. The original tools focused on terrestrial and freshwater systems, with marine and coastal tools added second, and the first urban tools added in 2019. The urban tools within InVEST are described in Hamel et al. (forthcoming); the supplemental information in Hamel et al. offers a description of other ecosystem service assessment tools and their applicability to urban systems.

Building on the use of InVEST tools to inform decisions outside of cities (e.g., Ruckelshaus et al. 2013), new Urban InVEST tools have now been used to inform ecological planning in Paris (France), Shenzhen (China), and Minneapolis/St. Paul (US) (Hamel et al., forthcoming). The InVEST modeling approach to key urban ecosystem services—urban cooling, flood mitigation, climate change mitigation, and mental and physical health—is described below.

Urban cooling: As cities around the world experience more intense and frequent heat waves, urban heat mitigation is increasingly becoming a priority. Vegetation provides shade, increases cooling via evapotranspiration, and modifies the thermal properties of an urban environment. This reduces the urban heat island effect, which improves the health and well-being of the community, both physically and mentally. Lower mortality and morbidity and greater comfort and productivity are associated with reduced urban heat islands. The InVEST Urban Cooling model integrates shade, evapotranspiration, albedo, and the distance from cooling islands (e.g., parks) to formulate an index of heat mitigation. The index is then used to estimate a reduction in temperature due to vegetation. Finally, there are two optional valuation methods to estimate the value of heat mitigation based on energy consumption and work productivity. Calculating the difference between present-day cooling and the amount of cooling provided by different scenarios will allow cities to evaluate the percentage gain or loss in service provisioning.

Flood mitigation (urban stormwater flooding and coastal flooding): Natural infrastructure can play a role in mitigating both urban stormwater flooding and coastal flooding.

For urban stormwater flooding, natural infrastructure operates mainly by reducing runoff, slowing surface flows, and creating space for water to drain naturally (in floodplains or basins). The InVEST model calculates the runoff reduction, i.e., the amount of runoff retained per pixel compared to the storm volume. For each watershed, it also calculates the potential economic damage by overlaying information on potential flood extent and built infrastructure.

For coastal flooding, natural infrastructure operates mainly by reducing the impacts of coastal hazards by decreasing the forces of winds and waves and by creating space for water along coastlines (e.g., parkland that can take floodwaters, thereby protecting buildings or transportation infrastructure). Coastal cities are at an increased risk of storm-induced erosion and flooding (inundation) as climate change and human development progress. There is a need to better understand how both biological and physical modifications to the environment increase coastal exposure.

The InVEST Coastal Vulnerability model produces a qualitative vulnerability index that differentiates areas according to their level of exposure to storm-induced erosion and flooding. When coupled with global population information, the model can highlight regions that are most vulnerable to storm surge along a given coastline. Model inputs include information about the local coastal geomorphology along the shoreline, the location of natural habitats (e.g., seagrass, kelp, wetlands, etc.), rates of net sea-level change, bathymetry, topography of the coastal area, storm wind speed and wave power data, and population distribution. The model outputs help to identify the relative contribution of each variable to overall coastal exposure, highlighting the protective benefits that natural habitats can offer to coastal communities. This information can better inform development strategies for city managers, landowners, and other relevant stakeholders. Rather than quantifying shoreline retreat or inundation, the model provides a more qualitative representation of coastal hazard and risk.

For both types of flooding, scenario analysis can calculate how much in ecosystem service provisioning a city is set

Ras Al Khor Wildlife Sanctuary, Dubai. Photo: Aleksandra Tokarz

to gain or lose from the different policies or development scenarios it might pursue.

Climate change mitigation: Both marine and terrestrial ecosystems sequester carbon from the atmosphere, helping to regulate Earth's climate. The InVEST Carbon Storage and Sequestration model uses spatial land use data and integrates four different carbon pools (above-ground biomass, below-ground biomass, soil, and dead organic matter) to estimate the total amount of carbon stored in a landscape or sequestered over time. Additional data on the market or social value of sequestered carbon, its annual rate of change, and a discount rate can be used to estimate the monetary value of this ecosystem service to society. This model can be used anywhere along the urban-to-rural gradient, from the most densely populated urban core to undeveloped hinterlands.

Coastal cities may also be interested in modeling the carbon storage and sequestration provided by coastal environments. Mangroves, coastal marshes, and seagrasses, in particular, store enormous amounts of carbon in their biomass (e.g., sediments, leaves, etc.). Carbon continually accumulates in marine sediments, resulting in massive reservoirs. This long-term storage of carbon in marine ecosystems mitigates climate change as the CO_2 is removed from the atmosphere. Management activities that alter coastal vegetation cover, such as the clearing of mangrove forests, also alter the potential to store and sequester carbon in those ecosystems.

The InVEST Coastal Blue Carbon model explores the amount of carbon stored and sequestered over a coastal zone at particular points in time as land cover changes. Using an estimate of the monetary social value for stored and sequestered carbon, or where available a market price, the InVEST Coastal Blue Carbon model also quantifies the marginal value of storage and sequestration. Results of the InVEST Coastal Blue Carbon model can be used to compare current and future scenarios of carbon stock and net sequestration, as well as to identify locations within the landscape where degradation of coastal ecosystems should be avoided and restoration of coastal ecosystems should be prioritized in order to preserve and enhance these carbon storage and sequestration services.

Mental and physical health: Particularly in cities, where people's contact with nature can be minimal, access to nature is often associated with improved mental and physical health (e.g., Bowler et al. 2010; Hartig et al. 2014; Kondo et al. 2018). An international group of experts recently laid out the conceptual basis for a spatial model like those in InVEST that could be used to examine how changes in access to nature in a city, district, or neighborhood might impact the mental health (and associated expenditures) of local residents (Bratman et al. 2019). The approach includes gathering information about natural features (such as parks and street trees), exposure of local populations to those natural features (e.g., street tree density or amount of local park area), types of experience (e.g., active or passive), and demographic information.

There is also a powerful connection between access to nature and physical health. Notably, contact with nature promotes physical activity; and increases in physical activity yield substantive increases in health (Remme et al. 2021). Insufficient physical activity is a key risk factor for morbidity and premature mortality globally. In 2010, physical inactivity was the fourth leading risk factor for noncommunicable diseases, accounting for over 3 million preventable deaths (WHO 2010). With sedentary urban lifestyles contributing to this risk (Fisher et al. 2017), policies that enhance access to and programming in urban nature have the potential to significantly increase health (Hunter et al. 2019).

General models for both mental and physical health—which can help shed light on how changes in climate, management, and land use in a city are likely to impact mental and physical health—are now being developed. Until they are available, bespoke local analyses of connections between urban nature and health can be used to inform decisions.

5. Conclusion

As described throughout this document, one important way for urban leaders to rise to today's challenges is to bring biodiversity and nature into urban design through urban ecological planning. Such planning recognizes that cities depend on biodiversity and that biodiversity depends on cities. Ecological planning not only illuminates the linkages between urbanization and biodiversity, but also helps integrate this understanding into urban planning, strategy, and investment. We have the knowledge, data, tools, and approaches to direct investment in nature to solve many different types of urban problems. Using these approaches today will help cities of the future become more sustainable, livable, resilient, and equitable.

More than any other parts of the planet, urban ecosystems are designed for and by people. They are a reflection and product of human culture and a vital arena in which the deep cultural shifts needed to drive greater sustainability and equity are originating and building. Leadership to address the escalating risks and costs of destabilizing Earth's life-support systems and climate must come from cities. The world-class cities of the future will be created today, as cities create and work toward livable, sustainable, and equitable futures using cutting-edge science, inclusive, expansive visioning, and comprehensive and strategic planning that works with, and not against, nature.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Panama City from Parque Metropolitano Rainforest. Photo: Jack Osborne

Cities are increasingly recognizing the role of the natural environment in shaping healthy and livable places that enhance human capital and urban resilience. This paper shares how cities are using innovative approaches for policy making and planning to account for natural assets and to protect and enhance biodiversity. A range of policy options is provided together with a practical action plan for conducting assessments of natural assets in and around cities. With this information cities can holistically assess, plan, create, and maintain natural assets to leverage their value for residents' wellbeing.

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