Nature-Based Solutions for Cities

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Nature-Based Solutions for Cities

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Foreword I

Dagmar Haase

More than half of all people already live in cities, and the trend is rising. This makes large cities the laboratories of the future where nature and people co-exist and co-habitate, but also where the effects of climate change and air pollution, as well as extreme flooding, hit people first and with full force. Not exclusively but also in cities, nature and people are inextricably linked, like two siblings growing up in the same environment. And despite the harshest treatment of nature by humans in urban environments, nature and its ecosystems hold many healing and supporting potentials for the humans inhabiting urban ecosystems. Green vegetation cools and binds pollutants, blue infrastructure buffers heat and lowers maximum temperatures, as we saw in central India during the first major heat wave of 2022. Finally, and amazingly, partially hybrid biodiversity ensures resilience and resistance of those ecosystem services. Green and blue infrastructures are important media and mediators between people and nature in cities. For many urgent societal challenges in maintaining and improving the human quality of life in our cities around the world, nature, natural but also designed ecosystems, is regarded as a promising problem solver. That is what *Nature-Based Solutions for Cities* is about. This book presents valuable experiences and applications of the concept of nature-based solutions from across the globe with a unique view and excellent interdisciplinary and transdisciplinary expertise. In this way, quantitative analyses of the effectiveness of nature-based solutions on the one hand and integrated assessments and governance approaches on the other are compared. In addition, one part illustrates the irreplaceable co-benefits of designing or mimicking nature for local biodiversity. Nature, so the authors argue, is most effective for many aspects of people's mental health to withstand heat waves, noise, and feelings of anxiety due to urban density. Finally, a more radical or direct approach to engaging with art and design for and with nature-based solutions involving Indigenous knowledge, presented by a group of authors in the last part of the book, became one of the definite highlights, of many, of this great book.

Dagmar Haase
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Foreword II

Karen C. Seto

The challenges that cities face today are innumerable and well documented. Whether it is their role in driving global environmental change or their vulnerability to economic, social, and ecological crises, cities are at the confluence of risks and threats from local to planetary scales. The 5th and 6th Intergovernmental Panel on Climate Change Assessment Reports make clear that urban areas are central to solving climate change because they contribute to 65–75 percent of greenhouse gas emissions. In order to limit global warming to 2°C or below, there needs to be a transformational change in urban systems and their infrastructure.

For cities that have already been built, the challenge will be how to redesign, transform, and renovate existing infrastructures so that they are low- or net-zero carbon. For new and developing cities with nascent infrastructure, their energy use and associated behaviors have not been locked in. Therefore, it is essential that the design of their urban infrastructure fosters low-carbon lifestyles. However, it is not only operational energy use of cities with which we need to be concerned about. Urban emissions are driven by many factors, including a growing urban population, the increased ownership of private vehicles, heating and cooling, and the growing use of steel, cement, and other building materials. Thus, cities need to consider the energy and embodied emissions of their built environment. Some studies show that the embodied emissions from *building*, not even *operating*, the urban infrastructure for the Global South will exceed the remaining carbon budget.

With urban areas expanding at a rate equivalent to 20,000 American football fields per day, the infrastructure challenge is enormous. With disorienting speed, older towns and metros all around the world are building up and spreading out. Agrarian towns and villages are being absorbed by or transformed into larger urban megapolitans. Rapid urban development will continue through the middle of this century at least, and in many regions of the Global South such as India and Nigeria, it will accelerate. According to the latest United Nations projections, the urban population is growing by approximately 1 million every five days. Although the long-term effects of Covid-19 on urbanization and birth rates are unknown, the current trends of city and infrastructure building and urban population growth are unprecedented in history. The global infrastructure gap is estimated to be $94 billion between 2016 and 2040. This is to

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develop the road, power, transport, water, and telecommunications infrastructure, and notably does not include the cost to build housing, schools, hospitals, and other built-up elements of cities.

How cities grow will affect not only global climate; it will also affect local climate. The urban heat island has been well documented, showing that cities are warmer—especially at night—than surrounding regions, due to urban materials, land cover, and activities. Urban expansion also drives changes in local temperature because of changes in land cover, evapotranspiration, and surface albedo—the ability of surfaces to reflect heat from the sun. Research from my group shows that in many regions of Sub-Saharan Africa and Southeast Asia, urban expansion-driven changes in local temperature will be much greater than climate change-driven changes in local temperatures. Given this, cities need to consider their use of building and infrastructure materials.

Cities must therefore achieve four goals: minimize greenhouse gas emissions, foster low and net-zero carbon behaviors, minimize changes in land cover that increase local temperatures and exacerbate the urban heat island effect, and create livable and vibrant communities. How can they possibly do this with limited human and financial resources and given the need for urgent action?

Nature-based solutions through natural infrastructure can help cities achieve all of these aims simultaneously. Numerous studies have shown that nature-based solutions can provide cost-effective solutions that have multiple benefits for people and the environment, such as reducing urban heat, providing shade to buildings and thus reducing demand for air conditioning, and absorbing storm surges. Furthermore, there are myriad economic, health, and social benefits of neighborhoods with green spaces and tree cover. Therefore, it is not surprising that nature-based solutions have garnered much attention from the science and practice communities in the past decade.

However, with a fast-growing literature on nature-based solutions, it is difficult to parse out what works where, when, and how. McPhearson, Kabisch, and Frantzeskaki have developed an ambitious, comprehensive volume that synthesizes the science and practice of nature-based solutions using real-world examples. This is an exciting and timely volume that will be of interest to researchers and practitioners. It addresses many of the aforementioned challenges and provides clear illustrations of how nature-based solutions offer benefits for people and the environment. Importantly, the book also addresses the governance and design of nature-based solutions, two aspects that are often underexplored. In creating this must-have handbook that should be on the shelf of every urban practitioner (and perhaps every urban resident), McPhearson, Kabisch, and Frantzeskaki have done an enormous service to helping make cities more livable and the planet more sustainable.

Karen C. Seto
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Acknowledgments

The idea for this book was born before the Covid-19 pandemic started. It took large effort, motivation, and enduring collaboration of all authors and editors to see it through two-plus years of pandemic, video calls across many time zones, and persistence to bring the multiple dimensions of urban nature-based solutions together for this volume. The result is a book that builds on the knowledge and expertise of the diverse and dedicated authors assembled here. We thank our authors first and foremost. Of course, this work also builds on and attempts to synthesize a quite broad knowledge base from the work of researchers and practitioners working on nature-based solutions across the world.

We are incredibly grateful for the NATURA global network of network support funded by the United States National Science Foundation (1927468 and 1927167) which has helped to share knowledge and create new pathways for impact on nature-based solutions globally. Our editor team was also supported by the Nordforsk Foundation, Kresge Foundation, Alfred P. Sloan Foundation, the European Community's Framework Program Horizon 2020 for the Connecting Nature Project (grant agreement no. 730222), and an even wider list of funding from private and public sources supporting our chapter authors. We were also supported by the research project "Environmental Health Interactions in Cities (GreenEquityHEALTH)—Challenges for Human Well-being under Global Changes" (2017–2022), funded by the German Federal Ministry of Education and Research (BMBF), funding code: 01LN1705A.

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speech, and dedication to research of climate change, sustainability, and urban sustainability transitions.

We are extremely grateful to Alyssa Dennis for providing the custom and inspiring art for every chapter, that included inputs from co-authors in every case and thus required her enormous patience as we co-created a vision for urban nature-based solutions art that can convey the complexities of how urban nature is seen, governed, stewarded, and cared for in the context of dynamic complex urban systems of all kinds across the world.

In addition to this, the support received by the New School, New York, USA, Utrecht University, The Netherlands, and Humboldt-Universität zu Berlin, Germany, to make sure this book is open access and as such accessible to all is a sign of hope for open science and collaboration across countries and universities.

Timon, Nadja, and Niki
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1. Nature-based solutions for sustainable, resilient, and equitable cities

Timon McPhearson, Nadja Kabisch, and Niki Frantzeskaki

We are living in the urban century, one where urbanization is driving multiple global environmental changes that in turn place stress and cause major disturbances to urban life and ecosystems. Cities across the world can be vastly different, but they also have in common the concentration of people, infrastructure, and economies that create and amplify risks from climate change, pandemics, and economic crises. The dominant mode of urban development paves over urban nature, traps heat, increases risk from flooding, and displaces human and ecological communities all while also creating efficiencies and opportunities to support the still expanding global population. Urban growth is expected to be the major source of population growth throughout the middle and end of the twenty-first century. Soberingly, the amount of urban growth needed to support future urban populations may exceed all previous urban development of the last centuries.

Already 4.2 billion urban residents need quality housing, food, clean water, and a good and healthy living and this need will expand with an expected two-thirds of the global population living in cities by 2050 (UN Habitat 2018; Dodman et al. 2022). We are thus in a critical moment to consider how we can build new cities and retrofit our existing cities, regions, and neighborhoods to be places that are desirable and thus meet the normative goals we share for our own futures, and those of coming generations. As we look out to the end of the century, which our children may experience first hand, it is clear that transforming our cities to places that are inclusive, equitable, resilient, and sustainable requires rethinking our relationship to nature, and investing in urban development, design, and governance that brings nature into the center of our complex and complicated urban systems. Reconnecting humanity to the biosphere has to be a focus in cities, places where not only the majority of humans now live, but where most future children will be born. The nature we have in cities may be the only nature many humans will know that is not touched or seen through a virtual experience.

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At the same time, climate change, biodiversity loss, pollution, and other human-driven environmental crises are still on a pathway that drives dystopian futures that dominate popular discourses of our shared futures. Rising sea levels, landslides, air pollution, and record-setting heat waves, wildfires, floods, and droughts with increasing frequency pose significant risks to communities and infrastructure – risks that are increasing in every part of the world but are particularly impacting cities where humans and values accumulate. Many cities are located in low-lying coastal zones and are likely to suffer from development intensification, increasing the exposure of people, infrastructure, and economic activity to coastal storms and the effects of sea-level rise (Dodman et al. 2022). Of course, it is not only coastal cities that are at risk. Cities around the world are more prone to suffer from extreme heat due to the combined impacts of the urban heat island, rising temperatures, and air pollution. In fact, cities already experience more than twice as much warming as non-urban regions due to the amplificatory effect of urban heat islands. Projections indicate that some of the world's largest cities could warm by as much as 7°C by 2100 (Estrada et al. 2017). As the toll from extreme events continues to mount, there is an urgent need for mainstreaming sustainable and resilient solutions for cities in the Anthropocene.

A turning point from climate-vulnerable to climate-resilient urban infrastructure planning is already happening with many cities striving for ways to reconnect with nature, to ecologically upgrade urban common spaces, and respond to climate change pressures in an inclusive and resilient way. Now more than ever, urban ecosystems are increasingly at the forefront of such sustainable and resilient innovations being employed as nature-based solutions (NBS) for improving urban livelihoods (Kabisch et al. 2017; Frantzeskaki et al. 2019; Keeler et al. 2019). Cities around the world are using ecological, nature-based design (i.e. green and blue infrastructure) as alternatives and complements to "hard" and "grey" engineered infrastructure to mitigate and adapt to the challenges posed by climate change and urbanization. At the same time, green and blue infrastructure, or urban ecological infrastructure (Childers et al. 2017), provides a variety of urban services for urban residents such as opportunities for recreation or social interaction. Urban ecological infrastructure and ecological, nature-based design are increasingly being framed as NBS to societal challenges.

But just how should we define NBS? There have been several definitions introduced in the last decade, but a useful starting place is a widely accepted definition put forward by the International Union for Conservation (2017), which says that NBS are "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." It is important to stress that NBS are systemic solutions that restore

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or create new feedback loops between social, ecological, and technological systems in the urban landscape and have the ability to deliver multiple co-benefits across social, ecological, and economic domains. As such, we see NBS delivering and playing an important role in restoring, sustaining, and establishing human as well as ecosystem health and thus critical to planetary health. Overall, NBS can be regarded as an inclusive umbrella concept of established ecosystem-based approaches, such as "ecosystem services," "green-blue infrastructure," "ecological engineering," "ecosystem-based management," and "natural capital" (Nesshöver et al. 2017). The NBS concept includes assessments of the social and economic benefits of resource-efficient and systemic solutions that combine technical, business, finance, governance, regulatory, and social innovation which are of particular importance in the context of urbanization and climate change (Raymond et al. 2017).

NBS are continuing to gain prominence in climate change and biodiversity agendas and targets (Frantzeskaki et al. 2019) since nature is increasingly seen as a critical infrastructure that provides fundamental and difficult-to-replace services for human health and wellbeing (Keeler et al. 2019; McPhearson 2022). In the last few years, the global research communities of sustainability science, urban ecology, landscape ecology, and climate science, jointly with policymakers and practitioners (e.g. International Union for Conservation of Nature, ICLEI), have expanded the case for NBS by anchoring them into global agendas and through science–policy dialogues (Frantzeskaki and McPhearson 2022). Examples of these activities include the United Nations (UN) Habitat III New Urban Agenda in 2016, the Intergovernmental Panel for Climate Change's (IPCC) Cities and Climate Change Charter in 2018, the UN COP20 in New York in 2019, the NBS COP25 event in 2019, which launched the NBS for Climate Manifesto focusing on NBS for finance and green jobs, the UN Environment Programme (2022) report on the viability of NBS for climate adaptation, recent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reports for promoting NBS governance (IPBES 2019; Mastrángelo et al. 2019), and the Dasgupta Review (Dasgupta 2021) and World Economic Forum report from the Global Commission on BiodiverCities, both of which provide the business case for investing in NBS for resilience (World Economic Forum and Alexander von Humboldt Biological Resources Research Institute 2022).

NBS has become central to climate adaptation and mitigation policy in the United States (U.S.) through U.S. President Biden's Executive Order on NBS announced in April 2022 (Diep and McPhearson 2022; U.S. White House 2022) and the U.S. NBS Roadmap released at COP27 in November 2022. The Biden Executive Order established the first U.S. National Nature Assessment, called for establishing guidance for federal agencies on adopting NBS as a climate strategy, and incorporated valuation of nature into federal

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climate action. The U.S. NBS Roadmap lays out a plan at the federal level for prioritizing research and knowledge synthesis, updating policies to include NBS, unlocking funding, and training an NBS workforce. Investments in NBS implementation, as well as research, have also scaled up in Europe, China, and other regions (Frantzeskaki and McPhearson 2022). Since the introduction of NBS in 2015 in the European Union agenda, NBS research investment alone in Europe has been ambitious, amounting to nearly €160 million in 2020 (Faivre et al. 2017). Additionally, a joint IPBES–IPCC report in 2021 (Pörtner et al. 2021) and the IPCC AR6 WGII and WGIII reports (Dodman et al. 2022; Lwasa et al. 2022) all position NBS as a cornerstone for addressing the twin crises of biodiversity loss and climate change (McPhearson et al. 2022).

In this book we start from two fundamental realizations. First, that NBS are multi-disciplinary projects, requiring interdisciplinary research and transdisciplinary collaborations. Second, NBS is a suite of solutions varying from natural areas including wetlands, forests, grasslands, lakes, and rivers to more highly managed and constructed urban green and blue infrastructures such as green roofs, rain gardens, street trees, pocket parks, and more. Fundamentally for the urban context, NBS must be considered as multi-disciplinary projects that require systems thinking and multi-level governance. As multi-disciplinary projects, NBS require the weaving and coordination of expertise across ecology, urban design and architecture, urban policy and planning, environmental engineering, and governance at multiple scales. As researchers working in the interface of science–policy–community we have recognized an increasing and imminent need to design, plan, and implement NBS with the integrated knowledge of different disciplines and a diversity of types of knowledge (Kabisch et al. 2022).

With NBS planning and implementation comes a plethora of critical questions to address: Where to build or invest in NBS in a city? Which area needs to be revitalized or regenerated with NBS? What type of NBS is most appropriate to a specific societal challenge and fits in a local place to be sustainable over time and yield the needed co-benefits? What are the technical characteristics and requirements for the chosen NBS? What are the maintenance requirements and demands for the NBS's sustainability? Can we more fully understand the larger suite of social-ecological-technological system benefits or trade-offs it will bring about? What are the health benefits of NBS? What are the benefits of NBS for climate change mitigation and adaptation? What is required for its planning and implementation and which actors need to be engaged in planning and implementing NBS? What are the justice considerations when planning NBS? What are the planning instruments and approaches for NBS? All these questions and more require an inter- and transdisciplinary knowledge basis and a collaborative approach across disciplines to guide their development and design. With NBS being an umbrella concept, bringing together knowl-

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edge and expertise developed over the years across fields of expertise (e.g. ecosystem-based adaptation, integrated water management, urban ecology), the lessons learnt about the importance of inter- and transdisciplinary research and collaborations apply here as well and we hope can enable leapfrogging the future development of the field of NBS and their mainstreaming.

In this book our authors consider NBS from a variety of interdisciplinary perspectives and include cases of different NBS types. These different NBS types are introduced in the chapters as elements that should respond to societal challenges. In urban areas, however, particular challenges need to be considered which come with particular demands for NBS implementations. These challenges include potential conflicts in the competition for space elevated by system density and system nestedness in the urban growth context; the very specific environmental conditions in cities with anthropogenically altered ecosystems, habitats, lacking connectivity with severe impacts on biodiversity; the need to consider multiple actors and values in the planning and governance of NBS to improve environmental and social justice conditions; the existence of long-lasting path dependencies in the cultural and planning history of every city; and to deal wisely with a potential pertaining misunderstanding that cities are artificial, technological landscapes in which nature is not part of the urban environment (Kabisch et al. 2022). This diversity of challenges is addressed throughout the chapters of our book.

STRUCTURE OF THE BOOK

Nature-Based Solutions for Cities brings diverse perspectives from across the globe together to describe the state of the art in advancing NBS for cities. Our goal is to provide a handbook for graduate students, early-career professionals, and emerging and advanced scholars to begin working with NBS in ways that consider multiple perspectives, disciplines, and ways of knowing. Together, the chapters in this book aim at understanding how NBS can be better managed, planned, and engaged with, and to center questions of NBS for whom and for what NBS are planned and implemented in cities. Through chapters led by experts in both Global South and North contexts, we describe key knowledge and learning for advancing the interdisciplinary science of NBS *in*, *for*, and *with* cities and discuss the frontiers for next-generation NBS. Our book is organized in five main parts framed by an Introduction and a Synthesis.

- *Part I: Nature-based solutions for what and for whom?* This provides a detailed focus on climate and environmental justice challenges that NBS aim to address. NBS are discussed in the context of climate change

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resilience in the chapter of Grimm et al. and of environmental justice in the chapter of Tozer et al.

- *Part II: The nature of nature-based solutions*. This describes how NBS can provide ecological benefits and specific conditions for supporting biodiversity as well as how ecosystems themselves must be resilient to urban environmental stressors in order to reliably provide NBS in chapters by McPhearson et al. and Knapp and MacIvor.
- *Part III: The multiple benefits of nature-based solutions*. These chapters discuss a wide range of regulating and health-related benefits and contributions of NBS in and for cities. NBS benefits, gaps, and recommendations for impact are outlined by the chapters of Coseo and Hamstead focused on heat and air pollution, McPhillips et al. on stormwater, and a focus on health by the two chapters of Besser and Lovasi and Kabisch et al.
- *Part IV: Nature-based solutions governance, planning, and value*. This brings contributions that deepen a systematic understanding when governing, planning, and valuing NBS. This issue of considering system density and system nestedness is introduced by the chapters of Hansen et al. and Frantzeskaki et al. and, from a multiple value dimension, which includes ecological, social, and economic benefits, by Guerry et al.
- *Part V: Engaging art and design for and with nature-based solutions*. This relates to how to engage with art and design for and with NBS which are deeply integrated parts of the urban landscape. McGrath et al. critically examine how indigenous knowledge and needs must be centered in urban design and two chapters – by Kennedy et al. and Lydon et al. – introduce how art can be used for this communication effort.

What follows is a brief description of the central contributions of each chapter.

Grimm et al. introduce the major challenge that climate change and weather-related extreme events pose for urban social, ecological, and technological systems. They then introduce the concept of NBS as an opportunity to invest in urban nature to improve the ability of cities to respond to shocks and stressors associated with climate change. They describe NBS opportunities and barriers in implementing them for improving urban resilience.

Tozer et al. focus on the challenge of addressing environmental justice in urban NBS implementations. The authors introduce different environmental justice dimensions and discuss how these justice concerns are addressed in NBS design, planning, implementation, and monitoring. They also introduce specific consideration of local cultural variations in values of and perceived benefits from NBS, designing NBS at appropriate spatial scales, and financing NBS. Three ways forward for advancing justice through urban NBS are introduced, including the development of novel socio-ecological relationships, applying co-production in transformative ways, and focusing on institutional

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and economic arrangements that widely consider social justice. Two African examples are provided including a nature reserve in Cape Town.

McPhearson et al. ask, how can we understand whether urban ecosystems are themselves resilient to urban stressors, including from climate and weather-related extreme events? And will these urban ecosystems be able to reliably provide NBS as planned and expected? The authors provide an urban ecological resilience conceptual framework that links species information with trait data to suggest a methodological approach for assessing urban ecosystem resilience. They provide examples from a case study of street trees in New York City to assess resilience to climate-induced stressors including urban heat and flooding, which can pose challenges not only for urban vegetation, but other taxa as well.

Broad NBS implementation and biodiversity conservation are considered major strategic aims in urban planning and decision making. *Knapp and MacIvor* provide an overview of the relationships between biodiversity and NBS. They discuss how different biodiversity dimensions such as genetic, functional, or habitat biodiversity together with groups of species (e.g. native and non-native) may support the provision of ecosystem services through NBS and the potential trade-offs. Using two elements of the urban green infrastructure network – street trees and green roofs – the authors illustrate how biodiversity can support the provision of climate regulation through NBS while also supporting biodiversity conservation.

Coseo and Hamstead focus on the parallel atmospheric threats of extreme heat and air pollution which directly cause illness and mortality, and lead to premature death by exacerbating existing health conditions. They take a joint planning, design, and engineering perspective to conceptualize atmospheric hazards as place-based experiences that can be partially addressed through NBS. This chapter reviews the state of scientific evidence for NBS in a variety of bioclimatic regions including reviewing the benefits of NBS for mitigating heat and air pollution, discussing current evidence, and identifying effective NBS types for heat and air pollution mitigation.

McPhillips et al. describe the role of NBS for managing water resources. They describe two NBS for water that range from hybrid ecological-technological features explicitly engineered to manage stormwater to other designed or intact natural features such as wetlands or parks that may provide water management as a co-benefit. They review criteria for choosing the most effective NBS for the intended goal and showcase several examples of NBS for water resilience from around the world. The authors then discuss remaining knowledge gaps for NBS for water implementation, including space challenges, changes in performance over time, and incorporation of NBS that are not explicitly engineered for water management into existing management and regulatory frameworks.

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Besser and Lovasi present and discuss recent research on the influence of NBS and health exposure on physical health outcomes. Authors provide an overview of individual studies, reviews, and meta-analyses from epidemiology and other related disciplines. Although a positive influence of nature contact with physical health outcomes is shown, the authors highlight that only limited conclusions can be drawn regarding causal relationships between nature exposure and health. This is an area ripe for new research.

Kabisch et al. introduce the mental health benefits of urban NBS. Several pathways of how urban NBS impact mental health are presented and explained using recent research. The authors highlight three particular pathways for NBS's mental health association. These include: (1) factors that determine urban mental health and adverse health effects of environmental stressors in cities; (2) co-benefits provided by green spaces as NBS for societal challenges shown via the pathway of reducing stressors; and (3) NBS targeted directly at supporting mental health by providing resources for human–nature interaction, enhancing social interaction and strengthening mental resilience. How these pathways perform in real life is illustrated by applying a conceptual model to a newly developed park on a former railway brownfield site in Leipzig, Germany, and to street trees in Hyderabad, India.

Planning and governing NBS is challenging. *Hansen et al.* introduce four examples from cities in Australia, Asia, Europe and Latin America to illustrate the importance of strategic planning for the implementation and maintenance of NBS, particularly in the context of climate change impacts and a potential reduction of the capacity to provide ecosystem services. Based on the city examples, the authors discuss how public green spaces and urban trees may be considered NBS in their particular local contexts while also relating to the challenges of NBS mainstreaming and maintenance.

Frantzeskaki et al. introduce the aspects of NBS governance. They first present two modes of governance: governance of NBS as a mode to deal with the approaches and instruments to govern existing or extended NBS in cities; and governance with NBS as a mode of considering NBS as a means to deal with urban challenges. Governance of and with NBS require being inclusive and the chapter further unpacks and proposes a conceptualization of inclusivity as inclusive to actors from multiple sectors (cross-sectoral inclusivity), considering more-than-human dimensions (multi-species inclusivity), bridging generational interests (intergenerational inclusivity), incorporating different origins and types of knowledge including local or indigenous knowledge holders (epistemic inclusivity), and spatially distributing benefits and accessibility equitably (spatial inclusivity).

Guerry et al. introduce multiple values associated with NBS in cities. Theory and practice approaches for both monetary and non-monetary valuation methods are explained by using examples from Guangzhou, China, and

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Minneapolis, U.S. The authors show an approach of mapping, measuring, and valuing the benefits provided by NBS, i.e. cooling, flood protection, and climate change mitigation but also recreation and improvement of citizens' health.

McGrath et al. focus on the role of NBS in urban design. They present a case study of Chiang Mai, Thailand, as an example of an integrative expansion of urban design practices as indigenous social-natural resolutions as a counterpoint to other articulations of NBS. The case study is framed by a critique of technocratic architecture-based urban design and landscape-based urban planning professions. The indigenous urbanism they discuss sees urban design reconceived as small-scale, local, and practical technologies for resolving the challenges inherent in socially and naturally occurring processes.

Kennedy et al. explore the history of ecological art since the 1960s, highlighting examples of artists working in urban areas. The authors discuss the increasingly crucial role ecological art plays in advocating for and implementing NBS, while also examining emerging and historic concerns about how to effectively integrate and support artists' visions in urban planning, design, and governance. They present a variety of artworks and practices from across the globe, ranging from artworks focused on remediating or regenerating degraded landscapes to examples of interdisciplinary exchanges between artists, scientists, planners, and other stakeholders utilizing community-based approaches.

Lydon et al. discuss how art and creative practices can inspire new ways of knowing and approaches to NBS. The authors present a three-step process: (1) awareness; (2) radical imagination; and (3) becoming storytellers, which they argue can be central to enacting NBS and improving human relationships with urban nature. They draw from a series of case studies that highlight participative practices that meld ecological and social perspectives in the U.S., Brazil, Italy, Cuba, South Korea, and Japan. The authors explore how these practices enable new paths to realizing NBS in cities by rediscovering relationships with urban nature and each other.

Finally, the book is complemented with a concluding chapter. In this, we summarize key insights from the content of the chapters for research, urban planning, and governance and provide a synthesis of knowledge gaps and an outlook on future research questions to be addressed in interdisciplinary research on urban NBS. We further highlight recommendations for mainstreaming NBS in urban planning, design, and management.

We hope this book not only provides a strong and modern introduction to NBS in its various complexities, but also inspiration for how we can embrace urban complexity to mainstream NBS for the urban futures we want. Cities are associated with particular challenges for NBS implementations (Kabisch et al. 2022) but at the same time are at the forefront in achieving sustainable development goals at local and regional levels. To achieve these goals, it is clear that

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NBS has emerged as a powerful and effective opportunity, yet it is not without pitfalls and need for improvement. How can we design, manage, and plan through a nature-based urbanism paradigm? For such an urban planet vision to trigger more ecologically based urban planning, we first need to understand the state of the art in the science of cities for NBS. Our book investigates this through multiple chapters that seek to understand the purpose and beneficiaries of NBS in the context of several urban challenges, the key lenses for advancing the science of NBS in cities, and the frontiers for next-generation NBS in cities.

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PART I

Nature-based solutions for what and for whom?

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2. Nature-based solutions and climate change resilience

Nancy B. Grimm, Yeowon Kim, Jason R. Sauer, and Stephen R. Elser

THE PROBLEM THAT NATURE-BASED SOLUTIONS MIGHT HELP TO SOLVE

In the Anthropocene, compounded challenges of global urban growth and climate change threaten the sustainability of the Earth system. Over half of humanity lives in cities today; two out of every three people will live in urban areas by 2050 and perhaps more than 80 percent of the global population will be urban by the end of this century (United Nations Department of Economic and Social Affairs Population Division 2019). The problem of sustainability, at least for the human population, will therefore most likely be focused in cities and their supporting areas. Many of the world's cities are located in areas of relatively high climate hazards: along coastlines and rivers and in water-stressed regions. As dense aggregations of human population and built infrastructure, cities are especially vulnerable to extreme weather risks like floods, droughts, and heat waves. Adverse impacts of climatic hazards in cities—which are projected to increase both in frequency and magnitude—are likely to be exacerbated due to the complexity of anthropogenic changes in urban environments (Revi et al. 2014). Cities in the Global North have been experiencing failing, aging infrastructure systems with changes in the profiles of extreme weather events (Aghakouchak et al. 2020; Grimm & Schindler 2018) and cities in the Global South are growing at a pace that often outstrips social and financial capacity to build infrastructure for the management of increasing climate risks (Browder et al. 2019; Eakin et al. 2017). Urbanization and climate change are thus on a collision course, and cities need solutions that are affordable and effective in delivering services, including protection from extreme weather events, while at the same time providing additional synergistic benefits to human well-being.

The solutions of the past have exacerbated the problems of today: our infrastructure systems were designed and built to withstand or contain climate

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hazards based on the historical data that predicted a low (or known) probability of occurrence of extreme events. For example, urban storm drainpipes are designed to accommodate up to a certain frequency of precipitation events (e.g., a two- or 10-year return period rainfall), and the size of these events is calculated based on past weather data (Milly et al. 2008). But today, they are experiencing failures from what were once believed to be improbable events as the occurrence of these events becomes more common: for New York City, Reed et al. (2015) estimated that coastal floods that once occurred every 500 years are now occurring once every 24 years. Infrastructure designed in a previous age to hold back flood waters or carry precipitation-driven runoff are susceptible to failure, with severe consequences for complex urban systems. An estimated US$50–60 trillion will be invested globally in new urban infrastructure by the year 2030, with an additional US$2.4 trillion per year needed to implement the United Nations Sustainable Development Goals (Schmidt-Traub 2015; World Bank 2021). But given the uncertainty and non-stationarity of climate change-driven extreme events (Milly et al. 2008) and social-environmental extreme events (Balch et al. 2020) such as floods, drought, extreme heat, wildfires, and pandemics, we need infrastructure solutions that are more flexible, diverse, distributed, and multifunctional—attributes that are theorized to improve resilience and yield multiple benefits (Biggs et al. 2012; Carpenter et al. 2001). Investing in the mere replacement of infrastructure that was designed with traditional approaches with safety thresholds (i.e., designed for historical 100-year events) is not the answer. Instead, we need a new approach that is safe to fail (Ahern 2011; Kim et al. 2019) and can accommodate the new normal, i.e., uncertain and changing probabilities of extreme events (Chester & Allenby 2019; Milly et al. 2008).

Urban nature is a potential source of solutions to the compound challenge presented by urbanization and climate change. Nature-based solutions, sometimes referred to as green infrastructure, ecosystem-based adaptations, or urban ecological infrastructure (Childers et al. 2019), are increasingly being implemented in cities to promote public health and safety, enhance livability, promote equity, and restore natural hydrologic and ecological processes (Depietri & McPhearson 2017; Nesshöver et al. 2017). There is also potential for nature-based solutions to improve urban resilience to the shocks and stressors associated with climate change (Babí Almenar et al. 2021; Hobbie & Grimm 2020), often through the provision of ecosystem services (McPhearson et al. 2015). Nature-based solutions are defined by the International Union for Conservation of Nature as “actions to address societal challenges through the protection, sustainable management and restoration of ecosystems, benefiting both biodiversity and human well-being” (see their website, https://www.iucn.org/our-work/nature-based-solutions). More simply, Seddon and colleagues define nature-based solutions as “working with and enhancing nature to help

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address societal challenges" (Seddon et al. 2020, p.2). Here we adopt Seddon et al.'s definition and focus our attention on the use of natural ecosystems or the incorporation of nature into infrastructure to ameliorate or prevent the impact of climate change stressors, especially extreme events, while recognizing the potential for multifunctionality and ecosystem service provision by nature-based infrastructure. Nature-based solutions may offer a sustainable alternative to traditional solutions for combating climate extremes; however, the limits to their efficacy are understudied.

EMERGING THEORIES AND FRAMEWORKS FOR CLIMATE RESILIENCE

Resilience is the body of theory most relevant to the ability of cities to prepare for and respond to extreme weather events. Resilience is a characteristic of a system that enables it to withstand, recover from, adapt to, and/or transform in the face of external shocks or disturbances (Folke 2006). Resilience has many meanings, frameworks, and theories arising from different disciplines within science (Folke 2006; Meerow et al. 2016; Quinlan et al. 2016; Woods 2015) and different sectors within practice (Moser et al. 2019; Muñoz-Erickson et al. 2021). The explosion of work on resilience of social-ecological systems expanding from ecological theory (Holling 1973), most prominently by the Resilience Alliance (Carpenter et al. 2001; Folke 2006; Folke et al. 2021), has emphasized the inseparable interplay between social and ecological factors and, as applied to extreme events, has shown how impacts can be modified—exacerbated or mitigated—by those interactions (Balch et al. 2020). More recently, the concept of resilience in engineering has been expanded to incorporate the technological and institutional capacity of infrastructures to extend their ability to respond to unknown surprises, such as extreme weather events driven by non-stationary climate (Woods 2015).

In urban systems, resilience has been widely adopted by both academic and practice communities as a means for envisioning urban transformation and dealing with the uncertainty of future climate conditions (McPhearson et al. 2015; Meerow et al. 2016; Moser et al. 2019). Meerow et al. (2016) offer a definition of urban resilience—"the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity"—that recognizes the diverse components (e.g., social-ecological and socio-technical networks) of cities. Many scholars are adopting the conceptual framework of social-ecological-technological systems (SETS) (Ahlborg et al. 2019; Depietri & McPhearson 2017; Grimm et al. 2017; Kim et al. 2021, 2022; Markolf et al. 2018). The promise of the SETS

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framework (Figure 2.1) promoting urban resilience against extreme weather events is that it allows cities to understand the dynamics—both synergies and trade-offs—of interlinked SETS comprising urban areas. In particular, with SETS we recognize that capital inputs to nature-based solutions often comprise human institutions and labor (S), natural resources (E), and the processing and manufacturing of built structures (T). Each component has unique vulnerabilities (Chang et al. 2021) and resilience characteristics, yet the interaction among SETS dimensions in conferring resilience or vulnerability to the linked system are underexplored. We do know that the outcomes when nature-based structures in cities are threatened by extreme events can include impacts to social (e.g., lives lost, displacement, loss of income), ecological (e.g., death of organisms, erosion, pollution events), and technological (e.g., structural failures and cascading impacts to other, linked systems) components. That S and T elements are interlinked with E (i.e., nature-based solutions) in cities cannot be overemphasized. Even under conditions when nature-based solutions are restored or preserved in ecosystems like mangrove forests or river riparian zones, the context within which they are embedded (an urban environment) means that the ecological dimension cannot be considered in isolation (Grimm et al. 2017; Hobbie & Grimm 2020; Kim et al. 2022).

The efficacy of nature-based solutions to address urban resilience to extreme events in SETS across and within cities in the diverse contexts of global urban environments is relatively unknown (Cortinovis & Geneletti 2018; McPhillips et al. 2021). Although cities are already investing heavily in nature-based solutions, the relationship between nature-based solutions and specific resilience (i.e., resilience to particular events) is also unknown. Given limited resources and the heterogeneity of urban contexts and challenges, more work is needed to understand how different cities should invest in nature-based solutions, what benefits they can expect to receive, and how nature-based solutions can effectively be scaled up in diverse contexts to improve local and global climate resilience.

OPPORTUNITIES AND CHALLENGES FOR NATURE-BASED SOLUTIONS IN ADDRESSING URBAN RESILIENCE

Nature-based solutions present prominent opportunities for broader applications addressing urban resilience to extreme weather events attributed to the benefits that they provide, compatibility with existing infrastructure systems, and flexibility in the design and management of solutions. The benefits that nature-based solutions provide to people, called ecosystem services, are essential for maintaining human well-being (Millennium Ecosystem Assessment 2005). Nature-based solutions are becoming more desirable in cities as climate

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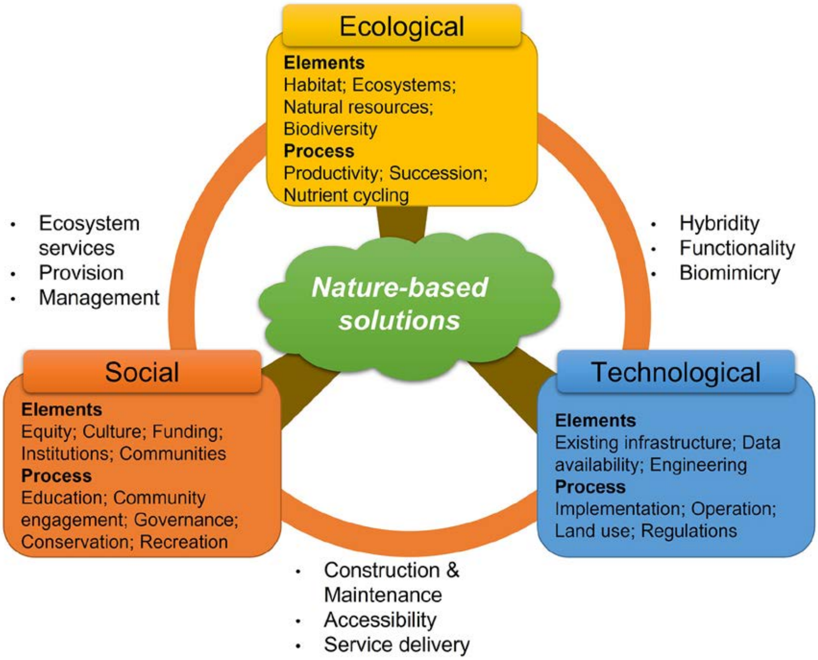

Figure 2.1 *Elements, processes, and interactions of nature-based solutions in social-ecological-technological systems in urban areas*

resilience strategies not only because they can directly mitigate impacts from climate change, like protecting from floods (Barthel et al. 2015; Uludere Aragon et al. 2019) and reducing heat (Jenerette et al. 2011), but also because they can provide an array of cultural ecosystem services, like opportunities for recreation and experiencing nature, which can improve human health (Hartig et al. 2014; Keeler et al. 2019). With more and more people moving to cities, it is increasingly important to ensure a resilient supply of diverse, locally produced, urban ecosystem services in order to maintain human well-being and promote equitable outcomes. Nature-based solutions are multifunctional, which means they also provide an array of different ecosystem services. However, nature-based solutions are diverse in their structure, which means that different nature-based solutions will provide a different suite of ecosystem services based on their physical characteristics. To make cities more resilient to extreme weather events, a diverse portfolio of nature-based solutions capable of providing a wide range of ecosystem services through time and

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space is needed (McPhearson et al. 2015). This portfolio should be integrated into the urban fabric of the built environment in ways that are just and equitable, meeting the needs of all segments of the urban population.

Natural and modified nature-based solutions have been successfully integrated with urban ecosystems and existing infrastructure. Since as early as 1960, the city of Valdivia, Chile, has designed its stormwater management system to incorporate wetlands as nature-based solutions for flooding, particularly for the ability of wetlands to store and convey stormwater (Figure 2.2). In Valdivia, wetlands represent 41.2 km (16.8 percent) of the total length of the city's stormwater management system. These wetlands—either natural or modified—in the urban core and in the peri-urban reaches act as points of retention to slow down or diminish peak flows before stormwater can enter the drainage systems and as system outlets that convey water safely away from the drainage system. In addition to reducing flood risk, these wetlands also contribute to regional identity, which cannot be said of the gray components of the city's drainage system. The wetlands in Valdivia provide cultural meanings to people (Figure 2.3). Over the years, Valdivia's wetlands have been threatened by development plans, pollution, and illegal infilling, but these threats have been met by collective action and resistance on the grounds that the culture and identity associated with wetland nature-based solutions would be irreparably harmed (Correa et al. 2018).

Restored or constructed ecosystems as nature-based solutions are becoming increasingly popular in urban settings. Cities may "daylight" their buried streams, or otherwise restore portions of their surface streams, to harness their ecosystem services of pollution control, infrastructure protection, recreation, and aesthetic appeal (Corsair et al. 2009; Kenney et al. 2012). Constructed wetlands may provide cities with pollution control (Chan et al. 2018; Sanchez et al. 2016) and flood risk management services. Even incidental or "accidental" forms of nature-based solutions can provide beneficial ecosystem services to cities (Palta et al. 2017).

Nature-based solutions are also considered to be more flexible in accepting changes to system design and management than traditional gray infrastructure and in responding to shifting risk profiles or environmental changes (Babí Almenar et al. 2021; Seddon et al. 2020). In this regard, nature-based solutions are well suited for the safe-to-fail approach. Safe-to-fail infrastructure design and management is an emerging approach that focuses on systematic control of the probable consequences upon system failure, which highlights the need for flexibility and agility of technological system design to adapt to a changing climate (Kim et al. 2019). Traditional infrastructure design practices that follow preset codes and regulations are limited in incorporating changing risk profiles or control of extended hazards beyond design calculations. In contrast, nature-based solutions have advantages of adding multiple functions

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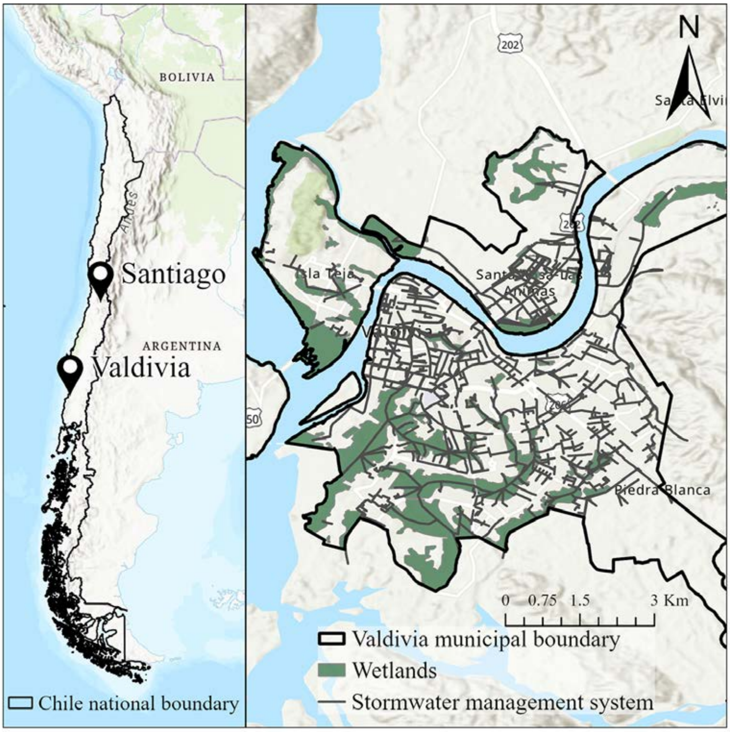

Figure 2.2 A map of stormwater systems and wetlands in Valdivia, Chile

to existing systems design or to the system—extending its function gracefully upon surprises or unpredicted hazards affecting the system (Kim et al. 2017; Woods 2018). This extension is a consequence of the ecological features of the design. For example, rain gardens or vegetated floodways implemented for flood mitigation can function as an environmental buffer to accommodate increased intensity of floods.

However, there are also challenges in implementing nature-based solutions in diverse contexts. While it is true that nature-based solutions are multifunctional and an important component for promoting positive outcomes in cities, we acknowledge that nature-based solutions are not a panacea. They cannot solve every problem (McPhillips et al. 2021), and there are trade-offs with different types of nature-based solutions in terms of the ecosystem services and nuisances that they produce. Nuisances, called ecosystem disservices (Grimm & Schindler 2018; Lyytimäki & Sipilä 2009), can be exacerbated by ignoring the connections between nature-based solutions and the social and technological aspects of cities. Street trees, for example, are a common form

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Figure 2.3 Urban wetlands in Valdivia, Chile

of nature-based solutions to provide shade and cool down urban environments. Depending on the tree species and where it is planted, tree roots can damage sidewalks and roads. Trees can also worsen human health outcomes by producing volatile organic compounds. Nature-based solutions do not exist in a vacuum, and we must consider the implementation of nature-based solutions in a holistic way, appropriate to the setting, to create more verdant, just, and resilient cities in the future.

Another big question in designing nature-based solutions for urban resilience is whether they can be implemented at scales comparable to traditional gray infrastructure characteristic of urban development in past centuries. Historically, solutions for tackling natural climatic hazards tended to be single-purpose, often monumental, gray infrastructure like levees, sea walls, channelized or canalized river channels, and large storm sewer pipes, because these designs proved effective in reducing predicted risks—when the calculated climatic hazard fell within design specifications. However, as climate hazards imposed on cities have become more varied and intensified with climate uncertainty, previously successful gray infrastructure has become inadequate in accommodating changing urban environments and risk profiles. Furthermore, scalability of nature-based solutions differs depending on the regional contexts and existing conditions of gray infrastructure where they are in demand for implementation. In urbanized countries of the Global North, much of the gray infrastructure is old and in need of replacement or repair

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(Chester et al. 2020), whereas in the still-urbanizing countries of the Global South, infrastructure development has not kept pace with urban population growth or expansion (Grimm & Schindler 2018). The problems of scaling nature-based solutions, their substitutability or potential for hybridization with built infrastructure, and their incorporation as a system or network of solutions in the urban fabric of rapidly developing urban areas are yet to be resolved (Andersson et al. 2022).

Nature-based solutions have much potential to help cities reach positive futures, but the strategies for planning and implementing nature-based solutions need to be holistic to make those futures more equitable. Nature-based solutions provide many ecosystem services to people in cities, but those services are not always distributed equally through space (Ernstson 2013), and it is not clear how to strategically implement nature-based solutions for achieving short- or long-term sustainability goals in diverse social, cultural, and biophysical contexts (Kabisch et al. 2016). Furthermore, new nature-based solutions projects in urban areas often lead to increasing land prices and rent, which can displace the populations whom the strategies are intended to help (Checker 2011; Lang & Rothenberg 2017). To address concerns about environmental justice and equitable outcomes into nature-based solutions planning and deployment, many researchers and practitioners use methods that involve co-production between citizen stakeholders, researchers, and practitioners (Frantzeskaki 2019; Lang et al. 2012), often using positive visioning exercises (Iwaniec et al. 2020; McPhearson et al. 2016; Raudsepp-Hearne et al. 2020). By engaging communities at the outset of planning, encouraging interdisciplinarity among participants, and developing consensus-driven positive visions of urban development, challenges to equity and equitable outcomes may be preempted rather than dealt with at a later date as emergent issues in the communities where nature-based solutions are implemented.

NET OF NETWORKS: GLOBAL KNOWLEDGE SHARING ON NATURE-BASED SOLUTIONS

In this chapter, we have laid out the rationale for considering nature-based solutions to challenges brought about by climate change. Because cities are locations that concentrate people and their infrastructure while also being loci of growing threats from extreme weather, they are appropriate sites for transformation to more sustainable living configurations for society. Nature-based solutions are beginning to be incorporated into the urban fabric in many areas, with the hope of building urban resilience. Despite the diversity among theories and perspectives of resilience, resilience concepts—especially when applied to urban SETS—are useful in advocating the kind of flexibility, multifunctionality, and adaptability that is needed for a changing world. There

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remain questions, however, about the scalability of nature-based solutions, their efficacy in the face of varying threats, their applicability in diverse contexts, and how nature-based solutions can be implemented in equitable and just ways. These are questions for which coordinated research, implementation, and knowledge sharing is beginning to provide answers.

Nature-based solutions are being integrated into policy in Europe under the Horizon 2020 framework (European Commission, Directorate-General for Research and Innovation 2015), and numerous projects have focused on the design and implementation of nature-based solutions in European countries (Frantzeskaki 2019). In the United States, the Environmental Protection Agency's directive on green infrastructure in 2007 spurred many cities to divert budgets for stormwater management to nature-based solutions (Hopkins et al. 2018), and interest in coastal protection using natural features (e.g., Arkema et al. 2013) has increased owing to several impactful coastal storms. There have been calls for greater attention to cities of the Global South (e.g., Nagendra et al. 2018), which as we discussed are prime candidates for new nature-based infrastructure. Given this worldwide interest and need, a global network of networks called NATURA (Nature-Based Solutions for Urban Resilience in the Anthropocene, www.natura-net.org) has been formed to bring together knowledge and experience—both academic and practical—from cities in five regions: North America, Latin America, Europe, Africa, and Asia-Pacific. NATURA coordinates communication, promotes data and knowledge sharing with its thematic working groups, and sponsors international exchange fellowships for early-career academic scholars and practitioners working on nature-based solutions. Over 40 networks, ranging from single projects working in a network of cities to large networks such as the International Union for Conservation of Nature, participate in NATURA's activities. The overall goal is to advance understanding of how to build resilience in cities to the growing threat of a changing climate. NATURA explores how bundles of nature-based solutions might provide synergistic benefits, and the roles of social-cultural (S), ecological-biophysical (E), and technological-infrastructural (T) contexts as well as their interactions (i.e., SETS dynamics) in the outcomes of nature-based solutions.

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3. Towards just nature-based solutions for cities

Laura Tozer, Harini Nagendra, Pippin Anderson, and Jessica Kavonic

APPROACHING JUST NATURE-BASED SOLUTIONS

Existing nature-based solutions (NBS) approaches often use a conceptual framework of urban nature as a universal good with multiple benefits accruing equally to all urban residents. Emerging approaches seek to address disparities in access to NBS, but more work needs to be done to disentangle the ways that NBS interact with long-standing environmental justice issues. NBS can ameliorate environmental quality, enhance climate change adaptation and resilience, and improve health and well-being. NBS can provide many benefits, but these are often contextual and existing urban landscapes have large disparities in the distribution of NBS. Environmental justice literature has made it clear that there is an uneven distribution of urban nature that disadvantages marginalized communities (Wolch et al., 2005; Heynen et al., 2006; Landry and Chakraborty, 2009; Park and Pellow, 2011). Indeed, 'where we find social inequalities by race and class, we tend to also find environmental inequalities' (Pellow, 2017), including exposure to risks and exclusion from benefits, as well as exclusion from relevant decision making. While urban NBS are generally intended to redesign human–environment relationships and are broadly linked to issues of well-being and social cohesion (Cousins, 2021), NBS also present risks related to the 'dark side of transformation' (Blythe et al., 2018).

NBS risk exacerbating injustices since they are still subject to the systemic processes that reproduce or exacerbate inequalities (Anguelovski et al., 2020). In particular, NBS can exacerbate gentrification and displace marginalized communities to vulnerable areas (Dooling, 2009; Anguelovski et al., 2019). NBS in cities can create or reinforce disparities unless there is an explicit integration of principles of equity, inclusion, reparation, and emancipation (Toxopeus et al., 2020). Working towards just NBS for cities therefore demands careful analysis of 'what, where, for whom and by whom nature becomes a solution to a problem' (Cousins, 2021). In this chapter, we outline

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theories of justice that are relevant for thinking about urban NBS, whether and how justice is integrated into dominant approaches to urban NBS in the Global North and South, and ways forward for advancing justice through urban NBS.

URBAN NBS AND THEORIES OF JUSTICE

There has been a rapid rise in attention on urban NBS in research and policy-making, but the issue of 'how to address issues of justice and socio-spatial inequality through NBS remains absent or unclear' (Cousins, 2021). Social justice refers to the fair distribution of the wealth, privileges, and opportunities of society. Classic work on environmental justice has described challenges faced by marginalized communities living and working next to unhealthy waste dumps, exposed to polluted air and water, or without access to open spaces for exercise and play. Environmental justice has been defined as:

> The fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations and policies. Fair treatment means that no population, due to policy or economic disempowerment, is forced to bear a disproportionate share of the negative human health or environmental impacts of pollution or environmental consequences resulting from industrial, municipal, and commercial operations or the execution of federal, state, local and tribal programs and policies. (USEPA, 2015)

Furthermore, approaches to Indigenous environmental justice are based on diverse Indigenous worldviews and express reciprocal and respectful relationships where humans are understood to be part of the natural world (McGregor, 2018; Gilio-Whitaker, 2019). In the following sections, we introduce three pillars that scholars have used to analyse social and environmental justice considerations for NBS: distributional justice, procedural justice, and recognitional justice. Distributional justice in this context refers to questions around the distribution of access to nature and its benefits across society. Procedural justice relates to the integration of civil participation into decision making. Recognition justice is concerned with the recognition of different needs or values for nature related to people's intersectional identities (Fraser, 2009; Toxopeus et al., 2020).

Distributional Justice

It is by now well known that NBS and the social, psychological, economic, health, and other benefits they provide are unequally distributed. Marginalized communities disproportionately tend to be located in areas without open spaces or urban green spaces, or lack access to NBS because of user fees,

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property tax regimes, security guards, or other visible or invisible barriers. The urban hazards managed by NBS are not distributed equally due to environmental injustice, which 'generally refers to a situation in which a particular social group is disproportionately affected by environmental hazards' (Pellow, 2017). Many cities, and certainly the scholarly urban literature on NBS, recognize this gap. Urban NBS can create or exacerbate injustice (e.g. through green gentrification) or it can redress injustice (e.g. co-production of green space in marginalized neighbourhoods), but it depends on who is involved in NBS planning, who benefits from NBS, and whether existing power relations are transformed through NBS design and implementation.

Access to urban nature is an environmental justice issue; marginalized or racialized neighbourhoods have fewer and lower-quality natural spaces, which means they lack access to the benefits of urban nature (Kabisch and Van Den Bosch, 2017). It is also a governance and structural issue – persistent challenges of power and subordination and suppression of oppressed communities and groups can actively reshape even well-intentioned NBS interventions to reinforce environmental injustice and inequality (Anguelovski et al., 2020).

Substantial research on the benefits of nature in cities has outlined the ecosystem and ecological, economic development, and health and well-being benefits. Urban greening provides diverse ecosystem services in urban areas (Elmqvist et al., 2016). Food production in urban areas has been linked to strengthen social connections, recreation opportunities, and place attachment (Anguelovski et al., 2020). Urban greening projects have also been shown to be an important component of climate risk mitigation, whether it is related to stormwater flooding, reducing the heat island effect or other risks (Zolch et al. 2016; Meerow and Newell, 2017). From an economic development standpoint, green spaces and parks contribute to the desirability of real estate and eventually contribute to property value increases (Conway et al., 2010). Finally, urban green space is associated with many positive health outcomes, including psychological well-being, lower anxiety and depression, lower mortality risk, and more vitality (Triguero-Mas et al., 2017; Anguelovski et al., 2020).

The expansion of NBS in cities can redress race and class inequalities related to access to the benefits of urban nature and, in this effort, many have focused on improving distributional justice by pursuing equitable access to green space. For instance, some city agencies use a threshold value for urban planning to try to ensure that all residents are within a certain distance of green space, seeking to ensure distributional justice. However, it is not just about where NBS are in the city since proximity does not necessarily ensure accessibility, quality or safety for different population groups (Kabisch and Van Den Bosch, 2017). Extensive research has also identified how green space improvement or expansion can exacerbate ongoing gentrification processes where nearby marginalized residents are driven out and do not benefit

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(Anguelovski et al, 2018; Rigolon and Németh, 2018). Scholarship on urban nature and justice warns that urban nature initiatives can have both positive and negative impacts on the health and well-being of residents (Toxopeus et al., 2020). The justice outcomes of NBS also depend on who participates in NBS planning and implementation and who benefits from NBS development (Kotsila et al., 2020).

Procedural Justice

A long-standing concern in planning and urban sustainability from a procedural justice standpoint has been how to include those that are affected by decision making, but participation processes have often fallen short in their efforts to achieve inclusivity (Owens, 2000; Fainstein, 2011; Certomà et al., 2015). A commitment to broad participation underlies NBS principles (Cousins, 2021), which means that the expansion of NBS is an opportunity to improve procedural justice outcomes. When it comes to the engagement process around NBS planning, implementation, and maintenance, scholars have also drawn our attention to the dangers of rendering NBS technical (Li, 2007), which runs the risk of creating apolitical solutions (Cousins, 2021). Research has shown that NBS that are co-produced with residents, especially marginalized groups, will allow residents to feel recognized in the NBS and develop attachments (Anguelovski, 2014). Engagement processes will also need to overcome the challenges of creating and sustaining multi-stakeholder and multi-sectoral partnerships (Cousins, 2021), which are often touted as the key to scaling up NBS (Toxopeus et al., 2020), as demonstrated by the case studies from NBS implementation in several cities in Africa in Box 3.1.

BOX 3.1 CASE STUDY OF THE URBAN NATURAL ASSETS FOR AFRICA PROGRAMME

The Urban Natural Assets for Africa (UNA) programme, launched in 2014 (ICLEI CBC, 2019a), works with local governments towards interventions for greater urban sustainability. The programme recognizes that for interventions to be effective they must be sought collaboratively through processes of co-learning and design (ICLEI CBC, 2019b). While this understanding is not novel, the practical means to do this in a way that truly empowers communities to make their voices heard, while preventing some of the tensions that arise when decision makers and community members collaborate around environmental solutions, is less well understood. The programme sought to try different means by which to ensure less hierarchical engagements and greater universal buy-in to proposed action. By way of

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example, the UNA programme trialled the use of a version of the Minecraft computer game as a means to involve citizens in the planning of a new riverside public park in Ethiopia. Here, women, vulnerable youth, and others from the community worked alongside municipal officials, using computer software, to generate a design for the public park where participants could collectively design NBS. The programme also tested the Photovoice methodology to engage community members over the course of a waste management and river revitalization project at an informal market in Malawi (ICLEI CBC, 2020). In Kenya, the programme brought together a diverse group of stakeholders to participate in an urban tinkering walking workshop (ICLEI CBC, 2020). This workshop saw local decision makers, national officials, community members, and researchers all walk along the Auji River, stopping to discuss environmental issues and challenges encountered in the field, exploring sites where pressing social and environmental issues might be addressed through 'tinkering' in the landscape in a safe-to-fail way using NBS. These methodologies proved effective in ensuring that local community voices were heard, loud and clear. Community members played a central role in designing and implementing activities and these approaches empowered often marginalized groups through neutralizing differences and disrupting power dynamics that existed between the different stakeholders. City officials noted that inclusive methodologies towards collectively designed NBS relieve them of a major burden of service delivery by easing capacity constraints and helping to slipstream activities (ICLEI CBC, 2020). Community members expressed that co-production measures allowed for increased ownership of NBS solutions as well as improved trust in their local authorities (ICLEI CBC, 2019c).

Recognitional Justice

The justice outcomes of NBS also depend on who benefits from NBS development. While nature is often treated as an unquestionable good, recent work has started to pay closer attention to people's varying relationships with and values for nature. For instance, larger parks in high crime areas may create feelings of insecurity (Anguelovski, 2014) and exclusionary practices of white residents in green space protection can impede use by immigrants (Park and Pellow, 2011). Depending on their design and governance, NBS 'differentially address deeper roots of environmental, social and racial privilege' (Tozer et al., 2020, p. 2). Scholars and community activists are working to find ways to expand urban greening while achieving economic, environmental, and racial justice outcomes (Klein et al., 2020). NBS have the potential to address justice

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issues related to urban nature, but only if NBS initiatives are pursued with a strategy to address these concerns and take advantage of opportunities to improve justice outcomes.

INTEGRATION OF JUSTICE CONSIDERATIONS IN URBAN NBS

In this section, we examine whether and how justice is being integrated into dominant approaches to urban NBS in the Global North and South.

Understanding Local Cultural Variations in Values of and Perceived Benefits from NBS

Recent work has highlighted the fallacy of associating unambiguous environmental 'goods' or 'bads' with NBS, appreciating the role of culture, socio-economic conditions, and aspects like caste, gender, age, and status in impacting values that residents derive from NBS, and in shaping perceptions of benefits and disservices from NBS (e.g. Anguelovski, 2015). In European and North American cities, with increasing proportions of migrant communities from different parts of the world, it is essential to conduct in-depth conversations with different ethnic communities to understand their perceptions of environmental quality and of the services and disservices provided by urban green spaces and NBS (Rutt and Gulsrud, 2016). For instance, a study in Berlin found that Germans prefer grassy lawns for sunbathing and locations for sport, while many immigrants seek family spaces such as barbeque areas where they can visit parks in large family groups. Women from some traditional ethnic groups may prefer to stay away from public parks because there are no areas where they can keep a distance from strange men (Kabisch and Hasse, 2014). In recently restored lakes in Bangalore and parks in Delhi, older residents and women may prefer well-visited spaces for reasons of safety while transgender visitors and parents of special needs children seek out quieter spaces where they are free to be themselves out of the gaze of public disapproval (Paul and Nagendra, 2017; Sen and Nagendra, 2020). Prioritizing recreational benefits of NBS may lead to the dis-privileging of sacred values and livelihood benefits, especially in Global South cities (Mundoli and Nagendra, 2020).

A key factor in many of these densely settled areas is to address how NBS intersect with major needs such as livelihoods and safe spaces for women. For instance, planting trees can cause concerns about increasing crime by providing cover for gangs. In contrast, marginalized communities in shrinking cities in many parts of Europe and North America have the opposite problem and are dealing with crime hotspots in large swathes of vacant land. Community agriculture has been one way to transform these areas into active community

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spaces via a mix of bottom-up and top-down initiatives (Vásquez and Dobbs, 2020).

Designing NBS at Appropriate Spatial Scales

NBS in cities can vary from the micro, such as green walls and roofs, bioswales, potted plants in apartment balconies, to the meso, such as seen in cases of daylighting rivers and networking parks via green corridors, to the macro, for instance by redesigning entire cities as sponge cities, restoring coastal mangroves and designing greenbelts to surround cities (Shi, 2020). NBS in densely settled neighbourhoods of growing cities, such as in the Global South, typically house low- to middle-income residents and battle space constraints. They need to be innovative by exploiting rooftops, walls, drains and ditches, empty sites, and roadsides to plant green infrastructure, conduct urban gardening, and create bioswales. Small-scale solutions such as planting edible *Moringa* trees to provide shade and supplement nutrition in low-income informal settlements in Bangalore, India (Gopal et al., 2015), or using GIS to locate green infrastructure to ameliorate air pollution, flooding, and urban heat island effects in areas of high social vulnerability in Detroit, United States (Meerow and Newell, 2017), seem to have the potential to address issues of social and environmental justice at the individual, household, and community levels. In such cases, NBS can be spatially networked into multi-functional solutions suited to these neighbourhoods that have often been historically deprived of access to nature, to enable influence at larger spatial scales.

However, numerous scholars (e.g. Dooling, 2009; Anguelovski et al., 2019) point out that the application of NBS at the city scale (macro), usually implemented by governments and environmental groups, and neighbourhood scale (meso), usually implemented by governments and private developers, leads to gentrification, exacerbating marginalization by displacing vulnerable communities and households to low-income, environmentally vulnerable areas. Yet macro- and meso-scale landscape planning is essential for NBS to address large, city-wide, and even basin-wide environmental problems like flooding, air pollution, and climate change (Shi, 2020). While they cannot be ignored, macro- and meso-scale landscape issues are areas where justice issues are often very complex and difficult to address, requiring special care. Some approaches such as those suggested by Gibbons et al. (2020) focus on understanding and minimizing risks of displacement because of urban greening.

Financing NBS

There is a clear need to advance the financial case for NBS, however, this is rarely done with considerations of justice in mind. Cities typically seek to

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finance NBS by approaches such as property taxes and user fees, private–public partnerships and developmental charges (Merk et al., 2012). Such an approach almost inevitably contributes to gentrification, increasing segregation between rich and poor neighbourhoods. In contrast, multi-functional approaches that combine goals of ecosystem restoration and environmental protection with urban agriculture, fishing, and grazing, providing livelihood support, improving nutritional levels, and increasing community empowerment, can provide important outcomes, such as helping marginalized migrants integrate into the city, improving health, and building social capital.

A good example is that of the East Kolkata Wetlands, which cover over 125 km^2 and filter the Indian city of Kolkata's sewage. These wetlands are constructed on natural salt marshes and constitute an area of rich biodiversity that is protected as a wetland of national importance under the Ramsar Convention. The wetlands support intensive vegetable, coconut, and rice production and cooperative fish farms, in turn supporting many low-income families including many Indigenous tribal communities. The economic services that the wetlands offer to Kolkata are high, providing sewage cleanup, carbon sequestration, and climate resilience. However, threats to the wetland complex are severe and continued, with many wetland areas outside the Ramsar-protected locations having been acquired for real-estate development (Banerjee and Dey, 2017).

Finding new ways of thinking about how to finance NBS solutions and linking these to appropriate bottom-up institutions at meso and macro scales becomes a stark necessity. Public policy, pushed by local communities, can also play a major role. Measure A, passed by Los Angeles County in 2016, makes funding available for green infrastructure projects in low-income neighbourhoods of colour which are deprived of public green spaces. Tax increment financing is another approach, now used in multiple cities, where loans can be taken on anticipated future tax revenues and used to develop green infrastructure in marginalized neighbourhoods (Gibbons et al., 2020).

Regional and Context-Specific Diversity and Divergence in the Application of Just NBS

All of the physical and psychological benefits associated with NBS emerging from research on cities in the Global North (Jennings et al., 2012) hold true for those of the Global South. Emergent trends in the Global North of gentrification following improved NBS delivery in poor neighbourhoods and associated debates around 'just green enough' are echoed increasingly in the Global South (Wolch et al., 2014). The Global South, however, has an additional thread associated with livelihoods (Davenport et al., 2012) and infrastructure and service support in the absence of municipal engineering equivalents (Shackleton et al., 2014) that is less characteristic to those benefits recorded in

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the North. The example in Box 3.2 shows how a nature reserve in Cape Town is managed to meet multiple ends.

BOX 3.2 CASE STUDY OF THE EDITH STEPHEN'S NATURE RESERVE IN CAPE TOWN

South Africa has one of the highest Gini coefficients in the world and green space in poorer neighbourhoods come under pressure for housing or livelihood needs (Goodness and Anderson, 2013). The Edith Stephen's Nature Reserve is situated on the Cape Flats, one of the poorest regions of the city of Cape Town, and bordered by a poor and informal neighbourhood (Gabrielsson, 2018). The staff of the reserve adopt an approach of ensuring their reserve meets multiple ends and offers more than just NBS to the adjacent community. Gabrielsson (2018) attributes this effective multiplicity of use as an outcome of significant and ongoing social engagement towards the production of a 'common ground'. The reserve staff recognize the need for collaboration and community engagement in ensuring the conservation of the biodiversity and rich vegetation on their small urban nature reserve. They spend considerable time in discussion with local leaders and neighbours to ascertain their daily needs and to ensure the reserve remains relevant to these important stakeholders. Adjacent communities inadvertently benefit from NBS from the reserve such as urban cooling, drainage, and recreational opportunities, but must also be offered features to meet their immediate daily needs in Gabrielsson's 'common ground'. Outcomes of these engagements have resulted in local social workers using the reserve for private counselling sessions, community groups using the reserve office space for meetings and events, and the reserve serving as a site for training opportunities for local youth. NBS must be packaged as part of larger engagement with a diversity of stakeholders towards a co-produced solution that meets the needs of broader society.

A significant factor separating urban areas in the Global North and the Global South is the rate of urbanization, where cities in the Global South are gaining people and expanding in area at unprecedented rates (Seto et al., 2013). This rapid growth often outstrips planning capacity and these cities tend to be characterized by a high degree of informality both in their economies and settlement patterns. Unsettled land can be contested for human settlement or green-space acquisition. Kusno (2011) presents the case of slum clearing in Jakarta for the reclamation of urban green space, which was an effort pursued by government and middle-class citizens at a high price for informal dwellers. Public green space, and associated NBS and benefits, is less prevalent than

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in developed counterparts and few guidelines exist to direct planning and development with public space in mind (Thaiutsa et al., 2008; McConnachie and Shackleton, 2010). Green spaces in the Global South, in contrast to those of the Global North, tend to be managed informally, often regulated by local leaders (Goodness and Anderson, 2013; Sultana et al., 2020). At the micro scale, patterns of public and private green space associated with wealthier neighbourhoods are shared across the Global North and South (Tratalos et al., 2007; Anderson et al., 2020). NBS in poorer, and often informal, neighbourhoods tend to be green space or trees and are infrequently constructed elements such as green walls. High immigrant populations seeking work and driving the expansion of cities in the Global South bring in rural farming and associated livelihood features, which, while unplanned, do present a significant NBS feature of cities of the South (Sultana et al., 2020). Urban agricultural sites or communal gardens are important NBS for their contributions to social well-being and for their nutritional value, but are frequently lost to the pressures for additional space to settle housing.

Urban greening policies emerging from noble goals like the Sustainable Development Goals and climate change considerations may not translate well between developed and developing contexts and result in injustices or negative externalities at the local level. Most global policy on NBS seems to be driven by research in temperate environments. Sultana et al. (2020) give the case of Dhaka where immigrants' use of nature for livelihood in small-scale farming or foraging is curtailed by policy fashioned on that of the Global North that is framed for economic growth and cosmopolitan well-being, but that in fact blocks access and excludes the urban poor. A crudely applied urban resilience approach with the import of NBS and green infrastructure can be readily criticized as depoliticizing the urban with a diversity of pressing issues and injustices resolved under a banner of greening (Mabon and Shih, 2018). Song et al. (2017) stress the need to develop context-relevant NBS for cities, stressing the fact that most urban NBS research emanates from temperate cities which have very different climate and ecology, as well as vastly different economic development and lifestyles, compared to tropical cities, which creates a gap in our understanding of which species tropical city managers can select that are most suited for their needs. International non-governmental organizations promoting tree planting may inadvertently overlook space requirements or access to water that could preclude informal settlements from benefitting (Sultana et al., 2020), resulting in greening in wealthier serviced neighbourhoods furthering something akin to a green Gini coefficient of NBS.

In addition to often inappropriate policy, matched by weak capacity to govern and plan in the face of rapid change in the informal cities of the Global South, Sultana et al. (2020) cite general ennui among stakeholders where the crisis-ridden daily lives of urban dwellers faced by so many demands tend to

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rob actors of their ability to act in the interests of longer-term and less immediately relevant NBS. This is not to say that NBS does not have a place in a developing context, but rather that it should be approached perhaps in novel ways.

WAYS FORWARD FOR ADVANCING JUSTICE THROUGH URBAN NBS

Here, we describe some approaches for moving forward, building on the definition of Cousins (2021, p. 6) of just NBS as 'harnessing the power of nature and people to transform the social, political, and economic drivers of socio-spatial inequality and environmental degradation into opportunities to create progressive, cohesive, antiracist, and social-ecologically sustainable communities'.

Creating Alternative Social-Ecological Relationships

Research has shown the importance of prioritizing policies, designs, and development outcomes that seek to eradicate existing inequalities (Anguelovski et al., 2020). A restorative justice lens for NBS encourages the open acknowledgement of geographies and histories of injustice and designs for NBS that aim to redress these injustices. A way forward is to recognize and redress 'both inequalities in access and inequalities that perpetuate dominant views about what nature is and for whom nature is produced and maintained' (Tozer et al., 2020, p. 2). It is not enough to assess whether projects prevent discrimination, but also whether they ensure positive rights to the benefits of NBS (Anguelovski et al., 2020). Indeed, the very definition of well-being is challenged and revisiting this in the context of environmental justice issues would be beneficial (Liotta et al., 2020). Also crucial here is opening up opportunities for the self-determination of socio-ecological relationships (Lowitt et al., 2019).

Transformative Co-Production

Co-production is one suggested approach that offers a way to substantively include diverse perspectives in urban NBS. Co-production among policymakers and residents, especially racial and ethnic minorities, makes it more likely that residents recognize themselves in urban green space and develop attachments (Anguelovski, 2014; Tozer et al., 2020). The key here is not to assume that all urban nature is equally beneficial to everyone and to focus solely on the even distribution of nature. Research on NBS in European cities recommends broadening participation, which 'means engaging beyond the

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"traditional" power hierarchies and the "usual suspects" by bringing in different urban stakeholders, e.g. volunteers, health services, religious groups and others' (Armstrong, 2020, p. 4). Further, as the critical environmental justice literature highlights, often problematic hierarchies of knowledge production play a major role in shaping environmental justice outcomes (Pellow, 2017). A questioning of assumptions about whose knowledge and which epistemological frameworks are given greater value must therefore also take place (Grabowski et al., 2019). Taking recognitional justice into account means finding ways to accommodate the fact that diverse people with multiple identities interact with nature differently and surfacing tradeoffs between these in NBS design, implementation, and maintenance. It also means designing NBS from the outset to redress pre-existing urban inequalities (Tozer et al., 2020), as Box 3.1 demonstrates.

Forging New Institutional and Economic Arrangements

Moving forward to enable just NBS also means striving towards policies and arrangements to support anti-racist and feminist NBS (Anguelovski et al., 2020). Political commitment to social inclusion within NBS will also help to align priorities so that inequities can be meaningfully addressed (Armstrong, 2020). For example, how best can we hear how value is expressed and realized differently? How can we highlight care, connection, cultural values, or other ways people interact with nature away from property and economic valuation (Anguelovski et al., 2020)? It is essential to open up planning, implementation, and maintenance processes so that alternative ways of experiencing and valuing nature are recognized (Anguelovski et al., 2020; Kotsila et al., 2020; Tozer et al., 2020). Additionally, urban green commons can play a critical role in the management of NBS for justice. As studies in Stockholm, Sweden, Cape Town, South Africa, and Bangalore, India, have demonstrated, managing NBS as commons rather than state or private goods can help in fostering more positive social-ecological transformations that address ecological issues combined with an appreciation of social diversity and equity (Colding et al., 2013; Nagendra, 2016).

Economy, environment, and health considerations cannot be considered in isolation and, by bringing these elements collectively into urban planning and not favouring one over another, one can avoid some common snags, especially perceptional issues of economy trumping environment and social well-being (Jennings et al., 2012). Important considerations include who is involved in processes of valuation and which values are taken into account. Valuation is a key process in the design, planning, monitoring, and evaluation of urban NBS. Moving towards just NBS requires interrogation of whose value, and value for whom, at the points in that process where valuation occurs (Cousins,

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2021). Research on NBS in European cities found that multi-actor governance is more likely to improve procedural, distributional, and recognition justice if decision making is transparent on the distribution of costs and benefits, if public control over urban NBS is maintained, and if scientific expertise is used in combination with bottom-up consultation practices (Toxopeus et al., 2020). Hybrid governance models incorporating multiple public and private actors have been popular for NBS governance in the context of limited local government resources and expertise. To realize just urban NBS using this institutional arrangement, Toxopeus et al. (2020) 'recommend urban NBS that are led through hybrid governance to be purposively designed to serve a broad public'. This still begs the question of what happens when different groups have competing expectations, or even different epistemologies – in such cases, whose 'environmentality' becomes dominant in shaping planning (Lemos and Agrawal, 2006; Graham and Ernstson, 2012)? Power is the elephant in the room here. Often ignored, power inequities play a deeply structural role in influencing outcomes when hybrid governance models are implemented.

There are a number of engagement approaches that municipalities can use to substantively engage residents in NBS development. Diverse groups from different backgrounds can be brought together in formats like future workshops, round tables, participatory planning workshops, and citizen panels to engage with each other and with local government representatives in order to enhance inclusion in NBS (Hörschelmann et al., 2019). Civil society organizations can also support citizen engagement in NBS development using approaches such as district forums, appreciative inquiries and public spirit workshops, district-based community work, and environmental education (Hörschelmann et al., 2019). Reaching marginalized groups through engagement processes can be particularly difficult, but approaches that may help include advocacy planning, where experts in planning processes are employed to assist citizens to represent their interests, and community organizing, where citizen organizations are established to enable residents to shape their city (Hörschelmann et al., 2019).

Mabon (2020) notes the importance of recognition – or close attention to *who* needs to be part of decision making – to achieving just outcomes in city planning. In cases of weak governance, local champions (individuals not recognized in traditional rule-based Global North cities under what Sultana et al. (2020, p. 5) refer to as 'the stable rules of municipal administration') are often significant players in negotiating access and use where lived understandings cannot be generalized. Consideration of context is important and due recognition of greening activities already under way or in place that are locally generated in Global South cities can counter the enactment of inappropriate policy drawn from the Global North. Similarly, identifying and matching existing

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practices and competencies and skills with resources for urban greening will result in more sustainable and context-appropriate NBS for all cities.

In conclusion, urban NBS offer the potential to pursue environmental and social justice, but only if they are explicitly designed for equity. Working towards just urban NBS means creating alternative socio-ecological relationships, fostering transformative co-production, forging new institutional and economic relationships, and respecting regional and context-specific diversity and divergence in the application of just NBS.

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PART II

The nature of nature-based solutions

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4. Urban ecological resilience: ensuring urban ecosystems can provide nature-based solutions

Timon McPhearson, Erik Andersson, Filipa Grilo, Bianca Lopez, and Nour Zein

NATURE-BASED SOLUTIONS NEED URBAN ECOLOGICAL RESILIENCE

With climate change-driven extreme events increasing in frequency and intensity, cities are on the front lines of needs for innovative climate adaptation and resilience efforts (Dodman et al. 2022). Nature-based solutions (NBS) are increasingly at the center of efforts to transform cities for climate adaptation, improve the physical and mental health of residents, and contribute to sustainability, equity, and inclusive human wellbeing (Kabisch et al. 2017; Frantzeskaki et al. 2019; McPhearson et al. 2022). However, NBS rely on biodiversity and well-functioning ecosystems to provide ecosystem services such as temperature regulation, coastal protection, stormwater absorption, human physical and mental health, and much more. Thus, urban ecosystems themselves must be resilient in order to be an ecological source of resilience for complex urban social-ecological-technological systems (SETS) undergoing change. Transforming cities to be flexible, adaptive, and resilient to a future that is increasingly uncertain requires many scales and types of transformation including increased attention to managing, protecting, and restoring urban ecological infrastructure to enable NBS to meet adaptation and urban livability needs (McPhearson & Wijsman 2017; Childers et al. 2019; McPhearson 2020).

However, if urban ecosystems are to deliver on the promises of NBS to provide social, economic, and infrastructure benefits reliably over time in the urbanized locations where most people live, then ecosystems must themselves be able to persist, even thrive in the face of multiple local, regional, and global pressures (McPhearson et al. 2015; Faivre et al. 2017; Lafortezza et al. 2018; Andersson et al. 2021a). At present the promises of NBS, not only in urban areas but in connected rural landscapes as well, are being promoted to deliver

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climate adaptation and mitigation solutions predicated on the assumption that ecosystems themselves are resilient and able to function adequately to provide critical ecosystem services. By resilient, we mean that ecosystems are able to sustainably maintain critical biodiversity and ecological structures and functions that underpin potential to provide NBS including carbon absorption, local cooling, stormwater absorption, flood attenuation, high-quality recreational spaces, benefits for human health, and more.

And yet, it is clear that ecosystems in all biomes and regions are under threat, with rapid biodiversity loss and ecological degradation driven by multiple human-induced impacts including climate change, invasive species, habitat fragmentation, and pollution (IPBES 2019; Pörtner et al. 2021; Parmesan et al. 2022). Urban ecosystems, including the species, community relationships, and larger social and infrastructure contexts that urban nature exists within, similarly face multiple threats from human-mediated disturbances. These threats include pollution, climate change, extreme weather events, localized human activity, invasive species, and many other drivers of change that not only act individually, but can co-occur in time and space threatening the health, viability, and ultimate ecological functioning of these systems. Ecosystem functioning is fundamental to the production of ecosystem services that NBS strategies are based on. Further, ecosystems face both chronic pressures and extremes that can make them more sensitive to various disturbances when they occur. When ecosystems are exposed to disturbances, their ecological functioning can be altered or impaired, affecting their ability to provide NBS. How can we ensure that urban biodiversity and the ecosystem functioning it supports will themselves be resilient to rising heat, storms, and other extremes and human-induced disturbances in cities? And fundamentally, how should we evaluate and measure ecosystem resilience in the first place?

Despite decades of research on the relationships between biodiversity and ecosystem function, we still lack fundamental conceptual frameworks and analytical methods to assess the resilience of ecosystems in complex urban contexts. Additionally, there is much less research on ecological resilience compared to social, infrastructural, and economic resilience studies in urban contexts. Yet, the resilience of urban ecosystems is key to understanding how to more effectively manage, care, and steward urban ecosystems to contribute to NBS, and thus must “catch up” to the decades of work on biodiversity and ecosystem functioning relationships that have advanced in more rural and non-urban contexts.

Further, the species composition of urban ecosystems is strongly affected by human-induced land-use changes, species invasions, and acceleration of species extinctions (Vitousek et al. 1997; Chapin et al. 2000; Fontana et al. 2021), though urban ecosystems can often be reservoirs of regional biodiversity (Aronson et al. 2017). Shifts in biodiversity affecting community

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assembly and structure can drive changes in ecosystem functions and services (Hooper et al. 2005), including species and ecosystem-level responses to climate and weather disturbances. In urban environments, we still lack fundamental understanding of the contribution of biodiversity to ecosystem processes and services, requiring new conceptual and analytical approaches, such as through functional traits (Cernansky 2017; Grilo et al. 2022), to reveal the role of ecological dynamics in complex urban SETS, though ecological theory using traits has developed over the last couple of decades seeking to explain mechanisms of community assembly, predict patterns, and understand relationships between biodiversity and ecosystem function (Fontana et al. 2021). Although conceptual frameworks (Fontana et al. 2021; Reynolds et al. 2022) and diverse methods have advanced, there has been little application or theory development using species traits to understand ecological structure, function, and resilience in urban contexts.

URBAN ECOSYSTEMS *IN* AND *AS* SOCIAL-ECOLOGICAL-TECHNOLOGICAL SYSTEMS

A growing number of urban ecologists conceptualize cities and urbanized regions as tightly intertwined and complex SETS (McPhearson et al. 2016a, 2016b, 2021; Grimm et al. 2018; Cook & McPhearson 2020; Andersson et al. 2021a; Hamstead et al. 2021; Zhou et al. 2021). The SETS conceptual framework applied to urban ecosystems (McPhearson et al. 2022) forces increased attention to the social and technological factors affecting species distributions, community structure, ecosystem function, ecosystem services, and also impacts on ecological resilience to disturbances. Thus, any urban ecosystem consists not only of ecological dimensions, but also interacting social and technological dimensions as well (Grimm et al. 2015; McPhearson et al. 2022). Put another way, NBS needs more than nature to work (Andersson et al. 2015), but the foundation of NBS remains functioning ecological entities from individual organisms to extensive, heterogeneous networked ecological infrastructures.

In the SETS conceptual framework (Figure 4.1) NBS are not simply a product of ecosystem structure and function, as they are often defined. Rather, NBS are deeply embedded in local and regional contexts and are generated by the combined structure and function of interacting social, ecological, and technological dimensions in each city or neighborhood along with their connected peri-urban and rural systems (Kabisch et al. 2022). The SETS framework acknowledges the interactions and interdependencies among social, ecological, and technological-infrastructural dimensions of urban systems. Social dimensions can include management, planning, policy, finance, institutional capacity, stewardship, human labor, perceptions, values, and cultural norms. Ecological dimensions can include climate, weather, biodiversity, species

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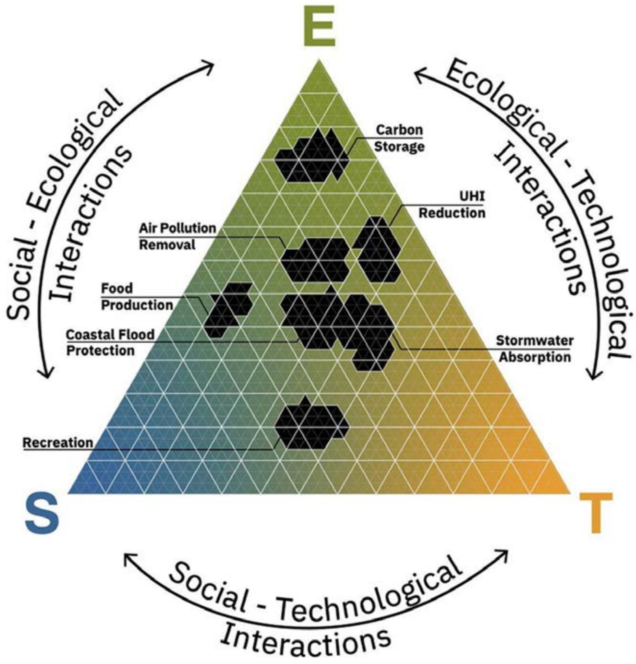
traits, ecosystem structure and function, and community-scale interactions that affect ecological functioning. Technological-infrastructure dimensions can include physical components (e.g. dams, levees, pipes, culverts), weather sensors, engineered basins, structural support, automated systems, irrigation, construction material, and data-driven monitoring systems (McPhearson et al. 2022).



Notes: Multiple NBS, here shown as specifical ecosystem services, illustrate how different and interacting SETS dimensions affect the production and supply of each ecosystem service and often do so with proportional inputs from social (S), ecological (E), or technological (T) dimensions. The left point represents 100 percent S, the apex represents 100 percent E, the right point represents 100 percent T, and gradations between them represent gradients of S, E, and T interactions. Filled shapes illustrate hypothetical contributions of social, ecological, and technological dimensions that affect each service – food production, urban heat-island (UHI) reduction, stormwater absorption, carbon storage, recreation – as discussed in the text. The relative location along the S, E, and T axes represent potential hypotheses to be tested within and among different cities and urban contexts, as SETS dimensions, interactions, and proportional contributions may be similar in some cities and very different in others. Here we ask how we can assess the resilience of E in order to better understand the E dimension of any NBS in a SETS.
Source: Adapted from McPhearson et al. (2022).

Figure 4.1 A SETS approach to nature-based solutions

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Furthermore, urban ecosystems are complex systems characterized by irreducible uncertainty, emergent properties, and non-linear behavior that when resilient can respond to and learn from changing conditions (Alberti et al. 2018). Framing cities as complex SETS provides a conceptual foundation for examining how SETS dimensions interact and affect their individual and collective contributions to NBS (McPhearson et al. 2022). However, given the lack of theoretical and empirical research on urban ecosystem resilience, we focus on how we can understand the ecological dimensions of urban ecological infrastructure (Childers et al. 2019), still situated in the context of SETS. Without ignoring the SETS nature of an urban ecosystem, we need to understand the ecological contribution to changes in ecosystem structure or function. Thus, there remains a need for field-based, remote sensing, or indicator-driven methods to measure and assess how ecological structure and functioning may change over time in response to disturbances.

ON URBAN RESILIENCE

Assessing the resilience of local urban ecosystems including individual, population, community, or ecosystem scales is critical to understand if we are to better link ecological resilience to social (community) resilience and infrastructure resilience, all important to developing and managing more generalized resilience of urban SETS. We follow a tradition of resilience thinking emerging from scholarship on complex adaptive systems (e.g. Levin 1999; Scheffer et al. 2001) and social-ecological systems (Berkes et al. 2000; Folke et al. 2021). In line with Elmqvist et al. (2019) we position resilience as a concept with bearing on both process outcomes (in some systems recognizable as states or regimes) and processes of change or renewal themselves. Urban (general) resilience calls for a definition of the core properties of "urban," which has been thoroughly debated in the literature on urban studies, so far without conclusive results. Instead, more progress has been made on studying multiple *specific resiliences* (Walker & Salt 2012; see also Meerow & Newell 2019). Specific resilience may, for example, relate to the ecological resilience of a species community or set of urban ecosystems.

To begin thinking about and assessing urban ecosystem resilience, it is critical to define resilience of what and to what (Carpenter et al. 2001), "of what" being whether we are interested in the resilience of species populations, communities, ecosystems, or a SETS, and resilience "to what" meaning defining the nature of the disturbance or shock including type, magnitude, severity, and intensity. Although other questions can be asked and answered, including the five Ws approach of resilience of what, to what, when, where, and for whom (Meerow et al. 2016), the "of what" and "to what" questions are the key start-

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ing point for defining what traits need to be considered to examine ecological resilience to a specific disturbance.

There are multiple attributes of resilience and in our conceptual framework we address the four Rs of resilience including robustness, resistance and response, recovery, and reorganization, with the proposition that traits that can indicate a value for each of the four Rs, or as many as possible, can serve as the foundation for a trait-based ecological resilience measure. In the four Rs, *robustness* refers to the ability of a population, community, or ecosystem to preserve its structure in the face of disturbance (Tu, 1994) or measured as the strength elements of the system in order to withstand external pressure without suffering any loss (Bruneau et al. 2003). *Resistance and response* are attributes that indicate the initial impact of the shock, i.e. resistance measures the magnitude of the reaction or response to shock and can thus indicate the ability to withstand or resist a shock or disturbance (Pimm 1984; Elmqvist et al. 2003). *Recovery* indicates the speed of returning to pre-disturbance functionality, determined by the degree of resistance to the shock at the first moment (e.g. Allen et al. 2019). Finally, *reorganization* is an attribute that considers the rearrangements of existing elements and establishment of new interactions in an ecosystem (or indeed a SETS) (e.g. Holling et al. 2002).

However, beyond ecological drivers of resilience, other factors will influence just how resilient an ecosystem will be, and thus how resilient the ability to provide a NBS may be. Being resilient does not mean simply being resistant to change or continuously functioning with no change (thus the four Rs to ensure we are looking at traits or characteristics that go beyond resistance). In fact, trying to remove or suppress variability has been one of the major fallacies of modern development (Holling & Meffe 1996). If NBS are to solve anything, variability in ecological functioning needs to be aligned with human demands and needs for NBS. Within certain boundaries, change helps to maintain ecological functionality over time (Holling 1973). Beyond these boundaries, change may lead to shifts in function (Scheffer & Carpenter 2003; Biggs et al. 2018) that cause NBS to lose their ability to contribute to urban livability.

Change is inherent in ecosystems, not least in the nature of urban environments where humans intensively use and manage ecosystems, create novel community interactions and ecosystems, and affect soil quality, water availability, and even light availability. These dynamics across SETS can potentially affect or “filter” the phenotypic expression of a trait (Grilo et al. 2022) and thus a species’ ability to be resilient to a disturbance even if it has a diversity of traits that we might argue confer some level of potential resilience. Additionally, intentionally and unintentionally, humans restructure landscapes and select and move around organisms, which means that species will meet and interact in new ways, forming novel and often transient urban assemblages (Hobbs et al. 2006; Kowarik 2011). Ecosystem functions, and

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the services and benefits they provide, may be contingent on specific assemblages, successional stages, and SETS contextual factors (Andersson et al. 2015; McPhearson et al. 2022). Challenging as it may be, we need to combine an understanding of when and why different species assemblages function in certain ways, together with planning and management practices that allow for more variability and change over time if we are to actively design or manage urban ecosystems for effective NBS.

INDICATORS OF URBAN ECOLOGICAL RESILIENCE

Ecological resilience to an environmental stress or disturbance can be determined by how individuals or species in a community respond to change and disturbance. These responses depend on species' specific life history traits and the SETS context a community is situated in. The structure of the community (i.e. the species and traits present), the types of environmental stresses or disturbances that occur, and the types of response of the community to the environmental change (e.g. changes in abundance frequencies, trait frequencies, or species composition) together determine the ecological outcomes of change. Detecting community resilience to environmental change (either in relation to species or population persistence or ecosystem function) ultimately requires tracking a community over time and measuring changes in community structure or function pre- and post-disturbance. However, theory predicts that aspects of the community, such as the trait states of individuals (i.e. high versus low tolerance to a particular stressor), redundancy (i.e. shared functional traits), and dispersal (i.e. ability to recolonize or reorganize), are useful indicators and can be predictors of community resilience to environmental change.

Management to maintain or enhance urban ecological resilience requires knowing the differential species-level responses to disturbances (e.g. some street trees die from insect pests, others may die from drought or negative direct human impacts, or from a storm but because they were previously weakened by pests) while recognizing that there are both short- and long-term disturbances and short- and long-term responses to disturbances that can together affect ecological resilience. The presence of certain species' traits can provide important indicators of potential species-level responses to a specified disturbance. However, the phenotypic expression of a trait may also be more or less sensitive to the pressures and disturbances that occur in urban environments. Thus, field-based data remain critical to advancing our understanding of impacts on urban ecosystems (Kraemer & Kabisch 2022), what attributes of ecosystems allow for them to be more or less resilient, and to serve as empirical tests of theory and hypotheses that can be suggested by theory and application of trait-based indicators. Conceptual frameworks too are needed to

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guide this data collection and investment in new knowledge and can serve as the locus for developing testable hypotheses (Fontana et al. 2021).

In the absence of field-based data, indicator data that are correlated with particular functions of interest to ecological resilience assessment are needed and species traits have become an increasingly useful indicator source. Dominant species, compensatory dynamics, and insurance effects are the main mechanisms by which biodiversity affects the stability of ecosystem functions and all act through the functional traits of organisms. These mechanisms can be assessed using different components of trait values within and between species (de Bello et al. 2021). Despite growing evidence that biodiversity promotes ecosystem functioning (Hong et al. 2022), working with organismal traits can provide a mechanistic understanding of community dynamics including their resilience to various environmental conditions and human impacts (Auber et al. 2022).

THE ROLE OF SPECIES' TRAITS

Biodiversity affects the stability of ecosystem functions by acting through the functional traits of organisms that form local communities (de Bello et al. 2021). Functional traits, the phenotypic features of organisms that affect their fitness (Violle et al. 2007), determine individual and population adaptation to the environment (through e.g. response traits), and in turn affect biotic interactions and thus drive ecosystem processes through biomechanical and metabolic activities (through e.g. effect traits). Variation in local populations can drive changes in community structure, the diversity of traits present, and then drive (or not) changes in ecosystem functions.

Functional traits are morphological, physiological, or phenological features of an organism, measurable at the individual level, from the cell to the whole-organism level, reflecting the outcome of evolutionary and community assembly processes (Díaz & Cabido 2001; Kattge et al. 2020). Ecological functioning can, in principle, be indicated by using components of trait value distributions within and between species, and thus serve as urban ecological resilience indicators of populations, communities, and ecosystems through both effect and response traits. By improving the predictability of such relationships, the ecology of functional traits offers new possibilities for generalization, hypothesis generation, and field- and remote-based ecological resilience assessment, especially in urban contexts. Therefore, considering the functional aspect of biodiversity has the potential to improve our understanding of important questions at the core of current urban ecological research. Further, trait-based approaches are independent of taxonomy and can be used as standardized measures of structure and function, allowing wider generalization of results (Hooper et al. 2005).

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Trait-based ecological tools and concepts have been developing for more than a decade, particularly along both conceptual and quantitative directions (McGill et al. 2006; Violle et al. 2007; Litchman & Klausmeier 2008; Bolnick et al. 2011; Lavorel 2013), though with little treatment, application, or overt consideration of how traits may be expressed, selected, or modified by social and technological dimensions of urban systems. Thus, despite a rich array of approaches that encompasses a range of trait types, ecological scales, and applications, urban ecology theory and urban empirical studies have only recently begun to embrace trait-based ecology (Andersson et al. 2021b; Grilo et al. 2022; Reynolds et al. 2022).

Traits have been considered as reflecting adaptations to variation in the physical and biotic environment and trade-offs among different functions within an organism (Violle et al. 2007; de Bello et al. 2010). The framework presented by Suding et al. (2008) that intended to determine how community dynamics influence ecosystem functions has classified traits into response and effect traits. Response traits reflect direct and indirect responses to environmental gradients and disturbances, which is translated into the organisms' resistance to environmental variability (Sterk et al. 2013). For example, disturbances can affect the expression of response traits that enable plants to rapidly regenerate between disturbance events or tolerate periods of unsuitable habitat conditions. More specifically, traits related to seed-bank size and longevity are known to respond to fragmentation, since the production of large and persistent seed banks increases the chance of colonization even when dispersal range is limited (Kolb & Diekmann 2005; Bossuyt & Honnay 2006).

Effect traits, on the other hand, are related to the organisms' recovery, impacting ecosystem processes and functions and therefore ecosystem services delivery and overall resilience of the ecosystem (Sterk et al. 2013). For example, effect traits related to pollinators' body size and forage range and flower traits associated with the length of the flowering period and concentration of nectar sugars contribute to the ecosystem service of pollination (de Bello et al. 2010; Prasifka et al. 2018). Specifically, flowers with higher volumes of nectar are often more attractive to pollinators, contributing to higher pollination services (de Bello et al. 2010). However, both functional response and effect traits can often coincide, particularly regarding resource use. For example, response traits related to higher resistance to environmental stress and herbivory are also known to determine functions related to slow decomposition and slow down nutrient cycling (Aerts 1995). Understanding patterns, dynamics, and interactions of ecosystems through a trait-based approach can help ecosystem management to focus on the functional processes that achieve and maintain resilience in both the short and long term (Sterk et al. 2013).

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Ultimately, trait-based ecology aims to explain mechanisms of community assembly, predict ecological structure and function patterns, such as the effects of biodiversity shifts on key ecosystem processes, and recently as a way to examine the resilience of green infrastructure (Reynolds et al. 2022). This body of work has stimulated the development of several conceptual frameworks and analytical methods, as well as the production of trait databases covering a growing number of taxa and organizational levels (from individuals to guilds). However, the expanding range of novel concepts and tools currently lacks a general and coherent framework that can advance theory and empirical assessment of urban ecological resilience, recognize the SETS context of urban ecological dynamics, and serve to generate testable hypotheses and unite the multiple disciplines contributing to studies of urban SETS, NBS, and resilience. Here, we provide a conceptual framework as a starting point for advancing urban ecological resilience theory in urban SETS, but also to guide the use of traits-based indicators to assess urban ecological resilience to environmental change.

A CONCEPTUAL FRAMEWORK FOR ASSESSING URBAN ECOLOGICAL RESILIENCE

We provide the urban ecological resilience (UER) conceptual framework to serve as a starting point for thinking through the multiple interacting components and dimensions of urban SETS that may affect the resilience of any particular population or community to a disturbance and to assess urban ecological resilience. In the framework we situate species and their traits in an ecological community context with other species (and their traits) that exist and interact dynamically within a given local SETS. This local SETS is itself nested within the larger city, regional, and global SETS that may create disturbances that act through local communities or specifically on individual species depending on type, intensity, and duration of a given disturbance. SETS at all scales interact and also serve as sources for other social (S), ecological (E), technological (T), or combined SET impacts that may affect the phenotypic expression of a given species' trait, bundle of traits within a species, or impacts on other species and their traits in the ecological community. Individual trait expressions can in turn affect the expression of other species' traits that may confer (or not) more or less resilience as described by the four Rs (*robustness*, *recovery*, *resistance and response*, and *reorganization*), building on previous functional diversity research and traits frameworks but here applied to urban contexts and resilience.

We conceptualize the SETS nested approach (Figure 4.2) to evaluating trait indicator values not only for response traits important to resilience, but also to consider how effect traits can be incorporated, including their potential

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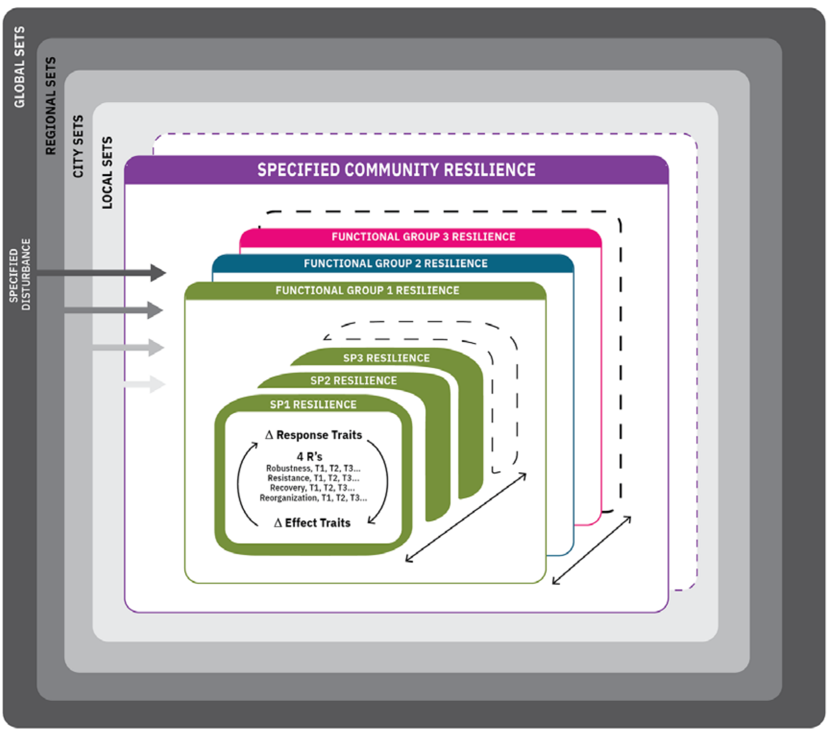
impacts on response traits, to predict ecological resilience of a species, population, or community. Within a local SETS, we start with an ecological community consisting of interacting functional taxonomic groups such as multiple species of trees in a forest, or a functional group of bird species in a grassland, or other such functional groups. Within each SETS at each scale there are multiple communities, made up of multiple functional groups, each containing likely multiple species that have interactions potentially affecting any species' response and effect traits (Figure 4.2). To start working with the framework it is simplest to consider first a local population of a specific species, then consider other species within a functional group that a given species may interact with in ways that affect the initial species response to a disturbance, or indeed any interaction affecting the phenotypic expression of effect or response



Notes: Response and effect traits may change (Δ) in value through their interactions. Arrows between species indicate species interactions that may affect trait expression, and arrows between functional groups indicate interactions between functional groups that may affect trait expression and resilience at population, community, and ecosystem scales.

Figure 4.2 The urban ecological resilience conceptual framework

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traits of the first species that may confer more or less resilience to a specified disturbance.

Disturbances can act on different levels of ecological organization (individuals, populations, communities) and can be any possible type of disturbance (e.g. heat wave, drought, local human impact, pollution, storm) occurring with any given intensity, frequency, or duration. This framework requires that a disturbance be identified to describe resilience to a specific type of disturbance starting with answering questions of resilience "to what disturbance?," "of what ecological functioning?," and "for which species or ecological community?," all of which are essential to answer to develop the list of effect or response traits that are important to conferring more or less robustness, resistance and response, recovery, and reorganization as attributes of resilience to a specified disturbance. Disturbance frameworks sometimes approach these questions but often do not deal with traits, and trait frameworks have not adequately examined their relationship to ecological resilience. We consider how a species or multiple species interacting in an ecological community may together exhibit more or less resilience to a specified disturbance based on their trait values with traits of interest chosen based on their potential to confer some or many resilience attributes. All community interactions that respond to disturbance in some way are nested inside the SETS starting at the local scale but recognizing the interactions at larger spatial hierarchies from local- to municipal- to regional- and even global-scale dynamics are important given they may simultaneously impact the structure and functioning of any particular ecological community. Disturbance can originate at any scale, but may be filtered through the lower scales before having an impact on a local community.

Species resilience then can be expressed as the product of the *n* trait values (T) (categorical or continuous) within each resilience category (4 Rs) that may change (Δ) based on response and effect trait interactions such that:

$$\text{Species Resilience } (SR_1) = R_1\,(T_1 + T_2 + T_3 \ldots) / [\#Ts] + R_2\,(T_4 + T_5 + T_6 \ldots) / [\#Ts] + R_3\,(T_7 + T_8 + T_9 \ldots) / [\#Ts] + R_4\,(T_{10} + T_{11} + T_{12} \ldots) / [\#Ts] \tag{4.1}$$

Functional group resilience is then the sum of the resilience of the local interacting species weighted by the abundance of each species within that functional group such that:

$$\text{Functional Group Resilience } (FGR_1) = [(SR_1 * A_1) + (SR_2 * A_2) + (SR_3 * A_3) \ldots] / \#Spp \tag{4.2}$$

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Specified community resilience then is the product of the resilience of the functional groups of importance in a local ecological community for a specific disturbance such that:

$$\text{Specified Community Resilience } (SCR_1) = (FGR_1 + FGR_2 + FGR_3 \ldots) / \#FGs \quad (4.3)$$

To consider multiple disturbance types, the process can be repeated for each SCR where the subscript 1, 2, 3, etc. refers to the SCR for a specific disturbance and then is summed and divided by the # of communities considered to generate a *generalized community resilience* such that:

$$\text{Generalized Community Resilience } (GCR) = (SCR_1 + SCR_2 + SCR_3 \ldots) / \#Cs \quad (4.4)$$

Where for all equations R_1 = robustness, R_2 = resistance, R_3 = recovery, and R_4 = reorganization trait categories, T_1 = trait 1 for robustness (R_1), T_2 = trait 2 for R_1, then repeated for each *n* traits for each $R_{1\text{-}4}$, Sp_1 refers to species 1, Sp_2 refers to species 2 within a given functional group, and repeated for each functional group from 1-n groups, where A = abundance of each species and C = # of communities, and where SR = *species resilience*, FGR = *functional group resilience*, and SCR = *specified community resilience*, and GCR = *generalized community resilience*.

These equations and the UER conceptual framework provide the basis for developing methods to assess urban ecosystem resilience at multiple taxonomic, hierarchical, and spatial scales using traits as indicators in the context of complex SETS. Indicator-driven resilience scores should be considered as *potential* resilience given the need to validate such approaches with field-based data, which is a crucial need for advancing trait-based urban ecology. Independently, species or community responses (which we assume are a function of their traits) can be measured, developing a resilience measure (i.e. change in species abundance across a disturbance or species persistence through time) that is then compared with the specified resilience score using this framework. A disagreement between a resilience score and a field-based resilience measure could mean that either the resilience score is wrong, because we haven't identified the right traits (or the traits values don't match the actual community considered), or the resilience score is correct, but measured resilience differs because of the influence of other components of SETS that are affecting the phenotypic expression of traits in response to a disturbance not fully captured by trait-based indicators. For example, protection against wind-

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throw of urban street trees by built structure (T) could positively influence tree resilience more than may be indicated by specific traits, or a post-disturbance change could drive changes in community structure due to direct human intervention through management (S) or otherwise affecting a measured outcome in species persistence or response following disturbance.

APPLYING THE URBAN ECOLOGICAL RESILIENCE FRAMEWORK TO URBAN STREET TREES IN NEW YORK CITY

Next, we provide a case study for how the framework can guide the assessment of resilience of a species as well as to compare resilience of multiple species within a functional group in an urban SETS. We intentionally developed the framework to be flexibly applied to questions about specific species, functional groups, or communities and here we use the framework to both develop a list of relevant trait indicators and to consider how resilience can be compared and examined across multiple species. Additionally, we consider how a resilience index can be applied for a specific disturbance or summed and averaged for more general resilience to multiple types of disturbances. To demonstrate a replicable approach to applying the UER framework using trait databases and spatially explicit biodiversity data to develop a resilience index we selected street trees in the urban forest of New York City (NYC) to assess their potential resilience to climate change and weather-related disturbances. We draw on data from a comprehensive street tree census dataset developed by the NYC Department of Parks and Recreation (2016) and relevant indicator trait data drawn from multiple trait databases with records for specific tree species in this study.

For context, NYC is the largest and most populated city in the United States (U.S.) with over 8.8 million residents (United States Census Bureau 2020) and also harbors the most parks and open space of any U.S. city. People, infrastructure, and ecosystems currently face multiple impacts of climate change, including extreme temperatures and coastal flooding from sea-level rise and hurricanes with risks and expected impacts projected to worsen in the coming decades (Horton et al. 2015). At the same time, urban parks in the city provide critical NBS to address multiple challenges including climate change impacts but also for improving public health. A report by the Trust for Public Land (2022) calculated that up to US$2.43 billion in avoided stormwater treatment costs is saved through runoff absorbed by parks and natural areas rather than discharged to sewers, streets, and waterways. Additionally, an estimated US$9.1 billion is provided in recreational value for residents, given the 527 million visits to parks by residents alone, who use the parks for playing in playgrounds, walking, picnicking, running, relaxing, observing wildlife, biking,

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visiting beaches, and participating in fitness classes. NYC parks provide US$1.14 billion in health-care savings for over 1 million residents who report using parks to meet Centers for Disease Control and Prevention guidelines for physical activity, while parks are also documented to reduce costs of heat stress illnesses due to parks' shrubs and tree canopies providing shade and lowering nearby ground temperatures, and avoiding the costs for associated emergency department visits or hospitalizations.

Urban street trees provide their own contributions to NBS. Analyses using the USDA Forest Service's iTree software found that over 1 billion gallons of stormwater valued at US$10.4 million is intercepted each year by street trees, as well as 1.2 million pounds of air pollutants removed, valued at US$6.4 million, 1.18 billion tons of CO_2 removed valued at US$3.9 million, and shading of buildings providing energy savings of 649 million kWh valued at US$82 million each year. With such critical services being provided by urban nature, understanding how resilient the urban forest and its street trees are likely to be to current or projected climate threats poses a critical question for urban forest management to guide broader investments in NBS as climate solutions. If such trees are not resilient to a variety of disturbances, then they will not be able to sustainably supply key NBS that urban residents rely on. Here we ask: how resilient are different species of street trees in NYC to climate-related disturbances? We examined the potential resilience of NYC's over 800,000 street trees to three distinct climate-related stressors – extreme heat, drought, and storms, which include potential impacts from strong winds, heavy rains, and coastal storm surge flooding.

METHODS

Street Tree Species and Traits

We incorporated species data on all NYC street trees from the 2015–16 street tree census, hosted on the NYC Open Data platform (https://data.cityofnewyork.us/Environment/2015-Street-Tree-Census-Tree-Data/uvpi-gqnh). This dataset includes the identities, diameters at breast height, health, and locations of all 129 species or genera of street trees across all of NYC, which vary spatially in density and identity (Figure 4.3). Data were collected by volunteers organized by the NYC Parks department in a street census that occurs every ten years. We then compiled relevant tree species trait data for each of the taxa (species or genera) in the street tree dataset from three publicly available sources including the Citree project (Vogt et al. 2017; https://citree.de/database.php?language=en), which provides data on tree species in Europe to inform species selection for urban tree plantings, the TRY global plant trait database (Kattge et al. 2020), and the University of Florida's tree

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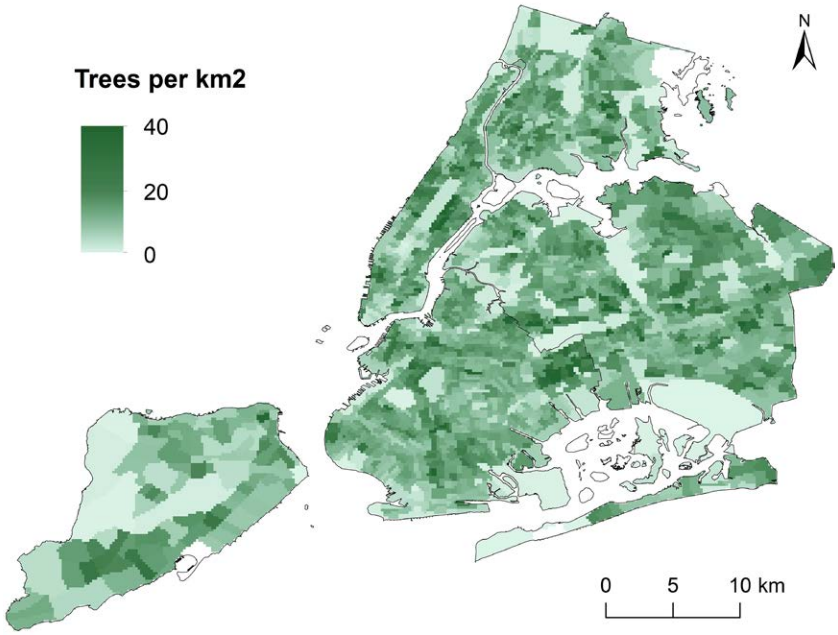

Note: NYC boroughs are outlined.

Figure 4.3 *Street tree density as number of individuals per km² for >800,000 individual trees and 129 species at the Census tract level*

fact sheets (UFL 2021; https://hort.ifas.ufl.edu/database/trees/trees_scientific.shtml). We selected traits to describe the potential resilience of street trees to heat, drought, and storms (Table 4.1).

There were 13 genera in the street tree dataset for which not all individual trees were identified to the species level. For these, we consulted two street tree standards and permitting documents from the NYC Parks Department to identify likely species from those genera in addition to those identified to the species level in the dataset. We added these candidate species to the list of species for which we collected trait data. Each genus-level tree identification was assigned mean trait values for all the species in that genus within the trait dataset. For categorical traits, genus-level tree identifications were not assigned a value when there was disagreement between species within the genus. In total we analyzed climate resilience traits across 129 species or genera. Table 4.2 shows the number of taxa with information for each trait

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Table 4.1 List of traits analyzed for each street tree taxonomic group in New York City

Trait	Unit	Description	Related stressor	Database	Trait type	Jenks intervals	Categories from the database	Final categories
Heat tolerance	–	Tolerance to heat (Vogt et al. 2017)	Heat	Citree	Categorical	–	(1) Low; (2) medium; (3) good	(1) Low; (2) medium; (3) high
Pest resistance	–	Plant resistance to pests (UFL 2021)	Heat	UFL	Categorical	–	(1) Free of pests and diseases/ no pests; (2) long-term health usually not affected by pests; (3) (very) sensitive to pests and diseases	(1) Low; (2) medium; (3) high
Leaf thickness	mm	Thickness of the leaf or component thereof (Kattge et al. 2020)	Heat	TRY	Numeric	Yes	–	(1) Low; (2) medium; (3) high
Specific leaf area	mm^2/ mg	Leaf area per leaf dry mass, undefined if petiole is included or excluded (Kattge et al. 2020)	Heat; drought	TRY	Numeric	Yes	–	(1) Low; (2) medium; (3) high
Drought tolerance	–	Tolerance to drought (Vogt et al. 2017; Kattge et al. 2020)	Drought	Citree	Categorical	–	(1) No dry tolerance/sensitive (2) dry tolerance; (3) high tolerance	(1) Low; (2) medium; (3) high
				TRY	Numeric	Yes	–	
Precipitation requirement	in	Species habitat characterization/ plant requirement: precipitation (Kattge et al. 2020)	Drought	TRY	Numeric	Yes	–	(1) Low; (2) medium; (3) high

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Trait	Unit	Description	Related stressor	Database	Trait type	Jenks intervals	Categories from the database	Final categories
Wood density	g/cm³	Stem dry mass per stem fresh volume (Kattge et al. 2020)	Drought	TRY	Numeric	Yes	–	(1) Low; (2) medium; (3) high
Rooting depth	m	Ratio of root length to dry mass of fine roots (Pérez-Harguindeguy et al. 2013)	Drought; storms	TRY	Numeric	Yes	–	(1) Low; (2) medium; (3) high
Limb breakage	–	Susceptibility to breakage (UFL 2021)	Storms	Citree	Categorical	–	(1) Low; (2) medium; (3) high	(1) Low; (2) medium; (3) high
				UFL	Categorical		(1) Resistant; (3) susceptible to breakage (either at the crotch due to poor collar formation, or weak wood)	
Salt tolerance	–	Occurrence of individuals along gradient of salt in soil solution or water solution (Kattge et al. 2020)	Storms	Citree	Categorical	–	(1) Low; (2) medium; (3) good	(1) Low; (2) medium; (3) high
				TRY	Categorical		(1) Low; (2) medium; (3) high	(1) Low; (2) medium; (3) high
Waterlogging tolerance	–	Survival/maintenance of growth rates under waterlogging at development relative to non-waterlogged conditions (Zhou et al. 2010)	Storms	Citree	Categorical	–	(1) Sensitive; (2) short term; (3) long term	(1) Low; (2) medium; (3) high
				TRY	Numeric	Yes	–	

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Table 4.2 Number of taxa with information for each trait analyzed and percentage regarding the total number of taxa analyzed (n = 129), for each database

Trait	# taxa in Citree database	# taxa in TRY database	# taxa in UFL database	# total taxa
Heat tolerance	74 (57%)	–	–	74 (57%)
Pest resistance	–	–	110 (85%)	110 (85%)
Leaf thickness	–	77 (60%)	–	77 (60%)
Specific leaf area	–	106 (82%)	–	106 (82%)
Drought tolerance	74 (57%)	114 (88%)	–	120 (93%)
Precipitation requirement	–	69 (53%)	–	69 (53%)
Wood density	–	98 (76%)	–	98 (76%)
Rooting depth	–	71 (55%)	–	71 (55%)
Limb breakage	74 (57%)	–	110 (85%)	111 (86%)
Salt tolerance	74 (57%)	94 (73%)	–	109 (84%)
Waterlogging tolerance	74 (57%)	114 (88%)	–	118 (92%)

analyzed and corresponding percentage of information drawn from each trait database.

Heat traits

We selected four tree traits relevant to potential resilience to heat and heat extremes and constructed a database for each of the 129 street tree species or genera in our study: leaf thickness, specific leaf area, pest resistance, and heat tolerance (Table 4.1). These traits were chosen to represent the species' direct resilience to heat since trees with thicker leaves and lower specific leaf area experience less water stress from water loss through the leaves at high temperatures (Soudzilovskaia et al. 2013; Michaletz et al. 2016). Additionally, since urban heat islands and global warming can also increase insect herbivory damage on trees (Dale & Frank 2014; Youngsteadt et al. 2015), pest resistance traits were considered since they can indirectly increase species' resilience to heat.

Drought traits

We selected five traits relevant to potential drought resilience to build a database to categorically score each species for drought resilience including specific leaf area, precipitation requirement, wood density, rooting depth, and drought tolerance (Table 4.1). Drought tends to favor trees with denser wood, which provides a lower risk of cavitation and sustained water flow (Hacke

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et al. 2001; Greenwood et al. 2017; O'Brien et al. 2017); lower specific leaf areas are associated with lower susceptibility to drought-induced mortality (Greenwood et al. 2017); rooting depth, one of the most commonly measured suite of traits, affects drought-induced tree mortality (Anderegg et al. 2016); and precipitation requirements reflect species' tolerance to drought.

Storm traits

We selected four traits relevant to potential storm resilience to assess species-specific resilience to storms including impacts of high winds, heavy rainfall, and inland and coastal flooding. Traits considered included rooting depth, limb breakage, salt tolerance, and waterlogging tolerance (Table 4.1). Species with greater rooting depths are associated with a higher resilience to strong winds (i.e. a lower probability of uprooting); species with greater risk of limb breakage have less resistance to strong winds; and waterlogging and salt tolerance are indicators of species' potential resilience to storm surges.

Analysis

We transformed both categorical and continuous numerical data for each trait into high, medium, and low categories (coded categorically as 1 for low, 2 for medium, and 3 for high resilience). For numeric trait data, we used Jenks natural breaks to split values into those three classes. Several traits (e.g. heat, waterlogging, and drought tolerance) were already designated as high, medium, or low in the trait databases, sometimes with an additional "none" category, which we included with "low." When there were discrepancies in categories for a species between datasets, we prioritized urban tree data from Citree followed by data from the U.S. from USDA plants (via TRY) and the University of Florida, followed by other datasets within TRY. Traits were then coded into high, medium, and low resilience categories, depending on whether high or low trait values confer greater resilience to the stressor (e.g. a high value of specific leaf area was recoded as "low" resilience and vice versa).

Each species was assigned a single resilience index value for each stressor (heat, drought, and storms), calculated as the mean of all trait resilience values (coded categorically as 1 for low, 2 for medium, and 3 for high resilience) within the stressor category (Table 4.1). The overall resilience of each species was calculated as the mean value of the resilience indices for the three stressors.

We examined bivariate correlations between the three indices and calculated an overall species-level resilience index by taking the mean of the three stressor-specific indices. We compared the species-level resilience indicators between the 15 most common street tree species (which together accounted for 80 percent of the street trees in the city) and the other 114 species in the dataset, using analysis of variance (Anova) assessments. We mapped the species-level

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resilience indices for individual trees to visualize spatial patterns in resilience to the three stressors across the city. We also calculated abundance-weighted mean indices (i.e. "community-level indices") at the census tract level and mapped these across the city to examine differences at a coarser spatial scale. We also compared the number of individuals of each species with the resilience index for each stressor.

RESULTS

In NYC, 15 taxa of street trees account for 80 percent of their overall abundance. Among these, about 22 percent belong to the *Prunus* genus and 11 percent are *Platanus x acerifolia* (Table 4.3). Within these 15 taxa, *Pyrus calleryana* and *Fraxinus pennsylvanica* showed the highest resilience to heat (2.33 and 2.25, respectively), *Zelkova serrata*, *Platanus x acerifolia*, and *Quercus palustris* showed the highest resilience to drought (2.75, 2.5, and

Table 4.3 Summary of the top 15 most abundant species of street trees in New York City, equal to 80 percent of the total number of street trees

Taxa	# of individuals	Relative abundance	Absolute abundance	Heat index (average)	Drought index (average)	Storm index (average)	Resilience index (average)
Prunus sp.	175,674	21.58	21.58	1.75	1.75	1	1.50
Platanus x acerifolia	87,014	10.69	32.27	3	2.5	1.67	2.39
Gleditsia triacanthos	64,263	7.89	40.17	2	–	3	2.50
Pyrus calleryana	58,931	7.24	47.41	2.33	3	1.67	2.33
Quercus palustris	53,185	6.53	53.94	2	2.5	2.33	2.28
Acer platanoides	40,112	4.93	58.87	1.75	2.25	2.33	2.11
Tilia cordata	29,742	3.65	62.52	1.75	2	1.67	1.81
Zelkova serrata	29,258	3.59	66.12	2	2.75	1.33	2.03
Ginkgo biloba	21,024	2.58	68.70	2	2	2.25	2.08
Styphnolobium japonicum	19,338	2.38	71.08	3	3	2.33	2.78
Acer rubrum	17,246	2.12	73.19	1.5	2.25	1.5	1.75
Fraxinus pennsylvanica	16,251	2.00	75.19	2.25	2	2.5	2.25
Tilia americana	13,530	1.66	76.85	1.5	1.4	1.75	1.55
Acer saccharinum	12,277	1.51	78.36	1.75	2.2	2	1.98
Crataegus sp.	11,952	1.47	79.83	1.67	2	–	1.84

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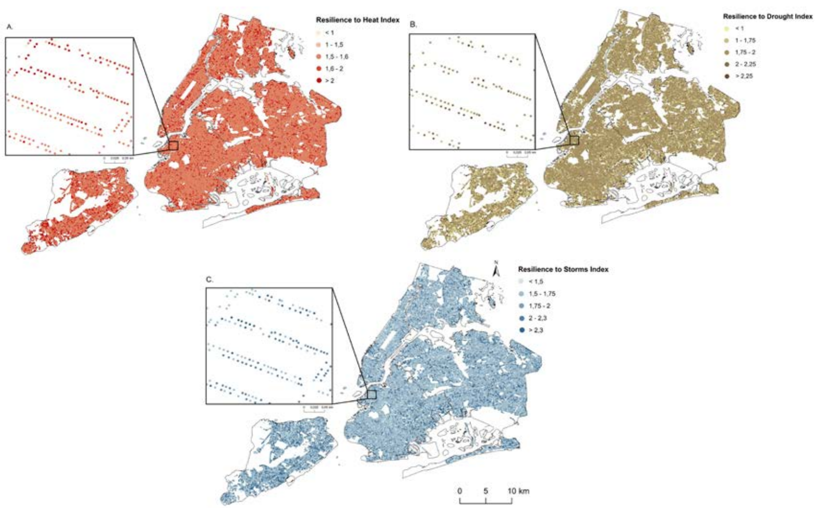
2.5, respectively), and *Gleditsia triacanthos* showed the highest resilience to storms (3). When considering generalized resilience to all three disturbance types, *Styphnolobium japonicum* and *Gleditsia triacanthos* had the highest values.

The most abundant street trees had higher values of drought resilience (F = 7.662, p = 0.006) and overall (i.e. mean) resilience (F = 4.673, p = 0.033) than less common species but no significant difference in the heat or storm resilience indices. Subsequent spatial analysis shows that at the census tract level, drought resilience was correlated with both storm and heat resilience, with a smaller correlation between storm and heat resilience, and there were spatial patterns in resilience indices across the city (Figure 4.4). Mapping individual trees shows that high- and low-resilience species are planted together, creating heterogeneity in resilience values across small spatial scales (Figure 4.4). The community-level resilience indices also show the heterogeneity of the different U.S. census tracts regarding their resilience to the different stressors analyzed (Figure 4.5).

When we look at the distribution of the resilience indices for the three disturbances across all species of street trees in NYC, we find that the most abundant species of street trees had low to high resilience to heat and storms, and a medium to high resilience to drought (Figure 4.6).



Note: Individual maps show species-level indices for resilience to (A) heat, (B) drought, and (C) storms.

Figure 4.4 Species-level resilience indices for individual street trees mapped across New York City

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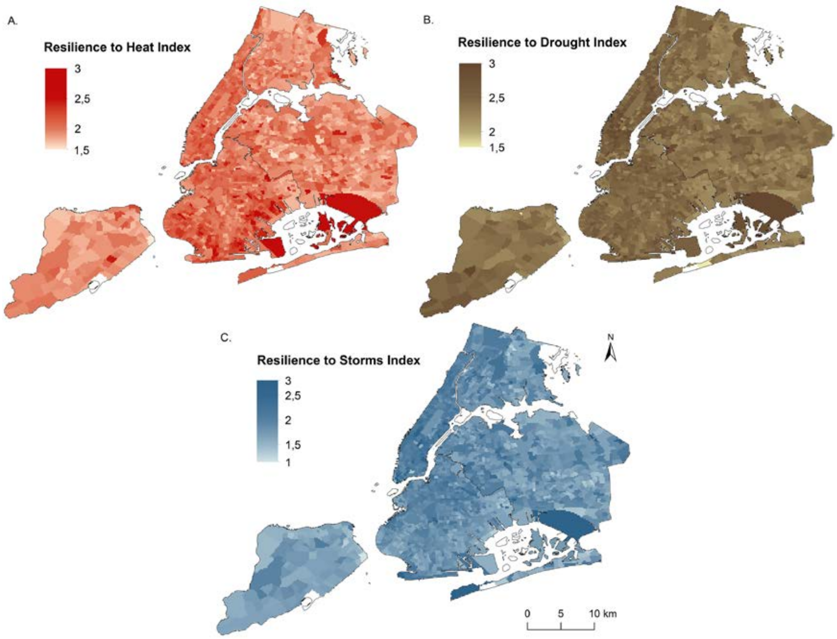

Note: Individual maps show species-level indices for resilience to (A) heat, (B) drought, and (C) storms.

Figure 4.5 Community-level resilience indices (calculated as abundance-weighted means) of New York City street trees at U.S. Census tract level

This approach to spatially assessing potential resilience to multiple disturbance provides one approach to moving from conceptualizing urban ecological resilience to assessment. However, in our application of the framework to NYC street trees we note some important limitations. First, traits may be expressed differently than the values we report in our database and resulting indices because traits in the existing global trait databases are not mostly measured in urban environments. However, these traits are generally only assessed in broad low, medium, or high categories and so may not be as impacted by variation driven by local conditions than if they were analyzed using continuous quantitative data. This suggestion argues for the strength of such categorical/qualitative approaches to best handle limitations in assumptions about trait data derived from non-urban sources. Still, we stress that the resilience assessment we provide for NYC street trees is not intended to be a definitive assessment of urban street tree resilience to climate change in NYC, but rather

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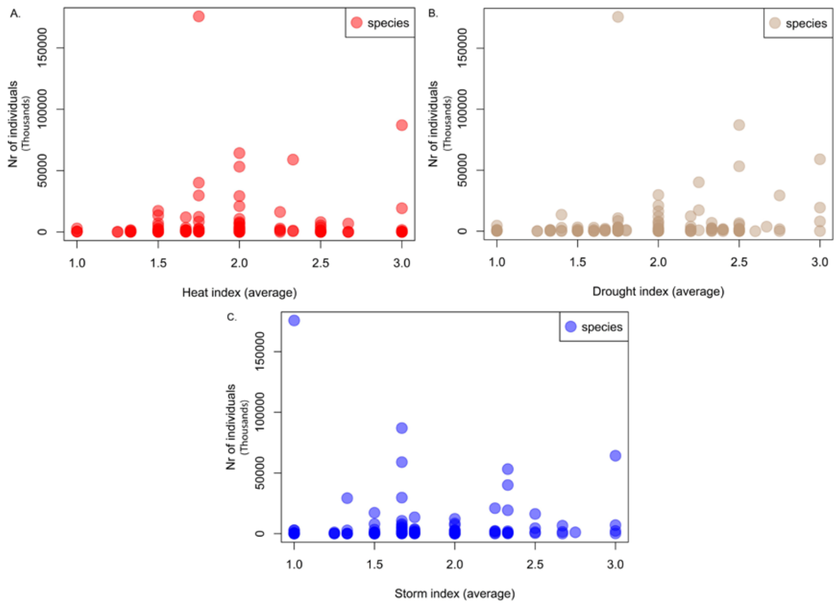

Note: 1 = low resilience, 2 = medium resilience, 3 = high resilience, for each species (circles) (y-axis). The taxa with more than 150,000 individuals is *Prunus sp*.

Figure 4.6 Number of individuals of street trees (x-axis) and (A) heat, (B) drought, and (C) storms index rankings

demonstrates a methodological approach to putting the UER framework into practice for urban ecosystem resilience assessment using local biodiversity data and existing trait databases.

Second, there may be other important traits that confer more or less resilience to a specified disturbance that do not exist in trait databases or that we simply missed in our analysis, which argues for caution in interpretation of case study results. We suggest results of this case and similar applications that others may undertake in other cities for other taxa be used as hypotheses to test in field-based empirical studies. In this sense, all stated results of our case study could be stated as hypotheses, ones that are advanced by underlying theory, a novel framework, and use of existing databases and rationales for trait selection based on existing literature.

Third, we use the language of "potential resilience" rather than actual to denote the hypothetical nature of our findings despite being data driven. A key reason for this caution is the inability given data limitations to adequately consider trait interactions or how phenotypic expression of a trait or mix of traits may be impacted by local or regional SETS processes. However, our

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approach is generalizable and could be applied to many other taxa where local and regional biodiversity data are available and where relevant trait data may also be found in existing trait databases, likely true for many urban bird and plant communities among other taxonomic groups. Though not comprehensive and still requiring testing through local empirical measures of both trait expression and resilience over time, we provide this NYC case study as a replicable method advancing urban ecosystem resilience research and assessment.

WHERE CAN WE GO FROM HERE WITH TRAITS AND URBAN ECOSYSTEM RESILIENCE?

The UER conceptual framework advanced here is provided to guide urban ecosystem resilience assessment using trait values as indicators of more or less resilience to a specified disturbance. In the development of the framework and its application to NYC street trees a number of questions and issues arise. First, how important is species diversity to ecological community resilience? If adequate diversity of traits exists within a community to provide resilience to multiple disturbance types, does it have impacts on ecological functioning and the provision of NBS if this diversity or traits are drawn from a smaller or larger species diversity pool? Field-based studies that systematically examine how trait diversity and species diversity correspond to ecological resilience at community scales will be needed to answer this question. However, for the purposes of using traits as indicators, we can use the framework to generate testable hypotheses such as: the greater the diversity of traits the greater the potential resilience to multiple disturbances, or, as the number of species in a community increases so will the diversity of traits associated with resilience to multiple climate stressors.

Some response traits (including those analyzed here) can also be effect traits, important for ecosystem functions and services such as climate regulation. For example, leaf thickness and specific leaf area, which respond to increasing temperatures, are positively correlated with higher rates of evapotranspiration and shading (Rahman et al. 2020). This overlap between response and effect traits has the potential to lead to loss of multiple functions if such traits are negatively impacted or prevented from being fully expressed by various filters in SETS. Although we are explicit about the nested nature of traits in biological communities, and within SETS, we do not currently have adequate empirical data to modify trait values in trait databases based on how the phenotypic expression of traits may increase or decrease due to biotic or abiotic influence at local or even larger spatial scales.

Despite the framework calling out specifically the need to understand how SETS impact or filter trait expressions, applying the framework to real-world cases using trait databases remains limited to the trait values that

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exist in trait databases, which generally do not consider social, ecological, or technological-infrastructure impacts on trait expressions. Further, SETS may impact some resilience aspects and not others through direct impact on the expression of specific traits but not others. Here too the framework can help to generate testable hypotheses, for example, on how a social impact through local management may improve a resilience response that either enhances the expression of a particular trait or even substitutes for missing traits, such as the impact of watering trees during summer drought months on trees that may not have drought tolerance traits.

Although difficult to handle in the development of a resilience assessment approach, it is important to recognize that any aspect of a local, city, regional, or global SETS can modify a disturbance's impact and also modify the expression of a given trait of a species or functional group of species. For example, the social context that a local ecosystem may exist in including active management or stewardship could positively or negatively impact trait expressions, and thus ecological functioning, while the ecological context including biotic interactions, effects of climate and microclimate, or other environmental drivers could filter trait expression and thus impact functioning and ecosystem services (Grilo et al. 2022).

Ecological functions and ecosystem services can also affect the SETS context itself, potentially influencing the strength of the stressors on other species or dimensions of SETS. For example, if trees provide shading and evapotranspiration and reduce local temperatures then other species, even other trees, may not need to be as resilient to heat as they would if they existed in communities without such a nature-based mitigation of heat exposure. Similarly, the built environment whether through buildings that shade vegetation during certain parts of the day, by generating excess heat, or through affecting hydrology by increasing surface water flow due to impervious surface cover may filter how a trait or bundle of traits is expressed during and after a disturbance. Thus, the context of the SETS may impact the expression of a trait and so a trait value drawn from trait databases must be interpreted with caution given it is unlikely to take into account possible local, regional, or other social, ecological, or technological-infrastructure impacts that affect the phenotypic expression of traits for a species or functional group.

Finally, traits and what they imply for resilience must always be understood as an outcome of the connected, cross-scale nature of both urban ecosystems and disturbances. The spatial analysis we presented for NYC could potentially not only inform a vulnerability assessment of individual communities but help us explore the emergent outcomes of different spatial arrangements and neighborhood associations between communities with different trait profiles. We have focused on the species level, but traits can be a useful tool also at the

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landscape and ecosystem levels (Andersson et al. 2021b) – we have only begun to explore the complementarity effects of trait diversity at larger scales.

CONCLUSION

Here, we bring a focus on why deepening understanding and assessment of the resilience of urban ecological infrastructure is critical to ensure that urban ecosystems themselves are resilient and are managed to ensure they can deliver the NBS we need and that underpin the ecological contribution to generalized urban resilience. We present a UER conceptual framework that situates species diversity, abundance, and species traits in the context of ecological communities that are nested in SETS with disturbances that emerge from any spatial or temporal scale. We provide a framework and set of nested equations to articulate how response and effect traits interact and may be further impacted by their biotic and abiotic environment they exist in to confer more or less resilience to a population of species to a specified disturbance or multiple disturbances.

We then demonstrate a methodological approach to assessing ecological resilience using a case study of 129 species and over 800,000 individual street trees in NYC. By developing a relevant trait value database that corresponds to traits found in the literature to be important to climate resilience including from drought, heat, and storm disturbances, we develop resilience indices for each species to each disturbance that are then mapped across the urban landscape. Resilience indices included abundance weightings to compare across species and for spatial comparisons to understand both locations and identity of species that may be more or less resilient to the specified disturbances we studied, and may indicate need for increased management and stewardship where resilience is low. We argue that this trait-based indicator approach is useful to advance ecological resilience assessment, especially given the lack of available field data on persistence over time in the vast majority of urban ecosystems of interest for providing NBS.

At the same time, we argue that knowledge on traits is one thing, but understanding how they are connected to specific functions and how urban SETS contexts affect the expression of traits requires a systems-oriented conceptual framework and additional field-based empirical studies to test the hypotheses generated from an indicator-driven approach to resilience assessment. We provide the UER framework and suggested analytical approach to support urban ecological resilience evaluation, to tailor management, and support stewardship to ensure ecological resilience as a baseline for making sure NBS that rely on ecological functioning are effective.

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5. Nature-based solutions and biodiversity: synergies, trade-offs, and ways forward

Sonja Knapp and J. Scott MacIvor

INTRODUCTION

The provision of nature-based solutions (NBS) and the conservation of biodiversity are two aims of modern urban research, planning, and policy. Understanding the role of different aspects of biodiversity (genetic, taxonomic, functional, phylogenetic, habitat) and of different groups of species (e.g., rare versus common, native versus non-native, functional groups) can assist with identifying key contributors to NBS as well as identify trade-offs and conflicts among the two aims. In this chapter, we outline the importance of biodiversity for NBS ecosystem service (ES) delivery and NBS for biodiversity conservation, highlighting two major components of urban NBS that gain in importance with changing climate: street trees and green roofs. We describe how biodiversity supports ecosystem stability, resilience, and multifunctionality, and what benefits there are using single versus multiple species. We determine that (1) NBS success results from local knowledge about setting and species, (2) those aspects of biodiversity that are well studied and are best manageable should be selected by practitioners, (3) so far unexplored biodiversity–ES relationships require additional research attention, and (4) communication and co-design involving various stakeholder groups will yield solutions broadly appreciated. NBS have the potential to support both the delivery of ES and the conservation of biodiversity.

BIODIVERSITY IN THE CONTEXT OF NATURE-BASED SOLUTIONS

Cities seek NBS to protect existing natural areas and adapt anthropogenic systems to mitigate the impacts of urbanization and climate change. To integrate into the urban form, cities allocate resources towards NBS design and implementation, and as a result, NBS are growing in type and number (Lepczyk et al. 2017).

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One approach often cited in NBS design is to include biodiversity (e.g., Kabisch et al. 2016; Knapp et al. 2019), which has been demonstrated to enhance and sustain ecosystem functioning in controlled experiments (e.g., Cardinale et al. 2012). Biodiversity covers important criteria for the success of NBS. However, whereas biodiversity encapsulates the variety of life at all scales within a given ecosystem, rarely can NBS support all this variety. Green roofs, for example, cannot support the full range of species able to persist in ground-level habitats (Williams et al. 2014). Presently, biodiversity in NBS design is limited primarily to the planting and maintenance of vegetation communities, but other organisms such as animals (Apfelbeck et al. 2020) or mycorrhizal fungi (Molineux et al. 2017; Fulthorpe et al. 2018) can or could be applied.

The Role of Different Aspects of Biodiversity in Generating Nature-Based Solutions

Taxonomic diversity

Decision-makers often refer to taxonomic diversity – including species richness and abundance – when describing the biodiversity included in a particular NBS. All species will support some ES, but not all may support the desired ES; and so, one might expect that the more species there are, the more likely the desired ES will be realized. For example, aside from floral abundance, higher numbers of flowering plant species included in an urban garden will enhance the type and variety of resources for wild bees, supporting their diversity and pollination services in nearby home and allotment gardens (Burdine and McCluney 2019). The more different plant species there are, the higher the likelihood of functional redundancy – and thus functional insurance buffering the loss of wild bee species. In the example above, this could result in multiple plant species in flower at the same time, and so there are no gaps in floral phenology of a particular NBS, thereby providing habitat constancy for pollinators. In another example, Lundholm et al. (2010) manipulated plant species richness on green roofs and showed that the presence of particular plant species led to the highest stormwater capture (and removal of water from sewers) due to overyielding and irrespective of the species richness.

Other measures of biodiversity have been suggested as suitable parameters for practitioners to use in place of or in addition to taxonomic diversity, including genetic diversity, functional diversity, phylogenetic diversity (Sæbø et al. 2005; MacIvor et al. 2016; Schwarz et al. 2017), as well as habitat diversity (Colding 2007). We discuss examples of each below.

Genetic diversity

Genetic diversity reflects the basic pool of information that contains a species' potential to respond to environmental changes. For example, different prov-

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enances of one species will likely differ in their genetic setup and thus their ability to adapt to climatic changes; this can be applied for the management of urban forests under increasing climatic extremes (Fady et al. 2016). However, when the gene pool is limited or ignored, and for example all stocks of street trees are clonal, potential is restricted. Certain genotypes will not be present and this could impact susceptibility to microclimate or pathogenic impacts (Broeck et al. 2018). Further, the population viability of planted populations with low genetic diversity could be threatened by inbreeding depression (Aavik et al. 2012). Genetic diversity is linked to resilience, and in NBS where single species are promoted due to overarching benefit, practitioners must be mindful of the genetic diversity of the stock and suppliers (Reynolds et al. 2012).

Functional diversity

Functional diversity captures the number, range, and/or abundance of functional traits (i.e., anatomical, biochemical, morphological, phenological, physiological, and structural characteristics of species; Violle et al. 2007; Kattge et al. 2011) present in an assemblage of species. As traits reflect both the environmental conditions species adapted to and effects species have on their environment (Lavorel and Garnier 2002), traits are key to designing NBS (Van Mechelen et al. 2015). For example, Lundholm et al. (2015) showed that plant height and plant leaf traits can be purposefully chosen to enhance the provision of nitrate removal, substrate cooling, and other ES on green roofs. The more functional trait attributes present in a system, the more functions it can fulfil.

Phylogenetic diversity

Phylogenetic diversity reflects the amount of evolutionary information represented by a species assemblage. A community that includes distantly related species would have more evolutionarily distinct attributes and therefore higher phylogenetic diversity. This is in contrast to a community consisting of closely related species. Phylogenetic diversity is often seen as a surrogate for functional diversity (but see Lososová et al. 2016) and as such can be applied in the design of (urban) NBS (MacIvor et al. 2018). For example, in grasslands, phylogenetic diversity positively correlates with biomass production, and thus the amount of fodder or bioenergy (Flynn et al. 2011), while on green roofs, phylogenetic diversity was found to support a range of ES including water capture and temperature cooling (Xie et al. 2018).

Habitat types and diversity

When large contiguous NBS (e.g., ravines, large urban parks, floodplain habitats) are to be designed and restored for biodiversity and ES, varying biotic (e.g., soil microfauna, invasion) and abiotic conditions (e.g., microclimate) will necessitate the consideration of different habitat types (Amoros 2001). To

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ensure success in NBS, seeking native habitat analogues of conditions present at proposed NBS sites (e.g., Lundholm and Richardson 2010) can inform design parameters that ensure the species selected are suited to the environment and will perform target ES delivery as desired. This “habitat template approach” works for example in Halifax, Canada (Lundholm and Walker 2018) and in Chiba, Japan (Nagase and Tashiro-Ishii 2018), where researchers select plant communities for use on extensive green roofs from nearby coastal areas, where soils are shallow, nutrient poor, and plant communities are drought tolerant but can withstand periods of waterlogged conditions, which are comparable to conditions on rooftops in the city (Lundholm 2006). Creating NBS by applying the habitat template approach parallels urban restoration targets that rely on regional habitats and provenances for restoring degraded urban sites (e.g., Fischer et al. 2013). Where nature “restores” itself, such as by establishing on former derelict sites, one can assume that established species are adapted to locally prevailing conditions. These “wild” habitats form NBS too and can either be left alone or designed – an example being Schöneberger Südgelände in Berlin, Germany, which is a forest that self-established on a former switching yard station and that was combined with arts to serve as an urban park (Grün Berlin 2021). The value for NBS of such “novel” habitats that combine native and non-native species (e.g., Hobbs et al. 2006; Heger et al. 2019) needs to be balanced among benefits (e.g., delivering ES) and risks (e.g., promotion of invasive species). Where practitioners are tasked with conservation of target species that require different habitat types to fulfil their life cycle (Colding 2007), habitat type diversity will also support a wider range of species and ES (Alsterberg et al. 2017).

Synergies and Trade-Offs in Biodiversity–Nature-Based Solutions–Relationships

While the number of studies that investigate how genetic, functional, phylogenetic, and/or habitat diversity of NBS influence underlying ES is increasing, mainly links to taxonomic diversity have been assessed for urban environments so far (Ziter 2016; Schwarz et al. 2017; Colléony and Shwartz 2019). These studies show that biodiversity is often positively related to NBS and to ES provision but negative relationships – i.e., promotion of ecosystem disservices or reduction of ES – exist as well. For example, aquatic habitats act as climate regulators but can be a source of disease-transmitting mosquitoes (Mohlmann et al. 2017; but see Crespo et al. 2019). Similarly, few tree species are used for plantings along streets in order to provide aesthetic pleasure and to allow ease of maintenance. Still, a number of tree species are increasingly threatened by a combination of pests and pathogens (e.g., ash trees and emerald ash borer, plant trees and Massaria, a fungal disease caused by *Splanchnonema platani*),

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edaphic stress (e.g., sealing, soil compaction), and climatic stress (e.g., prolonged drought) (Gillner et al. 2017). Street tree planting with multiple species adds "insurance" to uncertain future pest outbreaks that as a result of climate warming could drastically impact canopy cover, age, structure, and survival of tree species, and associated ES (Meineke et al. 2013; see Box 5.1 for more background on street trees). Climate change pushes the search for "novel" (Heger et al. 2019) urban- and climate-adapted species. The choice of plant species for urban environments needs to take all stressors into account as well as disservices created by some plant species such as emissions of allergenic pollen or biogenic volatile organic carbons (Karl et al. 2009). Again, the search for novel species might also trigger the use of non-native species and thus increase the pool of potentially invasive species (Potgieter et al. 2017).

BOX 5.1 STREET TREES

Street trees are a common form of NBS. They are valued by urban dwellers (Pataki et al. 2013), contribute to a number of ES (e.g., temperature regulation, air purification, aesthetic pleasure, reduced probability of being prescribed antidepressants; McPherson et al. 2016; Ziter et al. 2019; Marselle et al. 2020; Rahman et al. 2020), and so can be applied as NBS. As they cause disservices, too, choosing tree species for street plantings needs to take a number of criteria into account (Fernandes et al. 2019).

First and foremost, street trees face a range of challenges related to urban environments and need to be adapted to these to stay viable (Pauleit et al. 2002). Though supplied with growing substrate upon planting, tarmac, pipes, wires, and more infrastructure limit soil volume. Soil beneath streets is biologically dead, without transpiration or humus formation (Wessolek 2008). Soil in tree pits becomes compacted over time, also limiting drainability and gas exchange among soil and atmosphere. In regions experiencing frosts, de-icing salt is commonly applied, and other pollutants emitted by traffic, households, and industry (e.g., nitric oxide, heavy metals) tighten stressful conditions. Moreover, urban climate, characterized by increased temperatures (Kuttler 2008), and the high share of stormwater runoff compared to infiltration (Haase and Nuissl 2007) promote drought. The combination of stressful conditions weakens tree health, and trees become more susceptible to pests and pathogens.

Street trees can help cities to mitigate and adapt to a number of challenges affecting biodiversity and human wellbeing. The size and density of many cities makes urban dwellers search for recreational spaces close to their homes and workplaces, and street trees can contribute to direct engagement with nature even in the city center (Figure 5.1). The urban heat island, exac-

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erbated by climate change, promotes cardiovascular and respiratory disease in humans (McMichael and Lindgren 2011). With elevated temperatures, air pollutants can become even more aggressive, further increasing the severity of health problems (Michelozzi et al. 2009). Temperature regulation and air purification by street trees reduces these risks to human health. For example, urban trees and shrubs remove 711,000 tons of air pollutants per year from cities across the United States (Nowak et al. 2006). In California, street trees remove 567,748 tons of CO_2 per annum, equivalent to the emissions of 120,000 cars. The yearly monetary value of all ES provided by Californian street trees equals $1 billion (McPherson et al. 2016).

Note: Eastern Redbud is native to much of the regions just south of the city of Toronto, Canada and adapted to the warmer conditions imposed by the built environment. The splash of pink in early spring brings much needed visual relief for people post-winter and provides a significant resource for pollinators active early in the year.
Source: Charlotte de Keyzer.

*Figure 5.1 Practitioners must base street tree species selection on a number of criteria, and in the center of downtown Toronto, two Eastern Redbud (*Cercis canadensis*) thrive*

There is, however, no one-size-fits-all solution. For example, while trees with dense foliage provide strong cooling effect by shading (Rahman et al.

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2020), and so are recommendable as park trees in regions with hot summers, planting them along street canyons potentially traps pollutants from air traffic beneath dense crowns – at the street level, where pedestrians walk (Wania et al. 2012). Trees with sparse crowns or hedges should be preferred instead (Wania et al. 2012). Another example are allergens (Cariñanos et al. 2014) and biogenic volatile organic carbons (BVOC) emitted by a range of tree species (Karl et al. 2009). BVOC add to the formation of ozone, methane, and carbon monoxide (Kesselmeier and Staudt 1999). Moreover, street trees that are selected for survival in difficult growing conditions do not necessarily support biodiversity conservation goals. For example, non-native Ginkgo and Norway maple, or cultivars of native trees such as the thornless honey locust, replace other previously common native trees that might support higher levels of biodiversity but partly require additional care or cannot stand urban conditions. In some cities, such as Toronto, Canada, efforts are under way through the Every Tree Counts and CanopyTO programs (City of Toronto 2018) and partnerships with non-governmental organizations including Local Enhancement and Appreciation of Forests (www.yourleaf.org) to invest in neighborhoods and engage the public through training and support to help increase native tree biodiversity (Greene et al. 2011).

Consequently, urban planning needs to take context specificity into account. A diversification of tree species applied in urban settings is needed, as diversity will help ensure a set of tree species that is well adapted to urban conditions, and that provides many ES but low or no disservices. Also, in the long term, again and again new challenges will arise such as novel pests, pathogens, or interactions of pollutants and climatic extremes. High street tree diversity will act as a buffer against the loss of streetscape trees caused by such challenges.

Research into the role of different aspects of biodiversity (genetic, taxonomic, functional, phylogenetic, habitat) and of different groups of species (e.g., rare versus common, native versus non-native, functional groups) can help identify key providers of NBS. For example, short-rotation coppice (i.e., making use of the ability of some tree species to resprout from their roots or stump by cutting the wood and having it regrow) for the phytoremediation of zinc-contaminated urban soils yielded best results with poplar and annual coppicing, and with willow (*Salix* spp.) and robinia (*Acacia* spp.) when coppicing was not applied (Padoan et al. 2020). However, the example given above of street trees being increasingly threatened by pests and pathogens shows (as well as a range of other examples across the globe; Cardinale et al. 2012) that single-species and low-diversity systems are much more susceptible to stressors and disturbances than high-diversity systems. In summary, for single services and over short

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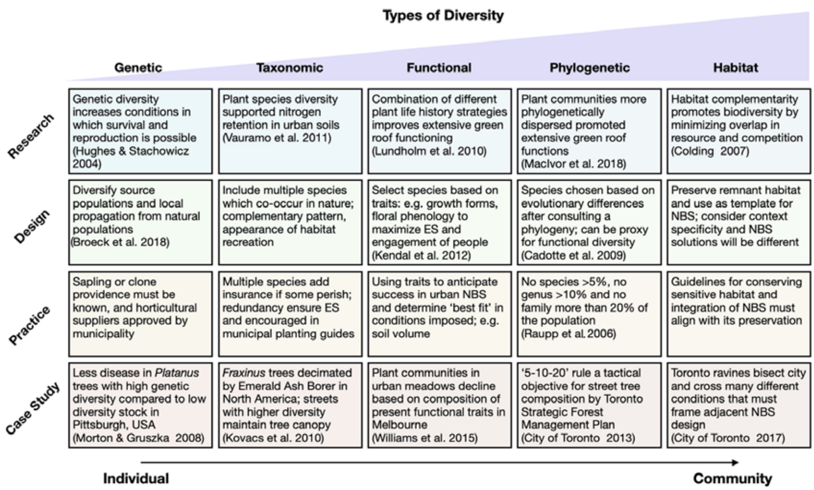
timescales single species can do the job, but for the provision of multiple services, multifunctional NBS, and over long time periods, biodiversity is indispensable for the stability, resilience, and thus also the productivity and efficiency of NBS.

DESIGNING NATURE-BASED SOLUTIONS TO PROMOTE BIODIVERSITY CONSERVATION

The aim of biodiversity conservation is to preserve the range of species that exist on Earth, including also those that might not be key to selected NBS or target ES. Our societies prioritize and deprioritize single ES (Livingstone et al. 2018), but organisms related to deprioritized services are also deserving of conservation in their own right, and might also support ES that become more important later on, or with new knowledge of mechanisms of ES delivery that indicate their value (Goeschl and Swanson 2002; Bartkowski 2017). Therefore, research on the design of NBS and biodiversity conservation should identify where the two targets – protecting biodiversity and creating NBS to support ES – form synergies, where they conflict, and how these conflicts can



Note: Insights from research about biodiversity in NBS are given that can be applied in urban design and practice. Additionally, case studies that tested application success are cited.
Source: J. Scott MacIvor.

Figure 5.2 Information matrix detailing the different aspects of biodiversity from which practitioners may draw in decision-making

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be solved or avoided (Apfelbeck et al. 2020). From this knowledge, ways of applying biodiversity in urban planning, design, and management practice can be identified to get the best of NBS and underlying ES (Figure 5.2).

As outlined above, studies on biodiversity–ES relationships in urban areas have shown that many of these relationships are positive (Ziter 2016; Schwarz et al. 2017; Colléony and Shwartz 2019). And so, NBS can be designed in ways supporting biodiversity conservation, while biodiversity conservation can support ES. Examples of urban nature conservation measures include urban meadows that have been planted to restore grassland habitat (Fischer et al. 2016). These meadows were found to support both native plant species and pollinators such as wild bees and, in turn, promote pollination services by including different species and traits (e.g., flower type, shape, phenology). In another example, plant species diversity supported nitrogen retention in urban soils (Vauramo et al. 2011), and so the need for clean water (free of nitrate) supports arguments for biodiversity conservation.

Synergy in biodiversity and NBS creation for ES delivery may also be captured at different spatial scales. At small scales, NBS using a monotypic option that is most suitable (e.g., street trees along a sidewalk and roadside) are possible when it can be shown that biodiversity is locally supported (e.g., where multiple tree species are planted across a neighborhood). Different tree species, ages, and configurations will collectively promote birds, insects, etc. For example, the addition of a row of honey locust trees – which are well suited to planting on a busy street – alone do not contribute substantially to biodiversity, but in tandem with existing trees in the neighborhood they do, by adding cover, shade, and perching habitat (Figure 5.3).

Protected areas within cities and across urban–rural neighborhoods provide habitat for a range of species (potentially including rare and threatened ones), as well as ES. Municipalities must strike a balance between environmental protection and access to nature by people; this requires careful planning and oversight. A great example is the 86 protected Environmentally Significant Areas (ESAs) in the City of Toronto, the largest city in Canada, that amount to four percent of the city's total land area (City of Toronto 2015). More generally, well-placed NBS adjacent to ESAs could act as stepping-stones (Ignatieva et al. 2011) that support and enhance urban biodiversity by increasing connectivity and movement between critical habitats (Beninde et al. 2015). Giving those areas (e.g., ESAs) the legal status of protection from development and from activities that are not conducive with the preservation of natural features and habitats forms barriers against them being degraded or destroyed. Beyond "classical" targets of nature conservation (such as remnants of native forest or dry lawns), some habitats shaped by humans should be legally protected (e.g., from future development), especially as they are abundant in many cities. Examples are emerging forests on derelict land, which often

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Notes: Just beyond the buildings seen here is Harbord Village, a neighborhood with a diverse canopy of native trees and other plants across a mosaic of residential yards, as well as native landscaping on the University of Toronto campus. Honey locust trees are resistant to many urban impacts and provide floral resources for pollinators and so are preferred by practitioners in both the species' native and non-native areas.
Source: Menilek Beyene.

*Figure 5.3 Monotypic street tree planting using the native honey locust (*Gleditsia triacanthos var. inermis*) along a busy street in downtown Toronto, Canada*

contain high shares of non-native species but increasingly support biodiversity through time (Kowarik and von der Lippe 2018; Kowarik et al. 2020). Beyond supporting biodiversity (as long as negative effects of biological invasions are avoided), as cities become more densely populated, such sites will regulate temperatures, help with air purification, provide opportunity for experiencing nature, and more.

Within cities, novel approaches of integrating animal species' requirements into planning and landscape design are needed, such as that offered by Animal Aided Design, which aims to include a focus on the complete life cycle needs of key wildlife (Apfelbeck et al. 2020). To succeed, these requirements should be thought about from the very beginning of projects (e.g., how the breeding needs of birds, bats, and insects can be integrated

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without raising human–wildlife conflict; how greenery within urban quarters can be designed multifunctionally). For existing buildings, the creation of green facades, green roofs, nesting opportunities in buildings, attached to buildings, and close to buildings, as well as an ecological-oriented management of garden- or park-like structures (e.g., extensive mowing that fosters species-rich meadows instead of species-poor lawn; Ignatieva et al. 2020), is possible (see Box 5.2 for more details on how green roofs can be optimized in terms of biodiversity support). Biodiversity should not be a burden or source of conflict among practitioners and other stakeholders tasked with maintaining or carefully treating it. Rather, its role in the long-term support of multifunctional NBS should be acknowledged throughout society. Environmental education, community science projects, and other ways of communication among scientists, politicians, residents, etc. is needed to promote appreciation of biodiversity.

BOX 5.2 GREEN ROOFS

With space for implementing NBS being a restricted resource, building roofs come into focus as they have a considerable share per ground surface area (e.g., McKinney and Sisco 2018). However, building roofs are examples of extreme habitats within a city, with cities themselves being an extreme environment for many species. In summer, conventional roofs can reach temperatures above 70°C (Schmauck 2019). Extensive green roof substrates are shallow to reduce weight load, and so tend to be very dry if not irrigated (Figure 5.4). This can limit the types of plant species that can be planted. Nevertheless, compared to intensive green roofs (deeper substrates, heavier, wider palette of plant types), extensive green roofs are widely deployed around the world because of their reduced costs and ease of retrofit onto existing buildings. Many roofs are fully sunlit for a large part of the day and subject to higher winds, both of which are exacerbated by surrounding buildings (e.g., sunlight reflected by nearby windows) and in heterogeneous ways across a green roof (Buckland-Nicks et al. 2016).

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Source: Sonja Knapp.

Figure 5.4 Even small roofs provide room for greening – an example of an extensive green roof in Rudolstadt, Germany

Green roofs are an ancient NBS found in traditional building techniques of several continents (Thuring and Grant 2015). For example, in Scandinavia, they were used to make roofs waterproof by stacking bark and turf (so-called grass or sod roofs; Thuring and Grant 2015). Today, different types of extensive and intensive green roofs exist, even including wetland roofs (Zehnsdorf et al. 2019). All can provide a range of ES. Examples include temperature regulation, stormwater retention, air purification, provision of recreational space, and of habitat (Oberndorfer et al. 2007). Green roofs will cool the roof surface and consequently the building itself. Reductions in summer temperature down to ~25°C have been shown in comparison to conventional roofs that can heat up to ~70°C (Schmauck 2019). This creates cooling energy savings during warm seasons (Sailor et al. 2011). A high share of green roofs across a city even has the potential to add to overall urban temperature regulation (e.g., −1.24°C with 50 percent green roofs across all roofs in an Algerian city; Sahnoune and Benhassine 2017). Concerning stormwater retention, in Germany, homeowners need to pay

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fees for rainwater entering the sewer system on their estate. Green roofs can help reduce this fee, by rainwater infiltration. Although costs for building a green roof can exceed costs of building a conventional roof, these hardly differ in the long run, as on top of the ES provided, the plants and substrate of green roofs protect traditional roofing membranes from needing to be replaced as frequently as they would if exposed to the elements on a conventional roof (Clark et al. 2008). Several cities sponsor the creation of green roofs, including the city of Hamburg in Germany (Behörde für Stadtentwicklung und Umwelt 2014), as well as Toronto in Canada, where its implementation is also mandatory on many types of new building projects (City of Toronto 2020).

Green roofs can provide habitat for a number of organisms. Still, being island-like, high above ground, and characterized by environmental extremes, they cannot fully substitute ground-level habitats, and will only support a selected set of species (Williams et al. 2014). While many classical extensive green roofs are dominated by a small set of succulent plant species (especially from the genus *Sedum*), much more heterogeneity can be established on roofs, with species (e.g., from dry lawns or coastal habitats; MacIvor et al. 2011), substrate variability, elements of water, deadwood, and more (Knapp et al. 2019). This way, a more diverse fauna will be promoted than in homogeneous green roofs (Kratschmer et al. 2018), including a wider set of social (e.g., aesthetics; Loder 2014) and economic (e.g., improved thermoregulation and water capture; Lundholm et al. 2010) benefits. The broad use of *Sedum* on extensive green roofs exemplifies important trade-offs: while *Sedum* are durable, outperform herbaceous plant species communities on green roofs through time (Sookhan et al. 2018), flower nicely, and support some pollinators, they also promote biological invasions and biotic homogenization in some regions where they are used (Kinlock et al. 2016).

In summary, as in all NBS, the creation of green roofs needs to weigh trade-offs against synergies, taking context specificity into account, such as different climates, municipal incentives and regulations, regional species pools, and prioritized ES.

WAYS FORWARD IN SUPPORTING BIODIVERSITY AND NATURE-BASED SOLUTIONS IN CITIES

In this chapter, we highlight the value of biodiversity for NBS, and the value of NBS for biodiversity. In summary:

- Biodiversity supports ecosystem stability, resilience, and multifunctionality.

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- For single services and over short timescales, single species can do the job, but for the provision of multiple services, multifunctional NBS, and over long time periods, biodiversity is indispensable for the stability, resilience, and thus also the productivity and efficiency of NBS.
- There is no one-size-fits-all solution. NBS success results from local knowledge about setting and species. Not every species or species mixture is suitable for every city, climate, or biogeographic region.
- Biodiversity has many aspects (Figure 5.1) but, for NBS design, those aspects that are well studied and are best manageable (such as species richness, abundance, and traits) should be selected by practitioners.
- So far, unexplored biodiversity–ES relationships (across all aspects of biodiversity – genetic, taxonomic, functional, phylogenetic, habitat) require research attention.

Scientists, politicians, practitioners, and citizens need to communicate their findings, requirements, restrictions, and perceptions among each other openly, and locally to globally, to support biodiversity and NBS in cities. Co-design of urban NBS including different stakeholder groups (conservationists, physicians, urban planners, residents, etc.) will yield solutions broadly supported among urban dwellers. Although nature in cities is far from resembling pristine nature (as is nature across all landscapes deeply shaped by humans), NBS have the potential to support both the delivery of ES and the conservation of biodiversity.

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PART III

The multiple benefits of nature-based solutions

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6. Just, nature-based solutions as critical urban infrastructure for cooling and cleaning airsheds

Paul Coseo and Zoe Hamstead

INTRODUCTION

> When I saw that rich communities had swimming pools, A/C and trees, and poor communities had no bus shelters, pools, trees or A/C, well you can immediately understand the health disparities and implications – ensuring there are representatives from those communities at the table from the beginning, for example the stories that were collected from residents, the centrality of this really matters. (Anonymous Nature's Cooling System Partnership participant; TNC, 2019: p. 86)

Earth's cities are nurturing a new generation of justice-oriented, nature-based solutions (NBS) to tackle twenty-first-century urban climate challenges of heat and poor air quality in the places we live (Stone, 2012) with the people that live there (Fekih et al., 2021; Guardaro et al., 2020; Langemeyer & Connolly, 2020; Puansurin et al., 2018; Tonekaboni et al., 2019). People need NBS (street trees, parks and open space, engineered stormwater controls, green roofs, waterways and wetlands, coastal habitats, and urban gardens; e.g. Keeler et al., 2019) to regulate neighborhood air, but decision-making for NBS needs to include justice dimensions (Langemeyer & Connolly, 2020) where solutions connect with community needs and preferences for long-term sustainability and resilience of its regulating qualities. Cohen-Shacham et al. (2016: p. 2) define NBS as "[a]ctions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." This chapter summarizes justice-oriented, place-based aspects of NBS related to heat and air pollution because (1) these atmospheric hazards are place-based phenomena (Wilhelmi & Hayden, 2010), (2) impacting vulnerable communities (Buijs et al., 2016; Harlan et al., 2006; Hoffman et al., 2020; Jesdale et al., 2013; Santamouris et al., 2007), where a growing body of evidence suggests that (3) a justice lens with community participation (Fekih et al.,

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2021; Guardaro et al., 2020; Langemeyer & Connolly, 2020; Puansurin et al., 2018; Tonekaboni et al., 2019) is an essential component in better assessing, planning, and implementing NBS for long-term community sustainability and resilience (Ahern, 2011; Meerow et al., 2016).

This chapter emphasizes NBS that *effectively* and *adaptively* address the societal challenges of social vulnerability to heat and air pollution. Although vulnerability can apply to people, places, and infrastructure (Cutter et al., 2008), social vulnerability to heat and poor air quality are urgent place-based societal challenges (Berko et al., 2014; Cutter et al., 2008; Harlan et al., 2006). There are other societal challenges related to heat and air quality, including: (1) decreases in water and environmental quality; (2) decreases in soil quality and tree health by drying and polluting soils; (3) failures in gray infrastructure such as buckling roads and power grid disruptions; and (4) increased energy and water use for air conditioning and additional irrigation to cope with the heat and poor air quality (Gartland, 2008; Rizwan et al., 2008; Stone, 2012). For these challenges, it may be possible to achieve progress in reducing ecological and technological vulnerabilities to these hazards without a participatory approach. It may also be possible to create outcomes that reduce social vulnerabilities without the participation of the community, but many research studies indicate that non-participatory decision-making for environmental hazards may lead to undesirable outcomes (Fischer, 2005). To reduce social vulnerabilities to these atmospheric hazards, researchers suggest it necessarily takes integrating lived experiential, place-based knowledge of those who are vulnerable, in the places they live, and empowering these same communities to build their adaptive capacity to the hazards for meaningful reductions in vulnerabilities (Wilhelmi & Hayden, 2010).

In many countries, these twin atmospheric threats kill more people than other weather hazards (Centers for Disease Control and Prevention, 2021; Wilhelmi & Hayden, 2010), which fall disproportionately on communities of color in places where they spend their lives (Centers for Disease Control and Prevention, 2021; Hoffman et al., 2020). Thus, effectively reducing people's vulnerability to these place-based hazards is an urgent matter of public welfare and social justice. Since heat vulnerability is a result of exposure in hot places combined with people's sensitivity and their adaptive capacity (Wilhelmi & Hayden, 2010), effectively reducing vulnerability necessarily requires participatory approaches to simultaneously examine exposure of places and the social dimensions of vulnerability determined by place-based lived experiences. Thus, justice-oriented, place-based NBS approaches should be assessed, planned, and implemented with communities to integrate social dynamics with community needs, identity, and capacity to co-manage their public and private NBS – from their backyards to their street sidewalks to their parks and open space.

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This chapter will discuss: (1) review of heat and air quality vulnerabilities; (2) NBS for urban resilience to heat and poor air quality; (3) assessment and performance metrics; (4) participatory approaches to cool and clean public airsheds; (5) a relevant case study; and (6) key concerns, needs, and next steps for research and practice. This chapter emphasizes learning about the root causes of uneven distribution of NBS and the associated regulating (i.e. cooling and cleaning) ecosystem services as a pretext for assessing, planning, and implementing NBS for cooling and cleaning.

HEAT AND AIR QUALITY VULNERABILITIES: EXPOSURE, SENSITIVITY, AND ADAPTIVE CAPACITY

Rising heat and air pollution in cities disproportionately impact communities of color and those unable to afford technologically controlled indoor environments (e.g. homes, cars, and other protections from hot and poor air) (Berko et al., 2014; Gronlund et al., 2014; Harlan et al., 2013; Hattis et al., 2012; Hoffman et al., 2020; Hondula et al., 2015; Madrigano et al., 2015; Voelkel et al., 2018). The unevenness of atmospheric environments is central to the nature of these hazards, which are produced by the built environment through economic and political processes that steer heat and air-polluting development to marginalized communities (Hoffman et al., 2020). Heat and air pollution are far less a problem for people with affluence than for people living in poverty and social marginalization (Harlan et al., 2007). Thus, solutions to challenges of heat and air pollution cannot be isolated from their environmental justice dimensions.

Technically, public and private land owners can create NBS, as many have in affluent communities across the world. The critical challenge is to create NBS in a way that serves those who are most vulnerable to heat and air pollution health impacts. To date, many authors have provided extensive writings on using NBS to address atmospheric hazards. This chapter synthesizes NBS literature around an emerging research and practice frame for heat and air quality of problematizing these NBS in the context of who requires NBS – neighborhoods with systemic environmental justice challenges. Many historically disenfranchised communities lack collective societal investment and action to equitably address the atmospheric crisis in cities including a lack of publicly supported, place-specific NBS (e.g. trees, vegetation, and other forms of urban ecological infrastructure) (Bolin et al., 2005; Harlan et al., 2006; Hoffman et al., 2020). Consequently, powerful social forces control the urban climate-regulating services by designing out NBS. An approach to NBS that does not account for the systemic social forces at play behind NBS will ultimately struggle to improve vulnerable communities' livability. The urgency

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of neighborhood-level atmospheric pollution crises is in the inter-relations across political marginalization, cycles of poverty, and environmental lived experiences (Hamstead et al., 2020).

Heat and dangerous air are not only killers. These atmospheric phenomena can lead to degraded quality of life, livelihoods, and poor physiological and mental health (Reid et al., 2009; Trang et al., 2016; Wang et al., 2014). From planning, design, and engineering perspectives, it is important to conceptualize atmospheric hazards as place-based experiences, rather than abstract meteorological hazards (Hamstead et al, 2020; Wilhelmi & Hayden, 2010). Stone, Jr. (2019: pp. 3–4) argues against framing heat risk as episodic or occurring as heat waves. He writes:

> unlike hurricanes, heat exposure can be deadly both during and outside of episodic heat wave events. In fact, heat often poses a significant health risk in the warm season, when even moderate temperatures can stress urban populations seasonally acclimated to cooler conditions (Gasparrini et al., 2016). As such, the threat of heat should not be understood as an episodic risk only, and one that can be managed within relatively brief windows of time.

In the past, heat waves and air pollution were often understood as invisible short-term phenomena, but this framing may be insufficient to reduce vulnerability to these hazards. This emerging frame of understanding heat (and poor air quality) as a non-episodic hazard that degrades quality-of-life experiences while increasing societal costs may increase the arguments for a NBS as critical urban infrastructure to reduce these atmospheric hazards.

Exposure

Oke (1987) described our urban atmosphere as composed of urban canopy layer and urban boundary layer. Yet, people move through space and are exposed to multiple airsheds in a given day such as outside on a sidewalk, indoors at home, work, in a car, or on transit. Building on Oke's conception, researchers are starting to describe people as mobile agents that move through diverse *airsheds* (e.g. outside and inside at home, in vehicles, and at work) throughout a day (Dzyuban et al., 2021). Like watersheds, airsheds are governed by fluid dynamics forming multi-layered mixtures of (1) gases and (2) particles with (3) radiative and (4) thermal properties. Ground-level airsheds are partially influenced by the upper atmosphere and partially with the land surface. Those dynamics structure how our airsheds near the ground (3 meters above ground level) interact with the land's surface. Urban neighborhood land cover composition and configuration along with human activities control the quality of temperature (i.e. surface and air), radiation (e.g. shortwave, longwave), particulates, and gases that make up airsheds. On a daily basis, people

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experience airsheds through complex traverses through public, semi-public/private, and private indoor and outdoor atmospheric environments. Thus, research and practice is progressing on emerging planning, design, and engineering approaches for airshed management (Figure 6.1) that includes: (1) a holistic conceptualization of people/atmosphere interactions; (2) recognition of the often "invisible" atmospheric justice challenges; (3) application of NBS in ways that address who most needs cool and clean airsheds; and (4) the unique governance challenges in planning with historically disenfranchised communities.

The urban atmosphere interacts with urban land cover composition and configuration of vegetation, water, concrete, asphalt, and other natural or built materials (green, blue, gray infrastructure) and human activities. Impervious gray infrastructures are excellent at absorbing incoming shortwave radiation and emitting it as longwave and sensible heat energy that serves to warm a local airshed (e.g. surface and air temperatures) (Coseo & Larsen, 2014; Stone, 2012). Urban heat reductions are most associated with reduction in air temperatures more commonly referred to as urban heat islands (UHI). Atmospheric UHIs can increase air temperatures by +4–12˚C between urban and undeveloped sites (e.g. +5˚C in Rome, Italy, Bonacquisti et al., 2006; +4˚C in Chicago, United States (U.S.), Coseo & Larsen, 2014; +6.5ºC in Shanghai, China, Djen et al., 1994; +12˚C in Łódź, Poland, Klysik & Fortuniak, 1999; and as much as +7ºC in London, United Kingdom, Wilby, 2003). The decision to widen roads, expand parking lots, and exclude or reduce NBS produces surface, air, soil, and water heat islands or urban areas that are locally warmer than surrounding undeveloped areas. Hence, social processes such as formal and informal decision-making are the root cause of toxic (Auyero & Swistun, 2008) and degraded environments such as airsheds. Like other environmental hazards, these public and private decisions to reduce the ratio of NBS while increasing gray urban infrastructure make some neighborhood airsheds hotter than others. Hotter airsheds also can accelerate the production of poor air quality (Stone, 2005). Cooling is often in short supply in these types of warm landscapes, due to the lack of NBS. In many neighborhoods, expansion of gray infrastructure is coupled with an increase in industrial activity and vehicle traffic, which further decreases air quality. The increase in gray infrastructure also exacerbates air quality issues by decreasing the land available for vegetation, which typically requires more space for its capacity to provide regulating services of cooling and air purification (Keeler et al., 2019). These trends make public investment in NBS more important to support cooler and cleaner public airsheds.

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Note: Peoples' experience with atmospheric conditions includes objective measures of surface temperatures, air temperatures, radiation, gaseous pollutants, and particulate matter. People's experience is mediated by our ability to adapt our atmosphere directly around our human bodies or airshed. Concepts such as thermal comfort integrate objective and subjective measures for a more holistic description of thermal experience. Through a combination of public and private shelters, technology (e.g. heating, ventilation, air conditioning, cars, buses, trains), and greening we can moderate our airsheds through artificial or natural processes. Differences in affluence allow some people to use semi-private or private airsheds to protect them and their families from public airshed heat and air pollution hazards, while others are more reliant on public indoor (e.g. public housing, public transit, public cooling centers) or outdoor airsheds (e.g. parks, streetscapes, schools, and other public spaces). As we move from the touch-human-site scale we become part of a neighborhood community airshed with diverse experiences in public, semi-public, and private airsheds. At the city level, research shows that some neighborhoods' community airsheds are more degraded (hot with poor air quality) than other neighborhood airsheds (Harlan et al., 2006), which require city-level policy and management to reduce inequitable distribution of atmospheric hazards.
Source: Illustrations by Paul Coseo using Google Earth images (March 20, 2021) and photography by Paul Coseo and Mary Wright.

Figure 6.1 *The three scales of airsheds for planning, design, and engineering*

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Sensitivity

Researchers have found many factors that make some people more sensitive to negative heat and air pollution-related health and quality-of-life outcomes, including: (1) poverty/income; (2) education level; (3) race and ethnicity; (4) living alone; (5) age; and (6) other determinants of health (Reid et al., 2009). Vaidyanathan et al. (2020) reports that between 2004–2018 heat-related deaths are highest among non-Hispanic American Indians and Blacks. Across the U.S., low-income communities of color are more likely to live in areas with more impervious land surface and less tree canopy than wealthier, whiter communities (Harlan et al., 2006; Jenerette et al., 2007; Jesdale et al., 2013; Santamouris et al., 2007; Schwarz et al., 2015; Solecki et al., 2005), and racial and ethnic segregation patterns have been linked to patterns of hot microclimates (Mitchell & Chakraborty, 2015).

In the U.S., non-Hispanic Blacks are overrepresented in communities with relatively high levels of particulate matter ($PM_{2.5}$) and ozone (O_3), and – like early U.S. environmental justice research findings on toxic waste exposure in the U.S. (United Church of Christ Commission for Racial Justice, 1987: p. xx) – "environmental justice concerns [regarding air pollution] are more prominent along race/ethnicity lines, rather than measures of poverty" (Miranda et al., 2011). More recently, Tessum and colleagues (2019) illustrated a "pollution inequity" metric for $PM_{2.5}$ which examines geographies of responsibility (Walker, 2009) – spatial difference in who is bearing the burden of and who is responsible for air pollution. The authors find that non-Hispanic whites experience ~17 percent less air pollution exposure than they generate, while Blacks and Hispanics experience 56 and 63 percent more pollution exposure than they generate, respectively. As of 2016–2018, childhood asthma rates were 6.8 percent among non-Hispanic white children, compared with 7.5 among Hispanics, 13.6 among Puerto Ricans, and 14.2 percent among non-Hispanic Black children, respectively (Centers for Disease Control and Prevention, 2021). Thus, heat and air pollution couple to become twin hazards for some communities more than others.

Adaptative Capacity

Part of people's uneven experience with hot and stifling atmospheric conditions is due to differences in adaptive capacity, particularly around the ease and ability to air condition or control one's airshed (O'Neill et al., 2005; Santamouris et al., 2007; Solecki et al., 2005). Although regional airsheds do not have physical boundaries, the difference in access to coping mechanisms (e.g. air-conditioned environments) essentially creates segregated airsheds and divergent exposure. These segregated airsheds vary by neighborhood,

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housing quality, transportation mode, and work environment (e.g. indoor or outdoor work) (O'Neill et al., 2005). O'Neill and colleagues (2005) found that African Americans in four northern cities (Chicago, Detroit, Minneapolis, and Pittsburgh) had a 5.3 percent higher heat mortality rate than whites. The use of air conditioning explained 64 percent of the difference in heat-related deaths (O'Neill et al., 2005). When hot and poor air quality is present in affluent neighborhoods, residents adapt with the help of technology to cool and clean their privatized air in their homes, cars, and offices (Harlan et al., 2007). Residents in less affluent neighborhoods with hot and stagnant air conditions are left to endure our publicly created heat and air pollution or enter into fuel or energy poverty (the added burden of high energy bills in relation to income) to afford the same luxuries of privatized cool and clean air (Guardaro et al., 2020; Santamouris et al., 2007). This reliance on technology for cool and clean air through air conditioning also contributes to poor air quality and additional warming due to waste heat and longer-term global climate change (Stone, 2012).

NBS FOR URBAN RESILIENCE TO HEAT AND POOR AIR QUALITY

NBS are key contributors to reducing vulnerabilities through building urban resilience as they may be more efficient and cost effective than gray infrastructure solutions (Bush & Doyon, 2019; Keeler et al., 2019; Lafortezza et al., 2018). NBS are part of an interconnected web of urban infrastructure that supports urban resilience, which includes gray abiotic infrastructure for energy, water, transportation, and information systems (e.g. powerlines, pipes, roads, and broadband networks). Meerow et al. (2016: p. 39) define urban resilience as "the ability of an urban system – and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity." Although both NBS (socio-ecological) and gray infrastructure (socio-technical) can contribute to community resilience to heat and poor air quality, this chapter focuses on NBS as critical urban ecological infrastructure for urban resilience to these atmospheric hazards.

Researchers, city officials, and the design community (i.e. planners, architects, urban designers, landscape architects, and engineers) are increasingly shifting toward increasing the percentage of NBS in cities as key components of a critical urban infrastructure system for health, safety, livability, and restoration of ecological and hydrological processes (Keeler et al., 2019) for urban resilience. In many cases, this is to retrofit urban areas constructed with a preponderance of gray infrastructure. Ahern (2011) argues that shifting

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toward NBS provides more resilient urban infrastructure that is "safe to fail" during extreme events; it contains and minimizes social impacts, but does not make them "fail safe," as is the aim with most gray infrastructure systems. As extreme events disrupt our urban ecological systems, NBS and gray infrastructural solutions may require adaptive planning and design "learn-by-doing" approaches. Ahern (2011: p. 343) calls for more research on "how to achieve greater social learning and meaningful social engagement and participation in decision-making and policy setting." Yet, people's ability to comprehend and fully participate in discourse about atmospheric hazard challenges are particularly difficult because of the scientific knowledge needed to understand the complex thermodynamics of these twin invisible atmospheric hazards. Only when air pollution is visible, such as high O_3 days or wildfire smoke, is there a more visible, shared experience of the hazard.

Rather than engaging in nuanced community participatory activities to develop a shared understanding of the complex and place-based nature of heat and air pollution threats – how they, for example, relate to housing and energy security in marginalized communities – it may be tempting for city officials to rely on a few universal solutions. Keeler and colleagues (2019: p. 35) suggest that a "systems approach that adopts a long-term perspective on the value of nature-based solutions, inclusive of co-benefits and disservices, is the only way to reliably compare green versus gray approaches to addressing urban sustainability challenges." Middel and colleagues (2020) caution decision-makers with viewing singular cooling solutions (e.g. cool pavements) as a panacea. Overly simplified universal solutions may take money, time, and other resources away from more productive, contextual, and nuanced community-oriented strategies that encourage ownership, stewardship, and longer-term sustainability of NBS. Thus, integrated participatory approaches that combine participatory action research with planning and action are a growing aspect of reducing heat and air quality vulnerabilities (Guardaro et al., 2020).

For Kemmis and colleagues (2014), a critical participatory action research involves examination of the root causes of challenges by those communities impacted for transformational change toward urban resilience.

> What is to be transformed in critical participatory action research is not only activities and their immediate outcomes (as in technical action research) or the persons and (self-)understandings of the practitioners and others involved in and affected by a practice (as in the case of practical action research) but the social formation in which the practice occurs – the discourses … that orient and inform it, the things that are done (doings), and the patterns of social relationships between those involved and affected (relatings). (Kemmis et al., 2014: pp. 16–17).

These participatory approaches should work with communities to identify (i.e. recognize) how heat and air pollution inhibit functionings in people's everyday

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lives (Langemeyer & Connolly, 2020; Schlosberg, 2012), co-create heat/air quality data relevant to those functionings, plan for interventions, and implement comprehensive place-based NBS and gray infrastructural strategies.

NBS are critical urban ecological systems for cities that offer broad ecosystem functions that are foundational for the health and wellbeing of regions, of which a subset of those functions include goods and services produced by nature for free that benefit human society – also known as ecosystem services (Millennium Ecosystem Assessment, 2005). Keeler and colleagues (2019: p. 34) suggest that "[n]ature-based solutions hold promise over built or technological alternatives, especially when co-benefits can be easily recognized and quantified." Approaching critical infrastructures from an engineering perspective, Cantelmi and colleagues (2021: p. 341) define critical infrastructures as:

> large-scale, man-made systems that function interdependently to produce and distribute essential goods (such as energy, water, and data) and services (such as transportation, banking, and healthcare). An infrastructure is defined as critical if its incapacity or destruction has a significant impact on health, safety, security, economics, and social well-being of a state.

For cooling and cleaning neighborhood atmospheres, NBS regulating services provide critical ecosystem functions of cooling and filtering the air. Advancements in ecosystem service frameworks (e.g. Langemeyer & Connolly, 2020) weave justice into what was foundationally more oriented toward ecology and economic values. Langemeyer and Connolly's (2020) empirical urban ecosystem services justice model, which integrates dimensions of recognition, procedural, distributive, spatial, and temporal justice, can serve as a foundational framework for just NBS to reduce heat and air pollution.

ASSESSMENTS AND PERFORMANCE METRICS: THE POTENTIAL OF NBS FOR COOLING AND CLEANING AIRSHEDS

NBS provide essential regulating ecosystem services to mitigate people's exposure to atmospheric hazards for building urban resilience – but "resilience for whom, what, where, when, and why" (Meerow & Newell, 2019)? How should communities assess their airshed hazards and existing NBS to meaningfully inform plans for NBS to cool and clean airsheds? How should long-term monitoring be conducted to better understand ecosystem service performance of NBS strategies for effectively and adaptively cooling and cleaning airsheds? Several researchers have found that many cities' heat mitigation plans do not adequately assess the complex way people and com-

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munities experience heat (Dare, 2019; Keith et al., 2019) or contextualize solutions (Guardaro et al., 2020). The majority of assessments and plans rely on narrow optimization-based strategies and simple objective measures of surface and/or air temperature and cities struggle to integrate the complexity of place-based knowledge (Corburn, 2009) and people's daily lived experiences into assessments and solutions (Guardaro et al., 2020). This includes assessing people's experiences as they traverse between public and/or private indoor airsheds (e.g. home, work, services), transportation airsheds (e.g. car, public transit), and outdoor airsheds (e.g. sidewalks, street corner waiting). Access to that experiential expertise might contribute to a greater understanding of the environmental justice dimensions of the hazards. For instance, framing urban cooling around only addressing UHI (i.e. air reductions) leaves many people-centered and justice categories of heat reduction unexamined as a growing body of evidence points to other factors such as radiation as a key driver of human thermal comfort (Lindberg et al., 2014; Middel et al., 2021). For research and practice, a key arena of this work of cooling and cleaning airsheds has focused on public outdoor airsheds.

For airsheds, urban climatologists have a diverse pallet of assessment methods for expressing NBS ecosystem services that includes both *objective* and *subjective* measures of the hazards. An understanding of people's perceptions, experience, needs, and preferences is needed due to the nature of the hazards as more of a subjective experience than a wholly physical one. Hamstead and Coseo (2019) describe this as akin to a "sense of place" (Tuan, 1977), using the term "sense of heat." "We lack a shared understanding of people's sense of heat – people's complex feelings about space and thermal place through different modes of experience (e.g. thermoreceptors, sensorimotor, tactile, conceptual, or linguistic)" (Hamstead & Coseo, 2019: p. 5). Subjective experiences can be difficult for meaning-making when they are not shared, but objective measures depoliticize the problem, which is inherently one of power – who gets to live in safe airsheds and have access to the resources needed to be safe (e.g. air conditioning). Integrating the two types of measures can help develop multiple types of meaning/pluralist understandings. Temperature is a discursive concept that was invented in the 1700s to objectively assess future risk. We are constantly conflating temperate with heat – but heat is something we experience. These measures bear a relation to heat, but they are not heat. Objective measures are metrics to approximate heat – to reduce social vulnerabilities, performance measures that governments need to use should be coupled with human heat experiences (Hamstead et al., 2020).

Airshed threats are particularly challenging to understand and apprehend since we do not see them with our eyes. Wilhelmi and Hayden (2010: p. 2) developed a useful place-based hazard assessment and planning framework to reduce urban vulnerability to heat, which is applicable to poor air quality as

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well: "This top-down, bottom-up approach strives to assess critical community participation in the development of adaptation strategies and subsequent ownership of these strategies (bottom-up) while concurrently engaging government officials (top-down) in the process to ensure program sustainability." This bottom-up, participatory action research approach using ecosystem service performance metrics could combine objective and subjective experiential measures to advance our effective and adaptive planning and management of airsheds for meaningfully reducing vulnerabilities. This section is organized around guidance for using objective and subjective measures for assessing the atmospheric hazards.

Objective measures of heat and air quality, developed since the 1960s, provide us with a foundation of understanding urban climates and NBS role in regulating airsheds. Common objective measures to assess heating and cooling include: (1) surface temperature; (2) air temperature; and (3) mean radiant temperature (MRT). Similarly, for air pollution, two objective measures to assess air include: (1) particulate matter (PM); and (2) gaseous pollution (GP). Through this integration of the objective and subjective measures, we can build a more complete assessment of heat and poor air quality social impacts as place-based hazards. Brazel (2013) explains that climates (i.e. airsheds) occur at multiple scales, from microclimate (< 0.27 km), local climate (0.8–9.7 km), regional macro (483–1,046 km), and global wind belts (> 1,200 km). For most urban regions, relevant scales for a people-centered and planning-oriented approach might extend from the human touch to parcel scale of a site to neighborhood, city, and regional scales. These are common planning, design, and engineering scales that align with ownership and land use regulations that govern the built environment and hence delimit interventions.

Objectively, urban climate scientists tell us that much of the heating of airsheds starts with physical characteristics of land cover and urban configuration, with human activities lending more heat and air pollution to local atmospheres (Solecki et al., 2005; Stewart, 2011; Stone, 2005). Shortwave radiation from the sun hits surface materials, where Taha (1997) estimated that between 80–85 percent of the shortwave radiation is absorbed by urban materials and the rest is reflected (Stone, 2012). Absorbed shortwave radiation is then transformed either into longwave or sensible heat which raises air temperatures or transforms into cooling through latent heat and photosynthesis by plants. Latent heat is produced through evaporation from water bodies and plants. Plants also shade ground surfaces. Tall plants can intercept shortwave radiation, so that it doesn't absorb into impervious surfaces such as pavements, roofs, and other gray infrastructure. Thus, NBS can provide ecosystem services by directly regulating the atmosphere and a person's experience of the thermal environment.

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Surface Temperatures

Surface temperatures are often used as an indirect proxy for other thermal measures to identify urban hot spots and assess NBS performance at site, neighborhood, city, and regional scales (Imhoff et al., 2010; Jenerette et al., 2007). Yet, surface temperatures are most dangerous to people at the touch scale. At the touch scale, high surface temperatures on cars, benches, play equipment, handrails, and other touch surfaces can cause burns. Although touch surfaces may only seem relevant for regionally hot locations, organizations such as the Canadian National Program for Playground Safety released a 2020 guide for “Thermally comfortable playgrounds” (Canadian National Program for Playground Safety, 2021) that includes thermal burns related to hold/touch surfaces. NBS regulate a person’s touch experience of surface temperatures related to materials through their physical properties, evapotranspiration processes, and shade. Vanos and colleagues (2016) found that playground rubber soft ground surfaces of black and green color in the Phoenix metro on a hot September day reached noon-time surface temperatures of 87.2°C in the sun, but only 42.2°C in tree shade and 46.7°C under an artificial shade sail. Plastic materials only take 3 seconds to burn a child’s skin at temperatures above 77°C. Yet, a natural material such as wood had much higher burn thresholds of 99°C at 3 seconds. NBS material properties do not get as hot as artificial manufactured materials. Shaded materials were found to be on average 16°C cooler than sun-exposed materials (Vanos et al., 2016). So, tall vegetation can play a key role in making any material thermally safer, touchable, and usable. In addition, trees, shrubs, and other tall vegetation convert less shortwave energy into sensible heat, making them cooler materials to touch. Movements to renaturalize school yards with NBS can reduce hot surfaces and provide an expanded conceptualization of safety to include heat safety. At larger scales, surface temperatures have an indirect impact on community and ecosystem health.

At the site scale, surfaces such as dark roofs can become extremely hot and transfer this heat into poorly insulated indoor environments. Similarly, pavements can transfer heat into the soil, drying out the soil and raising soil temperatures for vegetation (Shi et al., 2012) such as street trees planted in tree pits, compromising tree health and creating feedback loops with hotter, drier, and less shaded environments. At the neighborhood, city, and regional scales, surface temperatures are more problematic for unwanted warming of the lower atmosphere (warmer air temperatures). Land surface temperatures can serve as a proxy for identifying warmer neighborhood air temperatures because they indirectly control air temperature mediated by surface roughness of the urban land cover along with wind speed and wind direction (Weng & Quattrochi,

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2006), but that also limits surface temperature's usefulness as a performance measure as it only indirectly represents air temperature.

Air Temperatures

When surface temperatures are warmer than air temperatures, they indirectly warm neighborhood airsheds (3 meters) where people walk and bike and indoor environments where people shelter. For air temperature, touch is not relevant, but at larger scales, air temperatures have a direct impact on community and ecosystem health. Similar to surfaces, NBS regulate a person's experience of air temperatures through their evapotranspiration processes and shade. At the site scale, air temperatures are not dramatically different between adjacent sites, particularly on windy days. When winds are calm, site, scale, and physical characteristics play a larger role in local warming (Kljun et al., 2004). So, the scale of NBS interventions is critical for the amount of cooling that can be expected. Converting a backyard from pavement to vegetation may only minimally cool air temperatures due to the scale of intervention and the complexities of urban sites (Coseo & Larsen, 2015). Yet, once NBS interventions are to the scale of a neighborhood (1 km^2), greater reductions of air temperature can be possible. Coseo and Larsen (2014) examined eight Chicago neighborhoods and found there was an associated rise in air temperatures of 1°C degree for every 10 percent increase in impervious pavements, roofs, and other gray infrastructure covers during clear and calm summer nights. They also found that NBS provided relief even if impervious surfaces could not be removed or reduced and that for every 10 percent added tree canopy, the temperature decreased by 0.2°C. Rosenzweig and colleagues (2006) estimated the amount of plantable space for street trees in New York City neighborhoods was at least 17 percent of the area and that if tree planting was implemented, it could reduce air temperatures by up to 1.8°F on average at 3 p.m.

At the neighborhood, city, and regional scales, air temperatures are controlled by adjacent upwind conditions and thus, in certain wind conditions, neighborhood interventions may not be sufficient to provide local cooler air temperatures (Coseo & Larsen, 2014; Kljun et al., 2004). Grimmond and Oke (2002) suggest source areas that influence local air temperatures may be from 0.15 km^2 and 5 km^2 depending on atmospheric stability, wind speed, and surface roughness. Chang and colleagues (2007) found that parks larger than 2 hectares were most effective in cooling, which would be an important regulating resource for downwind neighborhoods. Other research (Shashua-Bar & Hoffman, 2000) from Tel-Aviv, Israel, has shown that the regulating services of parks (i.e. 20–60 m wide) on air temperature can be measured from 40 to 240 m outside the park. Yet, UHI in many cases may be an incomplete measure for reducing people's outdoor thermal experience. For people outside, air tem-

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perature is mostly relevant in the shade. When sunlight is added to people's thermal experience, we experience that sunlight as heat, which makes reducing the radiative loads on people critical to NBS cooling.

Mean Radiant Temperature

Increasingly, scientists and environmental planners are recognizing the importance of radiation on people's thermal experience and health outcomes (Middel & Krayenhoff, 2019; Thorsson et al., 2014). MRT is a measure containing air temperature, wind, humidity, and most critically radiative factors of short and longwave radiation (Middel & Krayenhoff, 2019). Exposure to high levels of shortwave radiation is why we feel warmer in the sun than in the shade. Thus, NBS used to mitigate MRT (reduced MRT) will have meaningful human-scale improvements to a person's thermal experience. MRT is growing in importance as a metric for reducing urban heat as it is a better objective proxy measure for a person's thermal comfort than surface or air temperature (Middel et al., 2020). In fact, MRT has shown promise as a performance measure even in more cloudy, high-latitude places such as Sweden (Lindberg et al., 2014). Advances in research show the critical role of radiation in people's lived experience of heat. At the site scale, pavements, glass, and impervious light-colored material environments increase the radiative reflectivity in an area, causing higher MRT, and increased thermal distress for people during the day; this includes light-colored cool pavements (Erell et al., 2014; Middel et al., 2020). Erell and colleagues (2014) used models to examine heat stress in Israeli, Australian, Singaporean, and Swedish urban canyons with highly reflective surfaces and found high levels of heat stress in the canyons with the most reflective surfaces. Hence, combining cool materials with shade is important to limiting pedestrian heat stress. Vegetation and trees could provide that cooling and shading of other cool non-vegetated materials because they have lower surface temperatures than walls or built structures and create shade through intercepting radiation (Lindberg et al., 2014). Depending on the species, the structure of leaves and vegetation can reflect 20–30 percent of incoming shortwave radiation, absorbing approximately 50 percent and transmitting 20–30 percent of light through the vegetation (Geiger et al., 2009), thus reducing the radiative load on people (Table 6.1). NBS can reduce MRT by shading people and by reducing the reflectivity of shortwave radiation in an environment, but how might it compare to other types of shade?

Recent studies have shown a large difference in MRT between sun and shade of between 32°C and 50°C in diverse bioclimatic regions (Ali-Toudert & Mayer, 2007; Mayer et al., 2008; Middel et al., 2021). Middel and colleagues (2021) found that, in the Phoenix metropolitan area on hot days, MRT can be reduced by up to 50°C through high-quality shade. Figure 6.2 illustrates

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Table 6.1 Estimates for reflection, absorption, and transmission of shortwave radiation by common street trees in the Chicago region

Common name	Genus species	% reflectance	% absorption	% transmission
Green Ash	*Fraxinus Pennsylvanica*	31	51	18
Cottonwood	*Populus Deltoides*	24	50	26
Silver Maple	*Acer Saccharinum*	23	48	29
Tulip Tree	*Liriodendron Tulipifera*	24	52	24
White Oak	*Quercus Alba*	22	44	34

Note: Reflectance + Absorption + Transmission = 100 percent of incoming solar radiation.
Source: Adapted from Geiger et al. (2009: p. 227) and Coseo and Larsen (2019).

the value of NBS compared to other shade types in reducing MRT. Although they found that building shade provided the best reductions in MRT, shade from vegetation was the second best above engineered shade structures such as shade sails. Although MRT is becoming a critical performance metric to reduce the experience of heat at the site scale, at larger scales the measure is not as useful for understanding cooling performance for people. For measuring the performance of NBS to reduce heat, these objective measures can help understand the efficacy of NBS, but should be combined with subjective measures to more fully understand impacts on people's thermal experience and comfort.

Air Pollution

NBS are increasingly being promoted to reduce air pollution through phytoremediation (i.e. use of plants to reduce pollution) (Ferrini et al., 2020; Keeler et al., 2019; Prigioniero et al., 2021). Keeler and colleagues (2019) report that although research supports the effectiveness of street trees and parks and open space to address urban air quality, our knowledge about how NBS performs compared to gray infrastructural solutions for regulating airsheds is still underdeveloped. Prigioniero and colleagues (2021) reviewed 143 peer-reviewed articles on NBS for air phytoremediation, examining both indoor and outdoor environments. Table 6.2 reports Prigioniero and colleagues' (2021) finding on the breadth of research on ecosystem services and disservices provided by NBS for reducing PM and GP. They found that 44.1 percent of 143 studies analyzed PM_{10}, 41.3 percent analyzing $PM_{2.5}$, and 16.08 percent analyzing $PM_{0.2}$ with gaseous pollutants nitric oxide (NO_2) (25.9 percent), O_3 (22.4 percent), carbon monoxide (CO) (16.78 percent), volatile organic compounds (VOCs) (15.38 percent), and sulfur dioxide (SO_2) (15.38 percent). Other pollutants

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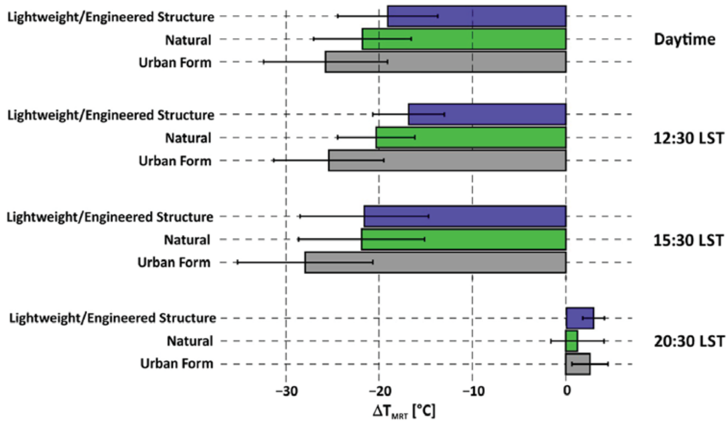

Note: The highest-quality shade for reducing MRT is urban form followed by NBS (trees) and engineered shade structure.
Source: Middel et al. (2021).

Figure 6.2 Observed mean radiant temperature reduction by shade group for three daylight times and one (20:30 Local Sidereal Time (LST)) after sunset

represented less than 10 percent of articles. Prigioniero and colleagues (2021: p. 9) emphasize:

> Due to major gaps in knowledge of NBS, the search for the most suitable plants for phytoremediation is still ongoing. Especially for the outdoor environments, assessment of species potentials for air phytoremediation is difficult as this requires consideration of the trade-off between ecosystem services and disservices. Moreover, understanding the interaction dynamics between plant organisms and the entire pool of pollutants present in each environment therefore represents a very important step in obtaining a reliable assessment of the performance of NBS.

Even with this underdeveloped knowledge base for NBS and air quality, we are starting to understand how NBS perform for reducing PM and GP. For air quality related to both PM and GP, species structure and function factors affect NBS performance (Ferrini et al., 2020; Keeler et al., 2019). In addition, city- and neighborhood-scale factors related to location of vegetation, size, and configuration contribute to the regulating performance (Keeler et al., 2019). Prigioniero and colleagues (2021) found that the most studied outdoor tree species on reducing PM, potentially toxic elements, and polycyclic aromatic hydrocarbons were *Robinia pseudoacacia* L. and *Tilia cordata*, suggesting that

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Table 6.2 NBS potential to reduce air pollutants from 143 articles between 2000 and 2020

Acronym	Pollutant name	Acronym	Pollutant name
BC	Black carbon	NO	Nitrogen monoxide
Benz	Benzene	NO_2	Nitrogen dioxide
BT	Bromotoluene	O_3	Ozone
BVOCs	Biogenic volatile organic compounds	PAHs	Polyciclic aromatic hydrocarbons
CH_4	Methane	pC	*p*-Cresol
CO	Carbon monoxide	Ph	Phenol
CO_2	Carbon dioxide	$PM_{0.2}$	Particular matter with mean particle diameter < 0.2 mm
DehP	Di (2-ethylhexyl) phthalate	$PM_{2.5}$	Particular matter with mean particle diameter < 2.5 mm
EA	Ethyl acetate	PM_{10}	Particular matter with mean particle diameter < 10 mm
EB	Ethylbenzene	PTEs	Potentially toxic elements
FA	Formaldehyde	Rn	Radon
H_2S	Hydrogen sulfide	SO_2	Sulfur dioxide
HNO_3	Nitric acid	Tol	Toluene
IsoP	Isoprene	VOCs	Volatile organic compounds
MonoT	Monoterpene	Xy	Xylene
NH_3	Ammonia		

Source: As reported in Prigioniero and colleagues (2021: p. 3).

future research needs to expand and target species examined, establish a methodology, and pursue real-time, continuous monitoring (Table 6.2).

Particulate Matter

For air pollution, Prigioniero and colleagues found that PM mitigation (reduced $PM_{0.2}$, $PM_{2.5}$, and PM_{10}) using NBS was the most studied partially because of regulatory policies and treaties such as the U.S. Clean Air Act. Increasing challenges with PM is an important justification by city officials for using NBS to clean the air. Vegetation can play an important role in capturing larger particulates through a process of dry deposition. PM can adhere to leaves at higher rates than gray infrastructure (Ferrini et al., 2020). Species microstructural leaf characteristics (i.e. surface roughness type and area, groove dimension, stomata density, trichome covered area) and macrostructural character (i.e. margin complexity, leaf shape, leaf growth expansion, and foliage) (Sgrigna et al., 2020) along with other factors such as stickiness

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(e.g. honeydew from aphids or conifer wax), leaf area density, and canopy structure control absorption and accumulation of PM by vegetation (Ferrini et al., 2020; Keeler et al., 2019). Examining 12 common urban tree species in the city of Terni, Italy, to capture PM, Sgrigna and colleagues (2020) created an Accumulation Index that inputs factors of micro and macrostructural characteristics with in situ measurements to rank the PM capture capabilities of those species. They found that *Acer saccharinum*, *Prunius cerasifera*, and *Populu tremula* ranked in the top three. Ferrini and colleagues found that these characteristics are then impacted by the "season, concentration of pollutants, wind speed, rainfall, and site geometry that, together, determine the adsorption coefficient (calculated as the percentage of particles actually trapped compared to those that impact the leaf) and the overall effect on air quality" (Ferrini et al., 2020: p. 5). They report the PM on vegetation can find its way to the ground by wind and/or rain where organic elements can decompose and inorganic accumulate in soils (Ferrini et al., 2020). Thus, there is emerging evidence that NBS can play a key role in cleaning local airsheds of PM, but the scale and capacity of NBS to remove PM are still underexamined, particularly concerning in situ interventions.

Gaseous Pollution

Prigioniero and colleagues (2021) find that NBS and GP inter-relationships are less examined than NBS and PM. Ferrini and colleagues (2020: pp. 6–7) report that vegetation use stomatal absorption to remove GP, which is controlled by:

> photosynthetic activity and turgor pressure (that vary according to the environmental conditions) as well as on the water-use physiological strategy of the plant. For instance, anisohydric species, which are able to keep their stomata open over extended periods, are more efficient at GP uptake than isohydric species, which close their stomata early in response to decreasing water availability.

They also report that the defense mechanism of species' leaves (e.g. membrane permeability) impacts the GP removal of such compounds as O_3 and NO_2 (Ferrini et al., 2020). NBS play a key role in reducing thermal conditions that make the conversion of VOCs to O_3 (Ferrini et al., 2020; Stone, 2005). GP mitigation (e.g. reduced O_3) is the reduction of:

> primary pollutants (emitted directly into the air from anthropogenic activities, such as sulfur oxides (SO_x), especially SO_2, nitrogen oxides (NO_x), and CO) and secondary pollutants that are reaction products of primary pollutants (such as O_3, H_2SO_4, and peroxyacyl nitrates (PAN)). In particular, O_3, a key component of smog, is formed in the lower troposphere, through a series of photochemical reactions, whose main reactants are NO_x and various volatile organic compounds (VOCs). (Ferrini et al., 2020: p. 6)

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Heat and sunlight accelerate chemical reactions such as O_3 production. Heat and sunlight play such a large role that some scholars have called for the U.S. Environmental Protection Agency to classify heat produced by urbanization as an air pollutant (Stone, 2005) that should be regulated under the Clean Air Act. One of Stone's (2005) recommendations is regional urban forestry efforts for cooling to reduce O_3. However, certain plant species can also contribute directly to VOCs (Ferrini et al., 2020; Prigioniero et al., 2021). So, planning and design approaches for NBS need to understand the latest scientific advances to reduce GP such as O_3.

Some tree species are natural (i.e. biogenic) sources of VOCs such as isoprene (Ferrini et al., 2020; Prigioniero et al., 2021; Stone 2005). In 2021, the American Lung Association ranked the Phoenix-Mesa metro area as the fifth most polluted air quality (2021). Maricopa County, which includes Phoenix's Department of Air Quality, partnered with non-profits and researchers to create the Maricopa County Urban Tree Selection Criteria database (Maricopa County Department of Air Quality, 2017) of trees for cooling and cleaning the air. In particular, the county was concerned that some tree species produced biogenic VOCs and NBS cooling efforts could exacerbate poor air quality. In the Phoenix region, commonly planted shade tree species such as non-natives *Dalbergia sissoo* (Indian rosewood), *Bauhinia x blakeana* (Hong Kong orchid tree), and *Eucalyptus torquata* (Coral gum) and natives like *Olneya tesota* (Desert Ironwood) produce biogenic VOCs and thus may make air quality matters worse. Overall, research and practice of heat and air pollution reduction have a foundation of objective measures that are commonly used to assess existing conditions and measure the efficacy of NBS performance. In addition, more subjective measures are becoming useful to gauge people's experience of hazards.

Subjective, Lived Experience for Heat

Although objective measures provide data to track the cooling and cleaning of NBS, researchers are challenging these purely objective measures and turning toward inclusion of subjective ways of understanding the community benefits of NBS for regulating airsheds. Increasingly, researchers, practitioners, and city officials are turning toward a social determinant of health framing to measure heat impacts (e.g. Guardaro et al., 2020), which includes subjective measures for atmospheric hazards. In many cases, expanding into documenting how housing, energy, food, and transportation security can all intersect with heat and air pollution threats is a critical improvement to airshed management (Hamstead et al., 2020). These types of insecurities can be rooted in residents' relation with a bureaucracy (that plants trees, determines bus routes, or provides energy assistance) or a landlord (that weatherizes or landscapes a home).

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Subjective data provide critical information about what ways these relations involve various types of power dynamics, which people may experience as empowering and from which they derive agency, or they may experience as disempowering, humiliating, and traumatic. Subjective measures can create co-learning opportunities between top-down officials and bottom-up communities in how processes and systems can promote fuller functioning of all residents, especially enhancing the agency/efficacy of marginalized groups. The objective measures above (surface temperature, air temperature, MRT, PM, and GP) can be coupled with subjective measures to better represent people's lived experience in airsheds.

A key foundational concept that integrates the objective and subjective in heat research is thermal comfort. Thermal comfort is a condition of the mind about people's perceived level of comfort with the thermal environment (ISO, 2005). Thermal comfort research examines indoor, outdoor, and semi-controlled thermal environments (Rupp et al., 2015). Wong and Chen (2009) describe the physiological factors of a person combined with climate/weather and the design of the physical space to influence people's thermal comfort. Reviewing outdoor thermal comfort literature, Chen and Ng (2012) suggest a framework for thermal comfort assessments, which include objective and subjective factors (Box 6.1) and which could be expanded upon as it includes many common social science methods. Some researchers are beginning to move toward innovative, participatory action research that integrates objective and subjective measures such as thermal comfort by coupling sensor data with hazard experiences (Dzyuban et al., 2021). Dzyuban and colleagues (2021) combined a thermal comfort index called physiological equivalent temperature with MRT measurements and interviews of transit riders at bus stops during hot, sunny days in Phoenix, Arizona. They found thermal perceptions at bus stops with NBS lowered people's perceived thermal sensation, even as objective measures of MRT did not show an objective improvement in thermal conditions. Part of the research also collected transit riders' needs and preferences for cooling to better document that lived expertise. Coupling objective and subjective performance measures to better document heat and air quality experiences may be an important advancement toward reducing vulnerabilities for these atmospheric hazards. As we will discuss more below in the case study, integration of subjective methods are expanding past traditional outdoor thermal comfort assessments to create new participatory action research that combines neighborhood thermal comfort assessments with NBS planning and action (Guardaro et al., 2020).

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BOX 6.1 OUTDOOR THERMAL COMFORT ASSESSMENT FRAMEWORK

Integration of Objective and Subjective Approaches

- Objective approaches to:
  - measure or model the microclimate (e.g. sun, temperatures, wind speed, humidity);
  - model or monitor people's physiological condition of thermoregulation or energy balance; and
  - observe and predict the social or behavior of a space.
- Subjective approaches to:
  - survey and interview people about their psychological condition including expectations, past experience, neutrality, and autonomy; and
  - interview people about their social or behavior in a space.

Source: Adapted from Chen and Ng (2012: p. 123).

JUSTICE-BASED NBS APPROACHES TO COOL AND CLEAN PUBLIC AIRSHEDS

A growing number of researchers are pointing to the importance of community participation in assessing, planning, and implementing cooler and cleaner airsheds (Fekih et al., 2021; Guardaro et al., 2020; Puansurin et al., 2018). Box 6.2 describes Kemmis and colleagues' (2014) approach, where they identify five steps for the practice of critical participatory research that can serve as the basis for just, place-based NBS for airsheds.

BOX 6.2 OVERVIEW OF STEPS IN CRITICAL PARTICIPATORY ACTION RESEARCH INITIATIVES

1. Ask yourself, and others in the setting, how things work here, how things have come to be, and what kinds of consequences our current ways of doing things (our practices and the practice architectures that support them) have produced and do produce.
2. Adopt a critical stance toward what happens: in conversation with others involved in and affected by our practices (as a public sphere) ask, "Are the consequences of our practices in some way untoward (irrational, unsustainable, or unjust)?" If we come to the conclusion that the

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consequences of our practices are in some way untoward, then we know we must make changes in our practices (and to our understandings of our practices, and to the conditions under which we practice) in order to prevent, avoid, or ameliorate those untoward consequences.
3. Make your conversation more practical and focused: engage in communicative action with others to reach (1) intersubjective agreement about the ways we understand the situation and the language we use, (2) mutual understanding of one another's points of view (and situations), and (3) unforced consensus about what to do.
4. Once having established, preferably by consensus, what you should do to prevent, avoid, or ameliorate the untoward consequences of our existing practices, act to transform our practices, our understandings of our practices, and the conditions under which we practice.
5. As we put our plan into action, document and monitor what happens to see if we are now preventing, avoiding, or ameliorating the untoward consequences of our previous ways of working, and to check that our new ways of working are not producing new or different untoward consequences.

Source: Kemmis et al. (2014: pp. 86–87).

Community-Led Assessments through Participatory Action Research

Since NBS to address heat and poor air quality impacts can be measured through objective and subjective regulating performance metrics, community participation with the help of technical assistants (e.g. urban climatologists) may be useful in the assessment process (Fekih et al., 2021; Guardaro et al., 2020; Puansurin et al., 2018). A key part of the assessment should be problem identification and framing of the challenge for more effective and adaptive just and place-based NBS. Participatory action research can serve as the basis for these heat and air quality assessments. Kemmis and colleagues' (2014) steps 1–3 provide a foundational approach to (1) assess and document "how things work here" in relation to vulnerable people's experience with heat and poor air quality, (2) critically examine the historic and current NBS practices that have resulted in vulnerabilities to these hazards, and (3) build a practice of communicative action for a shared understanding of the vulnerability challenge with common language that integrates multiple perspectives for action-orientation NBS.

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Participatory Planning and Co-Production

Community members are experiential experts on their neighborhood's heat and air quality challenges, existing neighborhood NBS, and the potential for enhancing local ecosystem services associated with NBS. Thus, urban climate mitigation for cooling and cleaning airsheds is turning toward more participatory planning and co-production of NBS (Corburn, 2009; Guardaro et al., 2020). After a literature and case study review of co-production concepts, Watson (2014) suggests that co-production provides several advantages over collaborative or communicative planning such as providing more creative pathways for low-income communities to improve their environments in response to government failures to do so. Watson (2014: p. 63) found that co-production serves "to 'deepen the pot' from which planning ideas can be drawn and hence potentially expand the scope of planning thought." She identified several rituals (i.e. practices) that are foundational to co-production, including: (1) self-enumeration and mapping of neighborhoods by community members; (2) engaging with governments on planning and neighborhood upgrades; (3) savings schemes to support the public good (i.e. public airsheds); (4) learning exchanges between community members, government officials, and other practitioners; and (5) exhibitions to showcase community expert knowledge including precedent setting of collectively built projects.

IMPLEMENTATION AND CO-MANAGEMENT

Participatory approaches should extend into implementation with longer-term co-management of NBS for more effective and adaptive improvements in people's heat and air quality experiences. Community advisory councils, embedded in city government, can advocate and create greater accountability for the joint management of NBS to improve airsheds. Cities have launched tree and shade advisory councils to serve this purpose. Pincetl (2010: p. 227) found:

> implementation of such a [million tree] program in Los Angeles is more complicated than it may seem due to several interacting factors: the need to rely on multiple public and private organizations to put trees into the ground and to maintain them; coordination of these multiple efforts must be centralized, but requires a great deal of time and effort and may be resisted by some of the partners; funding for planting and long term maintenance must be pieced together from multiple sources; acceptance of trees by residents varies by neighborhood as does tree canopy cover; appropriate nursery supply can be limited; the location of the program within the city administration is determined by who initiates the program.

Other emerging concepts can advance co-learning over time. Implementation can be coupled with airshed "designed experiments" (Felson & Pickett, 2005)

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or NBS projects that are research projects to monitor and measure the efficacy of interventions for cooling and cleaning airsheds. These experiments can help facilitate more informed incremental adaptations to:

- establish a learning-by-doing (Ahern, 2011) NBS practice;
- create a shared understanding of the regulating performance of different types of NBS;
- leverage the shared understanding to advance climate literacy;
- inform future NBS programs;
- improve ecosystem service benefits over time;
- adjust to cultural, demographic, and generational changes; and
- better anticipate declining NBS health as urban and regional climates change.

The three dimensions of participation (assessments, planning, and implementation) are mostly concerned with procedural justice as a pathway to increase democratic representation, local expertise, and agency by vulnerable communities in their own NBS, heat, and air quality outcomes. The best way to ensure equitable outcomes is not to necessarily change the NBS outcomes, but to change the processes by which we arrive at those NBS outcomes. From a process perspective, heat and air pollution inequity is not a function of NBS, but instead discriminatory banking practices, housing systems that encourage transactions (i.e. gentrification), and an uneven economy in which a small number of corporations have a great deal to gain from cooking the planet (e.g. New York City's case against Chevron, Exxon, British Petroleum, Shell, and ConocoPhillips, which was dismissed by the U.S. Southern District Court of New York, claimed that the defendants were collectively responsible for > 11 percent of all the carbon and methane pollution that have accumulated in the atmosphere since the Industrial Revolution).

At the neighborhood level, environmental quality improvements increase property values and the property tax base. These are often cited as "benefits" of NBS (FEMA, 2021), which is likely true if you are an affluent homeowner, a real-estate speculator, or a city government seeking to grow affluent communities that will increase municipal coffers. However, if you are a low-income renter or homeowner living on a fixed income (i.e. those who tend to have less ability to afford adequate energy and a weatherized home), then those "benefits" become costs. Low-income homeowners may find increased tax bills unaffordable, as low-income renters may find rent unaffordable. Our commodity-based housing system is designed to produce transactions, which comes at the cost of displacing people who are most energy insecure and housing insecure, both of which are related to thermal insecurity and vulnerability to heat-health impacts. As Anguelovski and colleagues (2019: p. 26140)

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argue, the "green and resilient city orthodoxy … that integrates nature-driven solutions into urban sustainability policy … either overlooks or minimizes negative impacts for socially vulnerable residents while selling a new urban brand of green and environmentally resilient 21st-century city to investors, real estate developers, and new sustainability-class residents."

Although community-based and participatory approaches to developing green infrastructure can help to prioritize the needs of residents who may otherwise be left out of these processes, even community-based green infrastructure or NBS strategies may ignore the reality of displacement – that since environmental improvements to reduce heat and air pollution cannot happen without dispossession and accumulation (Anguelovski et al., 2019), these strategies will come at the expense of socially and racially marginalized groups, precisely those who the strategies are presumably meant to protect. For instance, heat mitigation strategies such as Cool Neighborhoods New York City (City Cool Neighborhoods New York, 2021) prioritize tree planting in traditionally underserved communities where the risk of heat-health impacts is high, but this NBS strategy is isolated from housing policy. In this sense, it represents a narrow optimization-based strategy which ignores the broader and more systemic processes through which vulnerability to heat-health impacts comes about. In a number of cities, intentional anti-displacement measures are being taken to couple housing policy with NBS (Greening in Place, 2021) and provide more just pathways to targeted NBS.

CASE STUDY OF JUST NBS PROCESSES TO COOL AND CLEAN AIRSHEDS

> Uniting our voices in one vision
> projecting our vision towards the future
> we are a united community with our knowledge of food, different cultures, and languages,
> sharing ideas
> We are an example for the generations that follow what we see now tomorrow
> will be different
> A clean safe and green community the children could run play and enjoy
> the clean air without any danger.
> *Poem by: Martha Ortiz, 2019 Resident Leadership Council (TNC, 2019: p. 20).*

Community-based, justice-oriented NBS approaches that align people's experience and identity with cooling and cleaning airsheds at the center of greening actions are not as common as those for stormwater or general greening actions. In part, it may be the invisibility of the heat and air pollution, including the complicated atmospheric dynamics involved in being literate about our urban climate. Yet, it is because of the subjective aspects of the twin hazards that

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make it so important to place people's experience and identity at the center. As urban climate research has advanced, an increasing number of studies call for this people-centered approach to urban climate assessments and mitigation (Guardaro et al., 2020; Hamstead et al., 2020). Here we review one case of a co-created participatory action research project that provides important lessons for more justice-oriented pathways for cooling and cleaning airsheds.

Heat Action Planning Guide for Neighborhoods of Greater Phoenix

In 2017, The Nature Conservancy (TNC) partnered with Maricopa County Department of Public Health, Central Arizona Conservation Alliance, Arizona State University, and Center for Whole Communities to reimagine the planning, design, and engineering approach for cooling a neighborhood (Guardaro et al., 2020). Called Nature's Cooling System Partnership, this collaborative community of support developed a procedurally just approach to neighborhood atmospheric cooling and cleaning. NBS played a key role in efforts to cool three neighborhoods: two in Phoenix, Arizona, and one in Mesa, Arizona. A key aspect of their approach was to contextualize NBS for each neighborhood and to combine NBS with non-NBS, where NBS was not possible due to urban constraints (e.g. overhead and buried utility conflicts). Previous studies show that one-size-fits-all NBS can reinforce previous negative experiences for some communities (Carmichael & McDonough, 2019) unless communities are empowered to define their own NBS. A key aspect of the method documented in the collaborative's Heat Action Planning Guide (TNC, 2019; Figure 6.3) is a community of support made up of various organizations, non-profits, and government departments for strengthening multi-level relationship and trust building (Figure 6.4).

The partnership developed neighborhood prioritization criteria (Figure 6.5), including: (1) heat exposure; (2) usage of public places and services; (3) legacies of underinvestment; (4) community identity and cohesion; and (5) health and vulnerability to heat. In reflections after the effort, participants noted that they might have a town hall and invite more neighborhoods and create a negotiation process to select the neighborhoods with the greatest needs and high levels of buy-in, ownership, and having neighborhood leaders invite outsiders into working with the community.

The partnership developed a framework for community engagement that built relationships, mutual understanding, and social capital as part of the planning process (Figure 6.6). The iterative process encouraged learning between community-based organizations, municipal decision-makers, and technical advisors with community residents at the heart of the process. Reciprocal learning and sharing knowledge was a key aspect of the process to ensure residents' heat experiences were documented and given voice, where

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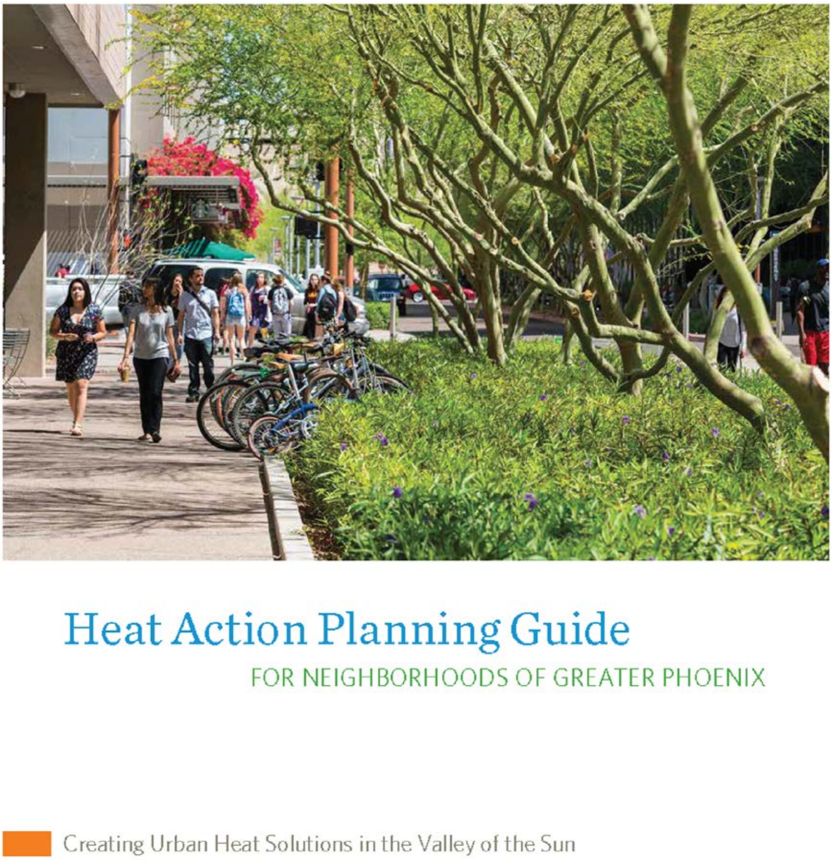

Figure 6.3 *Cover of the Heat Action Planning Guide by Nature's Cooling System (TNC, 2019)*

that experience could be backed up with objective measures of surface and air temperatures, MRT, and thermal walking surveys and interviews. The objective was to create a more holistic understanding of heat experience and match those with community-driven cooling solutions. Figure 6.7 describes those community-driven solutions. Note that while there was overlap in cooling solutions between neighborhoods, each community had unique solutions that might not be appropriate for the other two neighborhoods.

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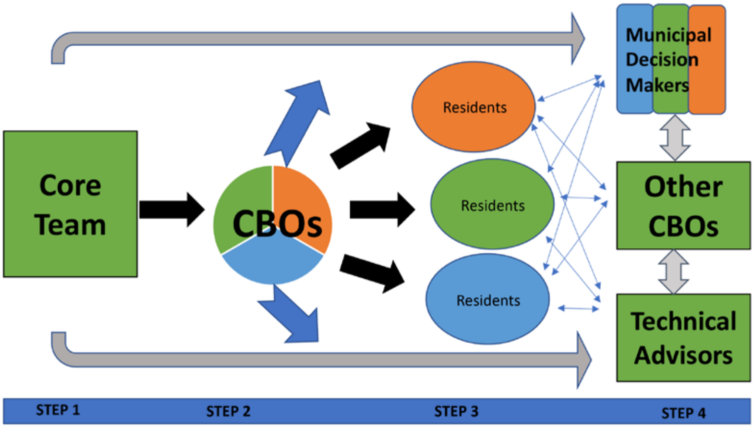
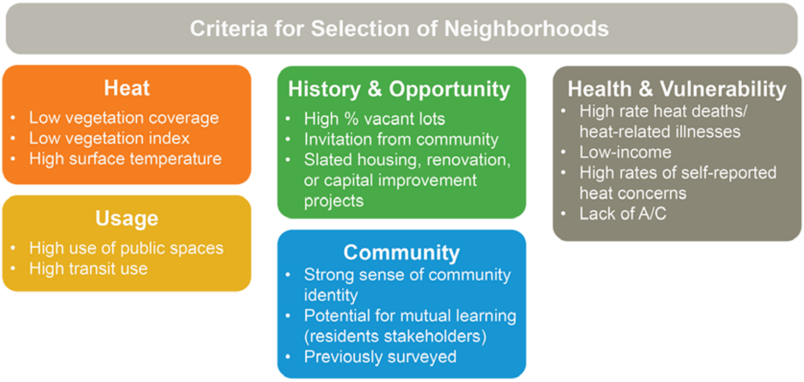


Source: Guardaro et al. (2020: p. 4).

Figure 6.4 Heat action planning process of the Nature's Cooling Systems partnership and four-step relationship-building approach



Source: Illustration by Nature's Cooling System (TNC, 2019: p. 14).

Figure 6.5 Nature's Cooling System criteria for neighborhood selection

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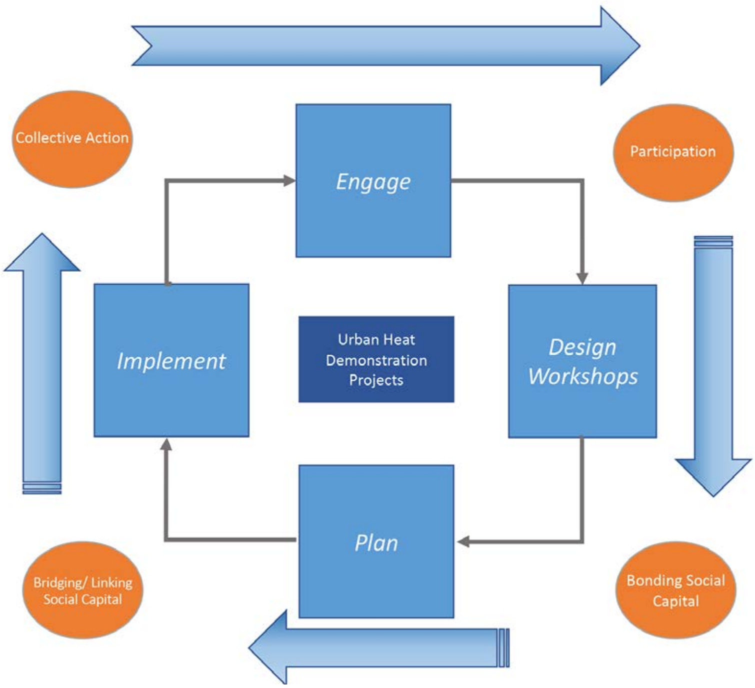

Source: Illustration by Guardaro et al. (2020: p. 4).

Figure 6.6 *Community process with urban heat demonstration projects at the core to show visible progress toward cooling*

Through the planning process, the partnership identified several barriers to cooling with NBS (TNC, 2019: p. 73):

1. Relatively low community involvement in formal city processes to advocate for cooling.
2. High heat days result in no good health choices, either be hot outside or face expensive bills for air conditioning at levels to provide health and comfort.
3. Mature shade trees cost homeowners too much to maintain, and consequently die. Dead trees are a physical and financial barrier to planting new trees.
4. Rental properties, where many low-income residents live, do not have many trees because landlords do not want trees because of the cost and ongoing maintenance obligations.

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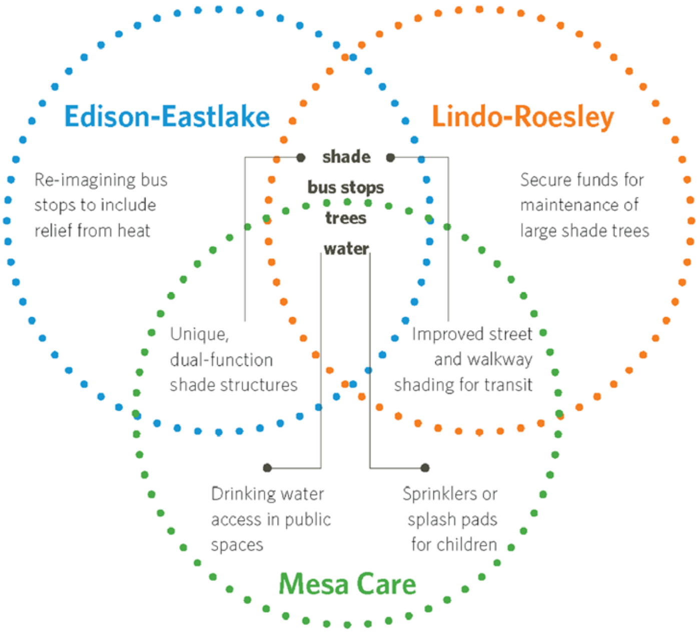
5. Shared discourse that Arizona is hot and nothing can be done to change the climate. Cooling strategies that are current options can take five to ten years for city capital improvement projects.
6. “Squeaky wheel” residents with more time, resources, and access to power receive cooling investments. This reinforces systematic environmental racism, injustice, and disinvestment.
7. New cooling ideas may require higher cost or trade-offs than established infrastructure practices. Existing legacy gray infrastructure is a barrier to implementing new ideas such as moving underground or overhead utilities to make space for such NBS as tree planting.

Guardaro and colleagues (2020) describe the partnership’s reflection on the planning process with some key lessons learned. First, credibility and trust established through place-based and socially connected community-based organizations was key. Intimidation between multiple partners was a key barrier to break. Trust building between the different partners was used to dismantle



Source: Illustration by Nature’s Cooling System (TNC, 2019: p. 64).

Figure 6.7 *Key cooling solutions for the three heat action planning neighborhoods*

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intimidation between community members, municipal decision-makers, and technical advisors. In addition to the intimidation as a barrier to relationship building cited by community members:

> The feelings of intimidation were echoed by the urban heat professionals, too. It is one thing to understand how the urban heat science works but to be in a room with people who are experiencing heat, often in catastrophic ways, was humbling and powerful. This process helped to build trust between the groups quickly. (Guardaro et al., 2020: p. 9)

Second, the process cultivated meaningful interactions to empower communities with the ability to pragmatically assess cooling options by increasing residents' urban climate and city bureaucratic process knowledge. Both are needed for residents to better understand the science and policy processes and then use that knowledge to advocate for more transformative change. Closely connected to the second lesson, the final lesson was to bridge the new scientific and process knowledge with increased agency and social cohesion of community members to select and advocate for options that better represent their community needs. Agency, trust, and social cohesion were deepened through storytelling that enabled new social relationships between community members who were strangers before the workshops. These new relationships provided a community support network for future learning and advocacy connected to municipal actors. Although these lessons might be important for any community-based, justice-oriented NBS approach, we suggest that due to heat and air pollution impacts on people's lived experience, these community-driven processes are more critical because of the invisibility of the phenomena and the complexity of the science.

KEY CONCERNS, NEEDS, AND NEXT STEPS FOR RESEARCH AND PRACTICE

Concerns

We argue that while there is still a need to improve our understanding of technological solutions to heat and air pollution, the equity, governance, and participatory dimensions of these problems remain a more central challenge to implementing NBS. Those who are most at risk of the heat-related and air pollution health impacts are also the least likely to benefit from NBS that are designed to ameliorate those impacts. Due to social-ecological-technological segregation practices and the privatization of adaptive capacities, low-income minorities have the least capacity to cope with these forms of environmental burden, burdens to which they are disproportionately exposed. At the same

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time, public solutions to NBS that do not consider how those solutions impact the private housing sector run the risk of displacing those for whom the solutions are designed. Thus, a key concern is that solutions to addressing heat and air pollution-related inequities will be optimized for a narrow set of goals and thus governed separately from housing, energy, transportation, and food systems that can be affected by NBS and are fundamental social determinants of health. Dare (2019) describes the current challenge. He found only about 25 percent of the 307 urban heat mitigation policies in 19 North American cities framed the context and importance of the policy, with roughly 75 percent calling for blind action (e.g. reduce heat for reducing heat) with no connection to impacts.

Needs

Intersectoral communities of practice are needed to contextualize how NBS fit within other components of urban systems. First, since exposures to heat and air pollution infuse indoor and outdoor residential spaces, occupational spaces, transportation spaces, recreational spaces, and others, all of these spaces must be considered in the governance of NBS. Second, governance processes should integrate methods of assessing potential unintended consequences to interlinked social determinants of health. For instance, communities should collaboratively examine how NBS could impact housing security and place-keeping solutions. Finally, a community of practitioners is needed to facilitate common understandings, language, and technical heat and air quality assessment methods that include people's experience. These practitioners are needed to support city officials' desire to manage heat and air quality in ways similar to stormwater.

Next Steps

City–university partnerships and participatory action research are important to support more rapid development of these communities of practice. A city–university agenda for co-developing the dimensions of cool and clean airsheds could include:

- just NBS community processes that emphasize recognition, validation, and documentation of lived experience and community empowerment while contextualizing NBS for neighborhood specificities;
- expanded airshed literacy and leadership programs to train community members and nurture an informed public for keeping institutions and managers accountable;

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- a city department of airshed management with city staff trained in urban climate science and urban ecology coupled with planning, design, and engineering;
- other non-governmental allied practitioners to provide consulting services for municipalities that do not have the capacity for city departments;
- city, state, and federal policy and regulation with metrics to measure improvements in vulnerable people's health and wellbeing; and
- a public NBS utility to provide the governance and funding needed for planning, implementing, managing, and maintaining healthy airsheds.

This partial list provides some ideas about next steps for developing the dimensions of research and practice of just NBS for cooling and cleaning airsheds. Combining heat and air quality under one conceptual justice frame can help develop foundational theory, evidence, and practice for healthier and more just airsheds.

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7. Nature-based solutions as critical urban infrastructure for water resilience

Lauren McPhillips, Hong Wu, Carolina Rojas Quezada, Bernice Rosenzweig, Jason R. Sauer, and Brandon Winfrey

THE CASE FOR NATURE-BASED SOLUTIONS FOR WATER RESILIENCE

Since the first human presence on Earth, people have had to contend with water-related natural hazards such as floods, droughts, and storm surges. For a long time, we have sought effective solutions to cultivate resilience by managing these hazards and preventing them from creating disasters. Early solutions used earthen or nature-based materials to manipulate water. One of the earliest recorded water management systems consisted of networks of small dams, ponds, and channels to capture receding floodwaters for both water supply during drought and to support aquaculture in southeast Australia (Jones, 2011). Pre-Inca cultures in the tropical Andes created earthen channels to divert water from headwater streams and encourage it to infiltrate into the ground and recharge groundwater supplies; this helped manage the threat of drought in the dry season (Ochoa-Tocachi et al., 2019). In another example from the Yangtze Delta of China, earthen levees, dams, and ditches were created over 5,000 years ago to prevent floods but also to provide water for irrigation (Liu et al., 2017). In areas where there was growing density of urban development, there was an increasing focus on efficient urban drainage, initially through above-ground conveyance via ditches or canals, and below ground via sewer pipes. In many cases, wastewater and stormwater flowed together in a combined system, creating water quality concerns and human health issues when not properly treated (De Feo et al., 2014).

In the last several decades, there has been growing recognition that rapid conveyance of stormwater that was central to nineteenth- and twentieth-century urban stormwater management has very detrimental effects on downstream

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water bodies. These effects include increases in peak flows and associated flooding, erosion, pollutant loading, and decreases in various biotic indicators (Walsh et al., 2005). In response, local, state/provincial, and federal governments have increasingly required the implementation of stormwater control measures, i.e., some physical means of detaining, retaining, and/or treating stormwater. In some regions such requirements have been in effect for decades, while in others they are just being considered (McPhillips & Matsler, 2018). In more arid regions, there has been renewed interest in retaining and harvesting stormwater not just to manage downstream impacts of flooding but also to aid in mitigating drought impacts and offsetting demand for imported water (Low et al., 2015).

Options for surface water management can take a wide range of forms and nomenclature. It is helpful to consider the different types in the context of an ecological-to-technological or blue/green/turquoise/brown-to-gray spectrum (Bell et al., 2019; Childers et al., 2019; Matsler et al., 2021; McPhillips & Matsler, 2018). On the technological or gray end are underground storage, infiltration, and filtration devices. Hybrid strategies include some mix of ecological and technological elements, but may be engineered explicitly with water management goals in mind; these include strategies such as bioswales, eco or green roofs, and retention ponds or basins. There are also strategies that have some level of engineering or planning, but are not designed explicitly with stormwater management in mind. However, they may provide surface water management as a co-benefit, defined as "ancillary positive ecological, environmental, and social outcomes that coincide with the installation" (Bell et al., 2019, p. 9). Such features include parks or vacant lots. Moving towards the ecological end of the spectrum, there are modified or managed ecological or natural features that provide water-related benefits, such as a wetland that has had some level of engineering or control retrofit. Finally, there are ecological features in the landscape that can provide water-related benefits; these features could include intact wetlands or forests (McPhearson et al., 2014).

Here, in the context of nature-based solutions (NBS) for water resilience, we consider all features that have multiple interacting ecological elements, or that are less than 100 percent gray or technological in form. These ecological elements include soils, water, vegetation, microbial communities, and other biota. Vegetation provides multiple functions related to water resilience. Vegetation impacts hydraulics of inflowing or conveyed water by decreasing water velocities and associated erosive potential, and by facilitating the settling and capture of entrained particles (Sabokrouhiyeh et al., 2020). Vegetation also transpires water and takes up nutrients and other pollutants from inflowing water (Berland et al., 2017; Bratieres et al., 2008; Hunt et al., 2012; Payne et al., 2014; Vijayaraghavan et al., 2019). Ecological communities can interact in complementary ways that result in desirable (and undesirable) functions.

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For example, plant species with long, thick roots may facilitate the movement of soil fauna, which can help distribute organic matter to the lower, wetter depths of the soil profile where denitrification is more likely to occur (Levin & Mehring, 2015). Soils provide or facilitate a suite of physical, chemical, and biological processes impacting water quantity and quality. An example of a function dependent on interactions between multiple elements is infiltration. While soil type and structure drive infiltration, incorporation of organic matter from senesced vegetation or development of plant roots affect soil structure and thus infiltration (Gonzalez-Merchan et al., 2014; Le Coustumer et al., 2012). Similarly, interactions between vegetation and microbial communities facilitate improved rates of nutrient removal (Morse et al., 2018). In blue and turquoise NBS, dissolved organic matter and microbial communities can affect the removal of fecal indicator organisms from stormwater runoff (Huang et al., 2018). Interacting ecological elements in NBS are also responsible for many of the co-benefits conveyed beyond water resilience. For example, vegetation can influence urban temperature through shading or evapotranspiration. Potentially, NBS features that are used to retain water in the urban environment may help to cool cities during heat waves when harvested water is used for irrigation, particularly when water restrictions are in place (Coutts et al., 2013).

HOW CAN NBS WORK FOR WATER RESILIENCE?

Given the enormous range in types and associated functions of NBS, it is critical to align desired goals with the choice of NBS, as well as to factor in regulatory, financial, geophysical, or other constraints. Major goals related to water resilience include peak flow reduction to delay and reduce the flood peak in downstream water bodies, runoff volume reduction to reduce flooding in downstream water bodies and to recharge groundwater, rainwater harvesting for beneficial reuse, attenuation of energy associated with flowing surface waters, and water quality improvement to reduce pollutant loading to groundwater or downstream water bodies. Desired co-benefits may also be a factor in the choice of NBS.

There are several axes or dimensions along which NBS can be organized (Figure 7.1). As previously mentioned, the ecological–technological spectrum is a key axis (Matsler et al., 2021; McPhillips & Matsler, 2018). The technological element refers to constructed and non-living components. The ecological element can be categorized using a blue–turquoise–green–brown spectrum (*sensu* Childers et al., 2019). This corresponds to the way that soil, vegetation, and water elements are combined and the hydroperiod, or pattern of water inundation. Blue NBS are aquatic features focused on primarily providing water storage and conveyance (Table 7.1). Green NBS are terrestrial

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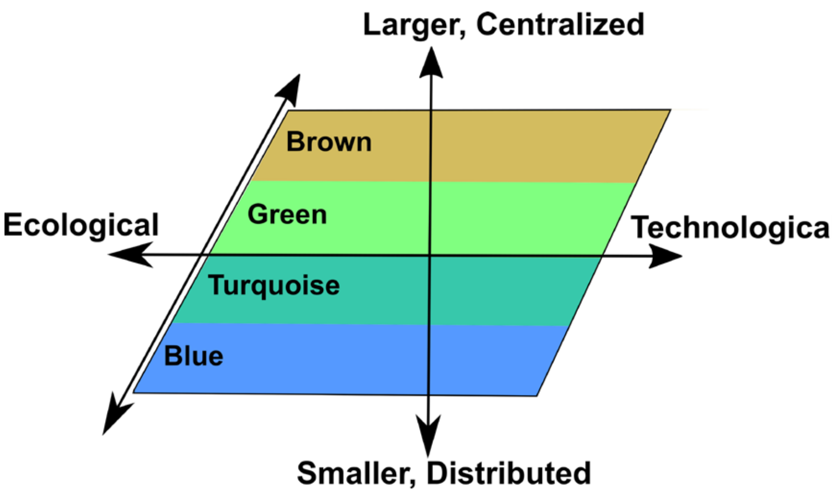
NBS with soil and vegetation. Key water-related functions of these NBS include infiltration, evapotranspiration, and water quality improvement, and they may provide temporary storage of water during storm events. Brown NBS are not often acknowledged in most NBS classifications, but are terrestrial NBS that include soil-based and minimally vegetated features such as fallow gardens or vacant lots. Brown NBS are more prevalent in arid regions, where most vegetation requires water inputs, and they are still able to provide critical water-related services such as infiltration, temporary storage of water, and water quality improvement. Turquoise NBS are a functional mix of green and blue NBS and include soil, vegetation, and water, with varied hydroperiods, with wetlands being the primary type. Primary water-related functions include storage, infiltration, conveyance, and water quality improvement.



Source: Adapted from Childers et al. (2019) and McPhillips et al. (2020).

Figure 7.1 Dimensions of nature-based solutions for water resilience

Another axis along which NBS can be organized is size and location, particularly with respect to watershed or catchment organization. Decentralized NBS features are often located higher in a watershed closer to points of runoff generation, which may help better mimic pre-development hydrology. They tend to be smaller NBS, but their more distributed nature can make their benefits accessible to more people or fauna. However, there also may be larger decentralized NBS that are primarily designed to provide other ecosystem services (e.g., parks or athletic fields) but may also provide water-related functions (e.g., storage and infiltration) during extreme precipitation events. Centralized

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Table 7.1 Examples of nature-based solutions for water resilience with key dimensions and functions characterized

Type of NBS	Dimensions	Designed function	Ancillary function
Bioswale/rain garden	Eco-techno hybrid Green-brown Smaller distributed	Flood management Water quality treatment	Aesthetic benefits Habitat
Rainwater harvesting	Primarily technological Blue Smaller distributed	Flood management Drought management	Aesthetic or recreational benefits
Intact wetland	Ecological Turquoise Smaller or larger	N/A	Flood management Water quality treatment Habitat
Park	Eco-techno hybrid Green Distributed	Recreation	Flood management Habitat Urban heat reduction
Restored floodplain	Ecological Blue-turquoise-green Larger centralized	Flood management	Habitat Recreation

NBS features tend to be larger landscape elements that collect runoff from a larger contributing area and tend to be located closer to a downstream receiving water body (e.g., stream, river, lake, or coast; Table 7.1). They are also often sized to manage larger precipitation events. Additionally, there are NBS that are implemented directly adjacent to or in line with streams and rivers, such as riparian buffers and floodplain or stream areas that have been restored or protected.

A key constraint in choosing the appropriate type of NBS is the regulatory or management framework under which it is being implemented. For example, in the United States, many hybrid engineered NBS (e.g., bioswales) are implemented to satisfy stormwater management goals under the Clean Water Act or local regulations that are often linked to new urban development. Generally, these hybrid NBS features are engineered explicitly to meet a particular required design storm standard, e.g., retention of a two-year, 24-hour storm event. Some states or municipalities may permit incorporation or protection of existing ecosystems into NBS (e.g., forest, wetland, grassland) to satisfy stormwater management regulations with new development, which is often referred to as low-impact development or environmentally sensitive design. However, hybrid NBS features that are designed to primarily provide goals beyond water resilience (e.g., parks) may not satisfy certain stormwater management requirements; reasons may include difficulty in ensuring that the feature satisfies desired design storm requirements, or could be due to

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challenges in managing and maintaining the facilities relating to governmental agency structure (Matsler, 2019).

Financial constraints can also impact the appropriate choice of NBS. There are almost always multiple NBS that may be able to provide desired benefits. Cost is often a key factor, particularly in less developed countries or regions where finances are tight. In less developed cities, conservation of or slight modification of existing intact NBS may be the most cost-effective option, rather than engineering new NBS for water management. An example of this is provided in the case studies to follow. There may also be constraints based on the types of funding available. For example, particular grants may only be available for certain types of NBS (Zimmerman et al., 2019).

Another key constraint relates to geophysical or climatic factors. Geophysical factors include underlying soil type and associated properties as well as geological formations. For example, poorly draining soils or high water tables can make infiltration-based NBS features impractical. Also problematic can be the presence of karst formations that can lead to sinkhole formation in urban areas if there is targeted infiltration. There can also be anthropogenic karst, created from the process of urbanization and associated use of aging, concrete-dominated, underground infrastructure (Bonneau et al., 2017). Thus, lined or storage-focused NBS might be recommended in these locations, though in some cases, infiltration and groundwater recharge could be facilitated by "urban karst." Climate also influences the appropriate choice and form of NBS, where brown NBS or green NBS using xeric vegetation are more common choices in arid environments.

EXAMPLE CASE STUDIES SHOWCASING NBS FOR WATER RESILIENCE AROUND THE WORLD

Leveraging Existing Wetlands for Stormwater Management

Valdivia and Concepción, two cities in the southern half of Chile, rely heavily on the ability of their coastal, riparian, and inland wetlands to manage coastal, fluvial, and pluvial flooding. These cities feature temperate rainforest ecosystems and riparian (Valdivia) and coastal (Concepción) settings, and also have a shared history of wetlands being generated in an earthquake in 1960. These factors have led to extensive wetland coverage within their urban areas.

Valdivia has conserved many of its wetlands specifically for their use as NBS for stormwater management (Figure 7.2a, b), with some notable exceptions where wetlands were conserved primarily for their cultural services and reasons of environmental justice (Correa et al., 2018). Valdivia has developed its stormwater management system to account for the water management services of its wetland network, and as a result flood risk in the city may change

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substantially if there are changes in wetland area and characteristics (Sauer et al., 2020). In some cases, urban development in Valdivia has converted either parts of or the entirety of wetlands to urban land uses. Additionally, some wetlands have been channelized to increase rates of water conveyance and to reduce storage levels prior to rainfall events. The lower water levels that result from this channelization in turn alter the ecosystem services the wetlands provide, such as habitat for plants and animals, and species composition may change in undesirable ways.

Notes: (a) A map of Valdivia, Chile with its land cover and drainage system demonstrates its extensive wetlands that are officially incorporated into its stormwater management system model. (b) A photograph demonstrates a channelized wetland that acts as wetland storage for, and conveyance away from, a medium-density residential and commercial area in Valdivia. (c) In Concepción, Chile, Los Batros Urban Wetland Park in San Pedro de la Paz demonstrates efforts to create public access to enjoy the wetlands. (d) The Rocuant-Andalién wetland shows an intact wetland adjacent to urban development.
Source: Jason R. Sauer and Carolina Rojas Quezada.

Figure 7.2 Wetland nature-based solutions in Chilean cities

Concepción is undergoing a process of wetland valuation as NBS for flood reduction and other cultural ecosystem services such as recreation. One result

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of this process is that the city has targeted a series of connected wetlands, called La Ruta del Agua, for protection as stormwater management NBS. Additionally, building permits that would drain or fill small urban wetlands were frozen in 2019, and public space projects were implemented at urban lagoons (Laguna Redonda and Laguna Lo Galindo) to develop and improve access to their cultural services. The city has collaborated with a community to develop Los Batros Urban Wetland Park, which conserved a set of urban wetlands and recognized their utility toward improving stormwater management, increasing urban biodiversity, and aiding in social integration via accessibility to green space for low-income neighborhoods (Figure 7.2c). The coastal wetlands of Rocuant-Andalién in Concepción (Figure 7.2d) have also played a historically important role in protection from tsunami-induced flooding (Rojas et al., 2019) and urban wetlands have supported freshwater provisioning following major earthquakes (Villagra et al., 2014).

Across Chile, concerns about the effects of urban wetland loss on stormwater management, biodiversity, and cultural services, and the environmental injustice it represents for many Chileans, have been elevated to the national level. In January 2020, these concerns led the Chilean legislature to pass a nationwide law protecting urban wetland cover. Whether and how this legislation will help protect the wetland NBS of Valdivia and Concepción remains to be seen.

Large-Scale NBS Implementation in Chinese "Sponge Cities"

Flooding and water quality impairment associated with rapid urbanization and climate change have become one of the most pressing environmental issues in China in recent years. Between 2014 and 2019, the Chinese Central Government implemented an ambitious initiative called Sponge City Development (SCD) to transform cities so that they perform like sponges to store, infiltrate, treat, and convey stormwater (MHURD, 2014), leveraging additional co-benefits of NBS to enhance quality of life (Chan et al., 2018). Promoting a holistic water management regime, SCD emphasizes the application primarily of green and turquoise NBS to facilitate infiltration and water storage. Numerous pilot projects have been implemented in 30 government-funded pilot cities across all the five major climatic zones of China with annual precipitation over 400 mm to test innovative stormwater management strategies.

One of the pilot cities, Zhenjiang, located in Jiangsu province in southeastern China, features an example that employed large-scale hydrological modeling to develop and mandate a stormwater management plan for a 22 km^2 demonstration zone in the Old Town area (Figure 7.3). With annual precipitation of ~1,100 mm, a population of ~3.2 million, and a strong industrial economy, Zhenjiang had suffered from repeated urban flooding, especially in

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older communities, and severe water pollution before SCD. The stormwater management plan proposed and implemented ~150 pilot projects to achieve the national performance goals of conveying a 30-year storm event with no city flooding while treating 75 percent of annual runoff volume to achieve a 60 percent annual reduction in total suspended solids. Besides upgrades of traditional gray infrastructure, the projects included a variety of NBS (Figure 7.3), including rain gardens, bioswales, bioretention planters, floating wetlands, and a regional terraced filter facility that treats combined sewage and stormwater. Following the pilot period, Zhenjiang adopted a city-scale SCD management ordinance and at least three other design and management guidelines to solidify the regulatory and technical foundations for future implementation efforts (Gu et al., 2019).

Notes: (a) Schematic of the Sponge Development Plan of Zhenjiang's 22 km^2 demonstration zone; (b) examples of a green street; (c) riparian stormwater treatment zone; and (d) a central park treating regional stormwater overflows.
Source: Hong Wu.

Figure 7.3 NBS implementation in the Old Town area of Zhenjiang

While the initial pilot SCD implementation has been viewed as a success in certain aspects, challenges have already emerged that could impede future implementation efforts (Li et al., 2017). In many cities, NBS were implemented largely individually, rather than taking a system or city-scale approach. Some cities found it challenging to break through traditional disciplinary boundaries, such as integrating engineering and design expertise, to most effectively plan and implement NBS. Additionally, while the Chinese government provided initial financial support for pilot projects, cities are concerned about finding

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adequate financial support for continued implementation of NBS, but there is hope for leveraging and implementing public–private partnerships in the future (Li et al., 2017).

New York City: Planning for Cloudburst Resilience

New York City's waterscape is diverse and includes canopies of skyscrapers drained by centuries-old combined sewers, subbasins with separated sewer systems, and historic residential communities that remained unsewered until the last decade. Located in the humid northeastern United States, the city has experienced an increase in annual precipitation over the past half-century, after much of its subterranean sewer system had already been built. The city's harbor has historically suffered from very high levels of pollutant and nutrient loading (Rosenzweig et al., 2018a; Taillie et al., 2020) and the city also has a history of frequent flooding, resulting from both coastal and precipitation-driven events (Depietri & McPhearson, 2018). All of these issues will be exacerbated by the more frequent cloudbursts (high-intensity precipitation events) projected for the region due to global climate change in the absence of mitigation efforts (González et al., 2019).

New York City has begun using NBS for stormwater management through several innovative programs – each focused on a different regulatory requirement or management challenge. As an alternative to building out stormwater drainage sewers in neighborhoods at the outskirts of the city, in the 1990s the city initiated its Bluebelt Program (Gumb et al., 2007), which integrates the conservation of existing wetlands with engineered stormwater detention basins. New York City has also broadly implemented primarily decentralized, turquoise and green infrastructure to meet national water quality regulations and reduce discharges from its combined and separate stormwater sewers and, more recently, discharge through separate stormwater systems (Rosenzweig & Fekete, 2018).

While the aforementioned programs have contributed to improved harbor water quality and provided important ecological and societal co-benefits, they are limited in their capacity to address New York City's chronic flooding issues (Rosenzweig et al., 2019). To enhance resilience to pluvial flooding from cloudbursts, the city recently conducted a Cloudburst Resiliency Planning Study, which includes a masterplan for a flood-prone area of the city that utilizes a network of primarily blue NBS to store and convey stormwater following intense rainfall events (NYC DEP & Ramboll, 2017). This study included a full cost–benefit analysis using the results of a dynamic flooding model. Its results demonstrated that the NBS provided flood mitigation and other social benefits that outweighed their capital and operations costs – a benefit–cost ratio of 1.8 over a century. As a first step towards imple-

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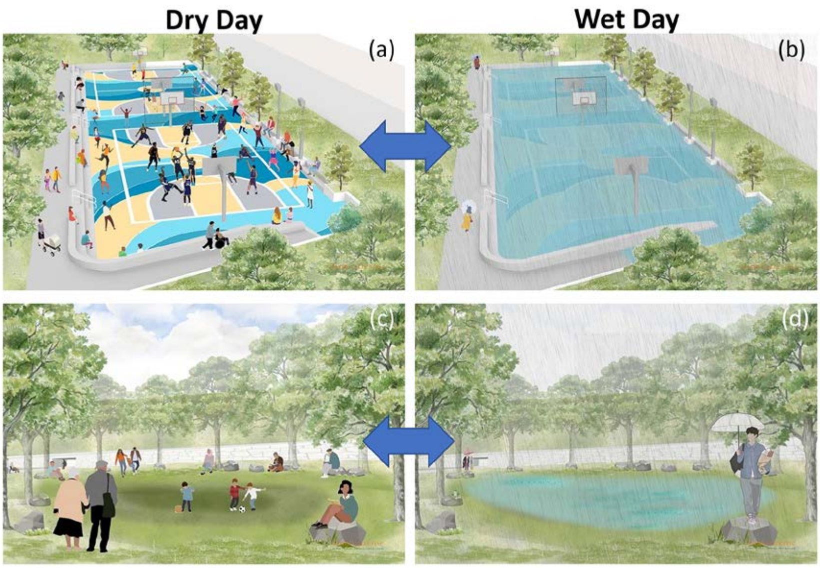
mentation of the full masterplan, blue and green infrastructure projects are being piloted for a low-income public housing development and adjacent to a conventional pumping station within the masterplan study area (Figure 7.4).



Source: NYC DEP & Ramboll (2017).

Figure 7.4 *Future concept vision for cloudburst management at a pilot location in New York City with multi-functional NBS serving as recreation spaces on dry days (a, c) and as stormwater detention spaces on wet days (b, d)*

Using Nature-Based Solutions to Manage Severe Drought in Melbourne, Australia

The Melbourne metropolitan area, surrounding the Victorian state capital city of Melbourne, Australia, sits on land traditionally owned by the people of the Kulin Nations. NBS for water resilience were demonstrated by aboriginal people before European colonization in numerous locations in Australia, particularly through a network of weirs and ponds used to capture receding floodwaters and facilitate trapping fish. This managed system also supplied water during drought. The complex network of engineered channels and rock walls near Lake Condah in southwest Victoria, known as the Budj Bim Cultural Landscape, is designated a World Heritage Site by UNESCO on the

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basis of its representation of cultural values connected to the indigenous group, the Gunditjmara (Bark et al., 2015; Jones, 2011). Today, Melbourne has a population of 5 million and covers roughly 10,000 km^2. Droughts are common in Australian historical records but they appear to be intensifying (Freund et al., 2017). During the Millennium Drought (which occurred from 1996–2010), the most recent and worst drought in the last 400 years (Freund et al., 2017), water supply inflows dropped by 37 percent while the population increased in Melbourne, resulting in a 64 percent reduction in stored water supply between 1996 and 2009 (Grant et al., 2013).

In response to this, water use restrictions, water-sensitive development guidelines, water pricing, wastewater recycling, and finally integrated urban water cycle management projects contributed to reducing per capita water consumption by nearly 50 percent (Low et al., 2015). Several large stormwater harvesting schemes were constructed in the later years of the Millennium Drought in an effort to augment water supply in the city for landscape irrigation. These projects used a range of blue to brown NBS features that are locally referred to as water-sensitive urban design systems (Figure 7.5). In addition to rainwater harvesting, NBS such as stormwater biofilters and wetlands were leveraged to treat runoff before storing it. It was not until the Victorian State Government invested in integrated urban water management in 2012 that treated runoff from biofilters was used as a substitute for potable water use (Low et al., 2015). Perhaps most surprising and unprecedented was the lasting effects the drought had on residents of the city. Average daily water use before the drought was 458l per person. Following the Millennium Drought, water use decreased to 246l per person per day (Grant et al., 2013). Between 2010 and 2020, average water use was 158l per person per day (Melbourne Water, 2021). Although harvested rainwater and stormwater runoff only comprises a small fraction (~3 percent) of the total demand in Melbourne, stormwater runoff available for harvesting comprises about 80 percent of demand (Melbourne Water, 2017). Using treated stormwater runoff to augment potable supply would require a higher level of treatment than current water-sensitive urban design systems are able to provide reliably, particularly for removing pathogens. Currently, researchers are investigating novel soil media amendments and bioinoculants (Palacios et al., 2021), plant species which exude antimicrobial compounds (Galbraith et al., 2019), and real-time control of effluent flow rates and water levels to better and more predictably remove pathogens from runoff in NBS features (Shen et al., 2020). Indeed, NBS such as stormwater biofilters and wetlands are an integral part of utilizing polluted stormwater runoff as a substitute for potable water use in Melbourne (Grant et al., 2013).

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Notes: (a) a sign indicating rainwater collection; (b) a street-side bioswale, non-turfgrass yard; and (c) a rainwater collection system and overflow conveyance swale.
Source: Lauren McPhillips.

Figure 7.5 Nature-based solutions in the Little Stringybark Creek catchment in Melbourne, Australia

Making "Room for the River" in the Netherlands

As more engineered and gray infrastructure strategies were implemented around the world to manage water in recent centuries, levees or embankments have been a key flood defense along river corridors. The challenge with this strategy is that it passes the problem downstream, preventing the river from using its floodplain and thus from diffusing its energy or reducing its volume and nutrient or pollutant loads.

In the Netherlands, there has been a recent shift from this "battle against water" to "living with water" and embracing NBS of floodplain restoration and reconnection (de Groot & de Groot, 2009). The €2.2 billion Room for the River program has been a keystone of this effort. This program has involved implementing a suite of strategies to expand the ability of rivers to store water in the floodplain, such as lowering floodplains and relocating embankments (e.g., dykes) inland (Busscher et al., 2019). More than 30 interventions have been implemented along the Rhine River, restoring 4,400 ha of former floodplain.

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Recent research is already documenting the reduced consequences of flooding and reduced probability of breach and failure of embankments as a result of these floodplain restoration practices (Klijn et al., 2018). Although this approach inherently takes up more space relative to raising embankments located close to the river, it has provided opportunities for multiple benefits beyond flood management (Busscher et al., 2019). These co-benefits of NBS are discussed more extensively in other chapters of this book (e.g., Chapter 4).

It is important to acknowledge the complex coordination and multi-level governance processes required by this example of large-scale NBS. While clearly challenging, this example demonstrates that it is possible to make such transformative change happen with careful planning, adequate funding, and a mix of centralized and decentralized implementation (Rijke et al., 2012).

CHALLENGES IN MAKING THE CASE FOR NBS FOR WATER RESILIENCE

In general, there is growing evidence documenting the hydrologic and water quality performance of NBS, particularly hybrid NBS designed explicitly for water management. This includes evidence of peak flow reduction, reduction of runoff volumes, infiltration to recharge groundwater, and retention or removal of numerous pollutants (Clary et al., 2017; Liu et al., 2014; Roy-Poirier et al., 2010). There is some documentation of NBS performance at the system scale (i.e., watershed or catchment); this evidence is more sparse than at the site scale, and is dominated by modeling studies (Jefferson et al., 2017; Lintern et al., 2020). Hydrologic metrics that have been evaluated include changes in riverine flooding or flashiness and water quality of downstream water bodies, but evidence of groundwater recharge or reduction in pluvial flooding are lacking (Rosenzweig et al., 2018b).

One knowledge gap is in understanding the function of NBS over time, and based on NBS location(s) in a catchment. Sources of temporal change include the accumulation of sediment and associated pollutants over time, reduction in infiltration, and changes in maintenance that feed back into physical, chemical, or biological processes. Most models assume constant performance over time. The few long-term field studies that exist have demonstrated wide variability, from no change in performance over time to decreases in hydrologic or water quality performance (Amur et al., 2020; Komlos & Traver, 2012; Natarajan & Davis, 2015). While some NBS, particularly those that are more ecological, may be self-maintaining, other more engineered NBS may require maintenance to maintain adequate water resilience functions over time (Conley et al., 2020; Sherk et al., 2020).

Another challenge relates to optimal spatial placement of NBS. In terms of water resilience, this challenge is addressed by catchment science engineering

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approaches that emphasize placement of NBS based on location of hydrologic hotspots, e.g., for stormwater management, places where concentrated runoff contributions converge (Hewett et al., 2020). With increasingly high-resolution spatial datasets, capabilities to target such hotspots are improving. In terms of stormwater management, the most efficient collection of runoff can occur at more centralized locations with a greater drainage area, but there is some evidence that more distributed NBS can offer greater redundancy and resilience, and better mimic pre-development hydrology and manage floods (Loperfido et al., 2014). Other challenges in this realm are more related to the practical and social-economical-political challenges of land acquisition in these “optimal” locations. For example, planning for large-scale floodplain restoration may require the buy-out of homes and the coordination of many agencies or stakeholders. The placement of NBS is often more opportunistic, leveraging land that is available at any given time.

A further challenge lies in valuing hydrologic and water quality performance of NBS features that are not explicitly engineered for water management. Hybrid NBS or stormwater control measures have target design criteria, such as storage or infiltration capacity or treatment efficiency. How can infiltration and storage benefits of a park or existing wetland be incorporated into existing infrastructure asset management that is often divided between engineered assets and NBS assets, and how do we better integrate these diverse features in our modeling approaches? It is also not always clear how the performance of more engineered NBS compare to more ecological NBS, and more research is needed in this realm.

Although these challenges remain, interest in and implementation of NBS for water resilience continues to grow. A key motivation is the ability to meet water-related goals or regulations while also addressing other goals or providing other benefits. In general, “gray” stormwater control measures provide one or two functions efficiently. As documented here and in other chapters of this book, NBS can offer a wide range of co-benefits. In considering the need to confront climate change and increased incidence of natural hazards such as high-intensity storm events or prolonged drought and extreme heat events, investment in NBS can aid in addressing multiple hazards, in addition to other goals, providing a much more cost-effective investment over simply prioritizing upgrades to existing storm sewer infrastructure.

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8. Human physical health outcomes influenced by contact with nature

Lilah M. Besser and Gina S. Lovasi

HEALTH IN HUMAN POPULATIONS

Clinical notions of human health often center on the diseases, disorders, and injuries that cause pain or impairment, and those risk factors or findings that signal a need for preventive treatment (Meertens et al., 2013). Yet, a holistic and positive definition of health necessarily considers the ability of individuals and populations to experience longevity and wellbeing, fending off or recovering from conditions that arise. A salutogenic approach key to this tradition of looking at positive definitions of health and their determinants has emphasized characteristics that offer resilience in the face of health threats (Antonovsky, 1996). When considering the health implications of contact with nature, the clinical perspective of associated adverse health outcomes at the individual level and the broader perspective which encompasses attention to the full spectrum of health states at the population level are both valuable (Arah, 2009).

Historically, the important role of urban planning in disease prevention centered on infectious disease threats (Corburn, 2004). Attention to disease prevention and health promotion, and not just disease control and treatment, has become increasingly emphasized over the last decades in the medical and public health realms (Institute of Medicine (US) Committee for the Study of the Future of Public Health, 1988). This shift in attention has come at a time when the leading causes of death in middle- to high-income countries such as the United States (US) are increasingly predominated by non-communicable chronic diseases. In 1900, the top three leading causes of death in the US were pneumonia, tuberculosis, and diarrheal disease (Centers for Disease Control and Prevention, 1999). In 2018, the top three causes of death in the US were heart disease, cancer, and unintentional injury (Centers for Disease Control and Prevention, n.d.). Globally, non-communicable chronic diseases were the cause of an estimated 34.5 million avertable deaths (Martinez et al., 2020). Non-communicable chronic diseases are the result of the complex interplay between genetics, environmental exposures, individual behaviors, time, and

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age. Diseases such as cancer and heart disease are affected by early life and cumulative environmental exposures, and by behaviors such as patterns of dietary intake, engagement in physical activity, and use of substances including tobacco and alcohol.

Considered together, the health consequences of our lifestyle behaviors have potentially important effects on leading causes of mortality, and the consequences of lifestyle for health also importantly extend to cognitive functioning, mental health, and wellbeing (Dale et al., 2014). Our lifestyle behaviors are in turn influenced by the natural and built environments that surround us. Built environments structure exposure to physical hazards that can undermine health and opportunities for social engagement. With increasing global urbanization, long-standing threats to human health from nature are being overshadowed by threats to human health arising from how we have built our environments, and by inequities in access to place-based resources including parks and other greenspaces (Sarkar & Webster, 2017).

Over the last few decades, public health researchers renewed connections to fields such as urban planning to jointly investigate how our built and social environments affect short- and long-term health outcomes. The aspiration is to devise strategies to modify our environments in ways that prevent the non-communicable chronic diseases and other lifestyle-associated adverse health outcomes that afflict a large portion of society. To this end, multiple threads of research highlight nature contact within cities as beneficial, supporting the value of nature-based solutions (NBS). While the available public health evidence has shaped our emphasis on lifestyle-relevant greenspaces and metrics related to vegetation, we note that NBS encompasses a broader range of place-based strategies that warrant attention (such as nature-based stormwater management strategies which may mitigate flood-associated health risks).

In this chapter, we first provide an introduction to the evidence, leveraging what has been assembled in previous systematic reviews and meta-analyses. We note that observations have not always confirmed expectations, and much is yet to be learned about the ways in which nature exposure can influence health. To inform and frame future research and practice to build on the evidence to date, we then discuss pathways through which nature-based environmental interventions, contact with nature, or other related contextual conditions may affect human health outcomes and population health more broadly and then offer brief concluding remarks.

EVIDENCE LINKING NATURE-BASED SOLUTIONS TO HEALTH OUTCOMES

Our search for peer-reviewed articles primarily relied on PubMed, a database with extensive coverage of established journals relevant to health. For each

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major health outcome, PubMed was searched for titles that included “nature” or “nature based solutions” or “greenspace” or “green” or “park” *and* keywords for each major health outcome (e.g., mortality paper titles included “mortality” or “death”). No restrictions were made on year of publication and only English language publications were included. Prior studies supporting connections between nature and major health outcomes are summarized based on strength of evidence as identified by systematic literature reviews, when available. Primary studies and narrative/traditional reviews were included if systematic reviews for a particular health outcome were unavailable. The PubMed search resulted in 29 pertinent literature reviews and eight primary studies. The major health categories of interest were determined *a priori* and include mortality, cardiovascular and cerebrovascular disease, cancer, respiratory disease, Alzheimer’s disease and associated disorders, pregnancy and birth outcomes, and other health outcomes (e.g., physiological markers and sleep).

Unlike other types of literature reviews, systematic reviews offer replicable and comprehensive summaries of the weight of the evidence from published research with respect to each study’s methodological limitations, such as risk for bias that could result in erroneous conclusions (for a consolidated set of terms relevant to assessing strength of evidence, see Table 8.1). Some systematic reviews include a meta-analysis (e.g., Ideno et al., 2017; Lambert et al., 2017) in which results from numerous studies are quantitatively combined to produce an overall statistic for the evidence of an association between the exposure (e.g., NBS) and outcome (e.g., mortality).

Even if not assessed for study quality formally in a systematic review, in order to soundly conclude that NBS positively affect specific health outcomes, studies need to meet common criteria for causality (World Health Organization, 2005). Studies will need to have been reproduced across different populations/regions and should have been based on rigorous study designs and methods to ensure that competing factors (i.e., confounders) or flawed methods cannot explain the observed associations between NBS and health (Fedak et al., 2015).

The subheadings for this section emphasize the health outcomes comprising the current leading causes of death and illness in the US, followed by pregnancy-related and other health outcomes (e.g., modifiable risk factors). In the field of epidemiology, the possible cause of a health outcome under investigation is commonly labeled an “exposure,” a term used in Table 8.1. From our review of the literature for this section, research studies varied in the specific exposure of interest. Common measures of nature contact included availability of greenspaces and greenery in or near residential neighborhoods (Table 8.2), although some studies had other foci, such as blue spaces (e.g., beaches, rivers, waterfronts), time spent in nature beyond the neighborhood, or trials of interventions involving nature contact.

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Table 8.1 Overview of study designs and limitations relevant to navigating the evidence

Evidence type	Key characteristics	Key limitations to consider within evidence linking NBS to health
Systematic review	Comprehensive and transparent search strategy, often includes analyses to guide interpretation such as insight into risk of bias	Publication bias in the underlying literature may lead to omission of unexpected or null findings
Meta-analysis	Quantitative combination of findings across studies, typically conducted among the studies identified in the course of a systematic review	Heterogeneity of measurement and analysis methods across studies make meta-analyses less common and interpretation challenging
Cross-sectional study	Data collection from one point in time (e.g., NBS exposure and health outcome measured at the same time)	Associations can be distorted by confounding bias, by having data on a sample not representative of the larger population (i.e., selection bias), by recalling exposure incorrectly based on outcome status or poor recall (i.e., recall bias), or by reverse causality (measured outcome actually causes exposure)
Longitudinal study	Data collection occurs over time, often monitoring changes in health for a fixed set of individuals (cohort study), facilitates distinguishing whether NBS was experienced prior to health outcome changes	Associations distorted by confounding bias or selection bias
Randomized controlled trial	Allocation to groups with and without NBS is by chance, creating balanced groups and evidence less susceptible to confounding bias	Standardization of NBS and inclusion criteria may limit opportunities to explore effect modification (differences in the strength or direction of association by NBS type or population group)
Natural experiment	Allocation to groups that differ in contact with nature is determined by events that are otherwise unrelated to individual health, approximating the advantages of a randomized controlled trial	Vegetation loss or other sudden change may not be perfectly aligned with the timeline and engagement surrounding a corresponding NBS proposal (e.g., tree loss versus planting)

Source: Webb et al. (2020).

All-Cause Mortality

In 2019, a meta-analysis was conducted to summarize findings from nine longitudinal studies that measured residential greenness at baseline or over time and number of participant deaths during a period of follow-up (Rojas-Rueda

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Table 8.2 Common measures of nature contact in health studies

Category	Example measures	Methods to collect/ develop the measures
Outdoor "greenness"/ healthy vegetation[a]	Density or average amount of: • Healthy vegetation (e.g., Normalized Difference Vegetation Index) • Tree canopy	GIS or self-report
Outdoor greenspaces/ green land cover[b]	Distance to, amount/percentage of, or number of: • Public parks and gardens • Private gardens • Open spaces • Forests	GIS or self-report
Contact with nature	• Activities in park spaces (e.g., recreation) • Time spent outdoors (e.g., per week) • Walking in the park versus walking on a busy street	Self-report, direct observation, or experimentally assigned

Notes: The information provided in this table is a summary of common measures used in studies cited in the 'Evidence linking nature-based solutions to health outcomes' section.
[a] Measures of greenness often derived using geographic information systems with maps and remote sensing data (e.g., satellite imagery). [b] Measures of greenspaces/land cover often derived from geographic information systems maps (e.g., to determine distance from home to nearest park).

et al., 2019). For all of the studies, residential greenness was measured in the area surrounding the residence using the Normalized Difference Vegetation Index (NASA Earth Observatory, n.d.), a quantitative measure developed from satellite imagery that indicates the degree of healthy vegetation on a scale from −1 to +1 (a higher positive indicates a relative abundance of healthy vegetation). The study found that greater residential greenness was associated with a reduction in mortality.

Other literature reviews have also observed associations between greater residential greenness or greenspace access and lower rates of mortality, but the reviewed studies employed heterogeneous and less rigorous methods than those reviewed in the aforementioned meta-analysis (Gascon et al., 2016; Kabisch et al., 2017; Kondo et al., 2018; Twohig-Bennett & Jones, 2018; van den Berg et al., 2015). Although the total number of related studies is still limited to make a definitive conclusion, the published studies provide mostly consistent evidence for a relationship between residential greenness or greenspace access and reduced risk of all-cause mortality. While at least one meta-analysis suggested associations between greater greenness and lower risk of mortality due to stroke, few studies of mortality identified in the prior literature reviews examined specific causes of death (Yuan et al., 2020). The

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concentration on all-cause mortality ultimately limits the utility of the findings because it does not distinguish among the several plausible causal pathways through which NBS could affect health. Some patterns of cause-specific associations could add nuance to the understanding of the observed association between nature exposure and mortality.

Cardiovascular and Cerebrovascular Disease

Cardiovascular diseases encompass a number of related conditions affecting the structure and function of the heart and blood vessels throughout the body (i.e., the vascular system) (American Heart Association, n.d.). In heart failure, the heart's effectiveness with each pump is chronically reduced. In other conditions, the heart's pumping action is slower (bradycardia) or faster (tachycardia) than normal or stops altogether (cardiac arrest). Coronary artery disease involves partial or complete blockage of the heart's blood vessels, and such blockage can contribute to the death of heart muscle tissue (myocardial infarction). Cerebrovascular disease refers to the disease of the brain's blood vessels, including stroke, which arises from lack of blood flow or excessive bleeding causing cell death and loss of function (American Association of Neurological Surgeons, n.d.). Cardiovascular and cerebrovascular diseases are chronic diseases with long latency periods, such as gradual narrowing of the space for blood to flow through blood vessels. Lifestyle behaviors and environmental exposures can thus have a cumulative effect on risk. However, an eventual crisis resulting in hospitalization or death may also be triggered by short-term elevations in air pollution, temperature, or stressors.

Modifiable risk factors for cardiovascular and cerebrovascular disease include high blood pressure, diabetes, high cholesterol, physical inactivity, overweight/obesity, psychosocial stress, and air pollution exposure. The relationship of NBS with such risk factors is discussed later under "Other health outcomes" in recognition of their broad health impact beyond cardiovascular disease.

In a systematic review, seven of 13 studies found associations between greenspace exposure and reduced cardiovascular disease or cerebrovascular disease risk (Yuan et al., 2020). Three other cross-sectional studies not identified in that systematic review found positive associations between greenspace/greenness and cardiovascular health (Ngom et al., 2016; Pereira et al., 2012; Yang et al., 2020). Together, these findings are suggestive that NBS that increase greenspace/greenness exposure may help prevent cardiovascular and cerebrovascular disease.

Nonetheless, the published relevant evidence is still limited by the number of rigorously conducted studies. There may be other differences in lifestyle and underlying risk between groups, and if such differences are correlated with

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opportunities for nature contact, that can lead to bias. Further distinguishing causal influence from competing explanations may be addressed through design and analysis innovation in future research.

Cancer

While cancer is best understood as a group of diseases, a commonality is that cells reproduce unnaturally without stopping (American Cancer Society, n.d.). Such cancerous growth can begin anywhere in the body and if left untreated may metastasize to other parts of the body and eventually lead to death. Cancers most commonly affect the skin, lung, breast, colon, and prostate gland (World Cancer Research Fund, n.d.). A key challenge that arises when linking NBS or contact with nature to cancer outcomes is the variable time between initiation of cancerous growth and detection by seeking care for symptoms or through routine cancer screening. There is limited information to establish a timeline of how cumulative or enhanced contact with nature relates to cancer progression, and population differences in screening may further impede our understanding.

Modifiable risk factors for cancers vary depending on the body site affected, but include environmental exposures such as pollutants/chemicals, diet, obesity, and behaviors such as smoking and sunbathing. Nature-based exposures may influence these risk factors and thus affect cancer risk. The available published literature on associations between natural environments and cancer is sparse, with no known systematic literature reviews available. Two studies in Canada and the US found that greater residential greenness was associated with lower risk of prostate cancer (Demoury et al., 2017; Iyer et al., 2020), while a third study in Germany found no such association (Datzmann et al., 2018). The same German study found that greater residential greenness was associated with lower risk of throat and mouth cancer and non-melanoma skin cancer. In contrast, a cross-sectional study in Australia found that having a greater percentage of the residential area made up of greenspace was associated with greater odds of skin cancer (Astell-Burt et al., 2014). Overall, based on the conflicting and scant studies, no strong evidence is available to conclude that NBS may reduce cancer risk, and it is possible that NBS may increase or decrease risk depending on the cancer type.

Respiratory Disease

Chronic respiratory diseases involve impaired breathing, with periodic or persistent changes to the airways leading into and branching through the lungs (bronchi and smaller bronchioles) and the small structures within the lungs that allow oxygen to enter blood (alveoli) (American Lung Association, n.d.). Of

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these, asthma is common in childhood, characterized by a reversible narrowing of airways that impedes breathing, with symptoms such as wheezing that peak during exacerbations. Chronic obstructive pulmonary disease is a progressive inflammatory disease characterized by daily cough and mucus production (chronic bronchitis) and/or anatomical changes reducing the surface area for oxygen exchange within the lungs (emphysema). The modifiable risk factors for respiratory disease that may be affected by NBS are obesity and allergen and chemical exposures, including long- and short-term effects of air pollution, tobacco smoke, dust, and other household/occupational allergens and chemicals.

No known systematic reviews have centered on exposure to nature and respiratory disease in adults, but several have focused on children and adolescents (Ferrante et al., 2020; Hartley et al., 2020; Islam et al., 2020; Lambert et al., 2017). A narrative review of 14 studies on urban greenness and allergic respiratory diseases concluded that there was mixed evidence as to the direction and magnitude of the association (Ferrante et al., 2020). Four of the studies observed a beneficial "effect," five a harmful "effect," and six no effect. A systematic review of greenspace and childhood development identified three studies on respiratory health, noting beneficial and harmful "effects" depending on the outcome (Islam et al., 2020). Urban greenspaces seemed to decrease wheezing and bronchitis in children, although one study demonstrated increased respiratory symptoms associated with greenspace-related pollen exposure. Two studies highlighted in a systematic review of biodiversity and health found lower risk/prevalence of asthma among children living on farms and areas with more natural land cover (Aerts et al., 2018). A systematic review of 11 studies and corresponding meta-analysis found no strong evidence for associations between residential greenness and asthma or allergic rhinitis (Lambert et al., 2017). Lastly, a systematic review of built environment and health found that greenspace tended to be associated with acute respiratory illness and not chronic respiratory diseases, based on 10 pertinent studies (Schulz et al., 2018), in which all but one focused on children. The authors concluded that based on the quality of the studies, the evidence for associations was minimal. Altogether, NBS have not been consistently associated with either reductions or increases in respiratory disease and symptoms. The evidence is particularly sparse for adult populations and conditions such as chronic obstructive pulmonary disease have been less commonly studied.

Alzheimer's Disease and Related Dementias

Alzheimer's disease and related dementias (ADRD) affect 50 million people worldwide (World Health Organization, n.d.a). These conditions are expected to greatly increase in prevalence in the next few decades with the rise in the

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population of older adults (≥ 65 years), who are the primary affected population. ADRDs manifest as cognitive and behavioral symptoms due to neurodegenerative diseases, including Alzheimer's disease, dementia with Lewy bodies, and frontotemporal dementia. Associated symptoms significantly disrupt normal daily functioning at the point of a dementia diagnosis. In the preclinical (before overt symptoms) and prodromal (prior to full-blown disease) phases of ADRD, cognitive function declines in subtler ways and can signal impending cognitive decline. Cognition encompasses a host of domains such as memory, reasoning and judgment, attention, processing speed, language, and visuospatial function. Memory is the typical cognitive domain affected in the beginning stages of Alzheimer's disease, while other domains are affected in the early course of other dementia disorders. Neuropsychological testing is frequently used to assist in ADRD diagnosis, but is also used to measure cognitive development, health, and resilience.

While the major risk factors for ADRD are older age and genetics (e.g., apolipoprotein E genotype), modifiable lifestyle factors such as physical activity have been associated with reduced risk and delayed onset of ADRD, as well as symptom improvements after dementia onset (Alzheimer's Association, 2020). ADRD pathology starts in the brain decades prior to symptom onset, thus early and mid-life environmental exposures and lifestyle behaviors have the potential to reduce late-life ADRD risk (Irwin et al., 2018).

Few studies have yet to focus on whether nature contact is associated with ADRD. A rapid review identified 22 studies on greenspace and ADRD-related outcomes across the life course (Besser, 2021). Five studies investigated associations with ADRD diagnoses, finding both positive and inverse associations (Brown et al., 2018; Wu et al., 2015, 2017; Yuchi et al., 2020; Zhu et al., 2020). Nine of 15 studies of cognition found positive associations between greater greenspace and cognitive measures which included assessment of intelligence, childhood intellectual development, global cognition, working memory, spatial working memory, attention, visual attention, fluency, and reasoning.

Since that rapid review, a paper was published showing that greater residential greenness was associated with a lower dementia risk in older adults (Paul et al., 2020). In another systematic review, more than half of included studies (21 out of 36) found positive associations between nature experience interventions such as nature walks and improved cognition including working memory and attention (Mygind et al., 2019).

Overall, greenspace exposure in later life has been associated with reduced ADRD risk and better cognitive functioning in the relevant studies to date, but the evidence remains inconclusive. The direction of the association (protective, null, or harmful) was not consistent across studies and the potential causal mechanisms have not been elucidated.

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Pregnancy and Birth Outcomes

Pregnancy and infancy may represent moments of increased susceptibility to environmental influences, including nature contact. Beyond the most severe outcomes such as maternal or infant mortality, there can be long-lasting health implications of pregnancy complications such as new diagnoses of diabetes (gestational diabetes) or high blood pressure (preeclampsia), and birth outcomes such as preterm birth or low birth weight (National Academies of Sciences, Engineering, and Medicine, 2020). Low birth weight can be defined both in absolute terms and relative to the infant weight expected for the stage of pregnancy (low for gestational age). Risk of adverse pregnancy and birth outcomes can be increased in the context of environmental or psychosocial stressors, such as air pollution or racial discrimination. In addition, risk is affected by maternal age, substance use, infections, and other health conditions.

A systematic review and meta-analysis of 36 studies on residential greenness and pregnancy outcomes suggested that greater greenness exposure during pregnancy is associated with lower odds of low birth weight and small for gestational age (Zhan et al., 2020). A second review and meta-analysis of 37 studies found that residential greenness was associated with higher birthweight and lower odds of small for gestational age (Akaraci et al., 2020). The second review included five studies of proximity to blue spaces, finding associations with healthier birth weight and lower odds of gestational diabetes. Other studies in the review found no associations with birth outcomes. Findings from these two systematic reviews suggest that being surrounded by greater levels of residential greenness may be associated with healthier in-utero development and birth weight. However, the evidence is not uniformly supportive of a beneficial association and future work may refine our understanding of whether and how pregnancy and birth outcomes can be improved by NBS.

Other Health Outcomes

General literature reviews on natural environments and health have presented associations between green and blue space exposure and a multitude of health-related outcomes beyond those covered above, with evidence that is mixed at best and subject to many of the weaknesses noted above (Fong et al., 2018; Frumkin et al., 2017; Kabisch et al., 2017; Kolokotsa et al., 2020; Kondo et al., 2018; Schulz et al., 2018; Twohig-Bennett & Jones, 2018; van den Berg et al., 2015). A limitation of these broad reviews is that relevant papers may be missed, with the wide scope making a comprehensive search prohibitively time-consuming.

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Focused literature reviews are needed to adequately appraise specific types of nature exposures and health outcomes, and several such reviews extend our understanding to outcomes beyond those discussed above. Examples provided here include reviews of obesity, physical activity, blood pressure and other physiological markers (e.g., heart rate), and sleep quality and quantity. First, 55 percent of 57 reviewed studies found that greenspace exposure was associated with lower odds of overweight or obesity (Luo et al., 2020). Second, 25 percent of 20 studies found positive associations and 45 percent found inverse (detrimental) associations between park access and physical activity in a review restricted to studies of objective physical activity measurement (usually accelerometer or other device-based data collection) (Bancroft et al., 2015). In contrast, 95 percent of 19 studies observed positive associations between urban trees and physical activity in another review (Wolf et al., 2020). Third, time spent in the forest and greenspace exposure were associated with better physiological markers in multiple reviews (e.g., lower blood pressure, lower cortisol levels) (Antonelli et al., 2019; Ideno et al., 2017; Twohig-Bennett & Jones, 2018; Yau & Loke, 2020). Last, sleep quantity and quality were higher amongst individuals with greater greenspace exposure (Shin et al., 2020).

All in all, nature exposure may be associated with a wide variety of health outcomes outside of the major causes of death and morbidity. Before concluding our discussion of the evidence, we turn to two study designs that are of particular interest: intervention studies and health impact assessments (HIAs).

Intervention Studies

The bulk of the findings outlined above were based on observational studies, and we use this section to highlight the few studies that provide greater rigor through use of designs such as natural experiments and randomized control trials. While such designs are less common, the available literature reviews of experimental studies focused on the health impacts of natural interventions in indoor environments, blue spaces, and workplaces may be helpful for informing future NBS. As noted in Table 8.1, experimental designs such as these are less susceptible to confounding than observational studies.

A systematic review of 26 studies of indoor natural interventions (e.g., indoor gardens and horticulture programs) and sleep, general health, functional abilities, and other health outcomes such as cognition found weak evidence for associations (Yeo et al., 2020). In a systematic review of 33 blue space interventions, activities in blue spaces (e.g., swimming) were associated with mental health but fewer associations were observed with physical health (Britton et al., 2020). Workplace nature-based interventions (e.g., green office designs and green exercise programs) had weak or no associations with cognition and

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physiological markers (e.g., blood pressure) in a systematic review of nine studies (Gritzka et al., 2020). To date, the evidence for positive health impacts following nature-based interventions is limited but growing (Kabisch et al., 2021).

Health Impact Assessments

Development projects offer prime opportunities to examine population-level health impacts of NBS. HIAs are tools that evaluate how a development project may influence various aspects of health. HIAs use established standards, tools, and methods to bring together information on the likely impacts of projects, plans, and policies at varying degrees of detail (Hebert et al., 2012). The health considerations depend on the scope of the HIA, but often include social and environmental determinants of health such as crime, social capital, jobs and housing, air and water quality, and stressors such as noise and traffic. HIAs can be conducted retrospectively, simultaneously, or prospectively in relation to the implementation of the project/policy. Although HIAs are still used sparingly for planned/implemented development projects in the US, they have been used more frequently in places such as the United Kingdom. Examples of HIAs in the US (Table 8.3) are provided by organizations such as the Pew Charitable Trust and the World Health Organization (Pew Charitable Trusts, n.d.; World Health Organization, n.d.b).

Table 8.3 Example health impact assessments of NBS in the United States

Project, program, plan	**Location**	**Health outcomes anticipated/evaluated**
Green Streets program (tree planting) (Pew Charitable Trusts, 2017)	Lawrence, Massachusetts	Hospitalization Death rates Cardiovascular and respiratory health Obesity Healthy diet Cancer
Tampa EPA Brownfields Area-Wide Plan (new community garden and park) (Pew Charitable Trusts, 2018)	Tampa, Florida	Respiratory health Heat-related illness Physical health (e.g., physical activity, obesity, diabetes) Premature mortality
Eastside Greenway project (trail and greenway network) (Pew Charitable Trusts, 2015)	Cuyahoga County, Ohio	Transportation, physical activity, and safety

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As an example, a comprehensive HIA was conducted for the Beltline project in Atlanta, Georgia (https://beltline.org). The Beltline is an ambitious undertaking to convert unused freight rail lines into a 33-mile network of mixed-use trails, light rail, and 1,300 acres of parks. In addition to its large scope, the project is unusual in that one of its primary aims is to promote human health. The HIA was conducted in 2005 to assess how the proposed project would affect access and social equity, physical activity, safety, social capital, and health-related environmental factors (Ross et al., 2012). Centered on the residents living within a half-mile of the affected areas, the HIA appraisal involved a characterization and analysis of the affected communities and identification of the possible health impacts based on published scientific literature. Although the direct impacts to health from the addition of new parks and trails were primarily focused on physical activity, the HIA prospectively identified indirect impacts to health via increased social interactions and improved environmental functions (reduced stormwater runoff). The major identified concern for the parks and trails was providing equal access. The actual health benefits following full implementation of the Beltline have yet to be evaluated, but would be a fruitful avenue of research to help inform new NBS.

To date, the majority of HIAs on NBS were prospective in nature, projecting potential health impacts. Prospective HIAs have an important function in providing recommendations to guide action, but new retrospective HIAs or evaluation studies based on implemented NBS will be needed to contribute evidence for the health-promoting qualities of NBS.

SUMMARY OF EVIDENCE

In summary, the restricted number of published studies and low to moderate rigor of their study methods limit conclusions regarding the health impacts expected from NBS. We provide a qualitative summary of the weight of the evidence, which is based on the number of studies conducted, available evidence from systematic reviews and meta-analyses (i.e., reported strength of evidence), and the percentage of studies conducted that found associations (Figure 8.1).

The extant literature suggests moderate evidence for reductions in all-cause mortality, as well as low to moderate evidence for maintained or improved cognitive functioning, lower risk of cardiovascular and cerebrovascular disease, and poor pregnancy/birth outcomes (Figure 8.1). All other health outcomes have been infrequently studied, studied in only a few settings, or have shown minimal or mixed associations with nature exposure.

Continued publication of high-quality studies, even those with null and unexpected findings, will be important to provide a clear evidence base for future research synthesis, theory development, and for NBS planning and

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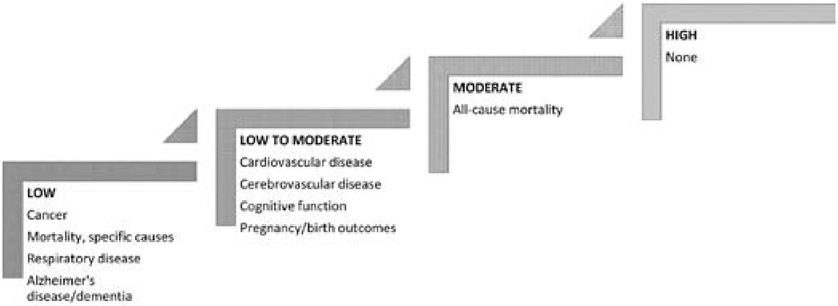

Figure 8.1 Qualitative summary of evidence for nature and health associations

evaluation. The vast majority of reviewed studies focused on greenspaces/greenness, and therefore the observed associations cannot be extrapolated to other indoor or outdoor natural environments or specific NBS (e.g., urban tree planting or nature preserves). Nonetheless, greenspace exposure has been positively associated with a wide range of health outcomes, suggesting that stronger evidence may emerge in the next decade if similar studies continue to be conducted at their current pace. With the need to continue adding to the evidence base in mind, we now turn to a discussion of the mechanisms posited to connect NBS and contact with nature to the range of health outcomes we have discussed.

MECHANISMS RELATING NATURE AND PHYSICAL HEALTH

Based on the emerging literature connecting NBS to health as discussed above, the influence of nature contact on physical health can be integrated visually in ways that may guide future research and practice. Elaboration or correction to these models may be needed as our understanding advances, and it will be important to continue to make apparent the assumptions underlying our interpretation and planning efforts.

TEMPORAL INFLUENCE OF NBS ON HEALTH

Figure 8.2 illustrates a model through which NBS may influence health over time. In the shorter term, NBS stands to increase awareness of and interactions with nature and wildlife. Contact with nature may replace time spent exposed to harmful traffic and noise, while fostering engagement in social and physical activities. The change in setting and experience can lead to alterations in stress,

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mood, fatigue, and preference, even as physical exposures and behaviors alter physiology. In the moderate term, NBS may contribute to building healthy habits and intentions such as regular physical activity, buffer against chronic and harmful physical exposures (e.g., inhaled, surface/contact, or noise), reduce the impact of psychosocial stressors and bolster perceived health, and improve physiological functions such as sleep, heart rate, and blood pressure. In the longer term, the continued influence of NBS may prevent or delay the onset of diagnosable chronic mental and physical health outcomes such as depression, obesity, diabetes, and hypertension, or NBS may ease management and recovery following such diagnoses. Chronic health states and conditions affected may include those with long latency periods, such as atherosclerotic cardiovascular and cerebrovascular disease, cancers, or Alzheimer's disease. By reducing risk factors, NBS may prevent or delay onset for serious disease and death, resulting in increased longevity and resilience against disease. Of note, in this model, attention is also needed to potential harms from NBS exposure, such as those due to vector-borne infectious disease exposure, allergen-related exacerbation of existing conditions (e.g., asthma), or injury.

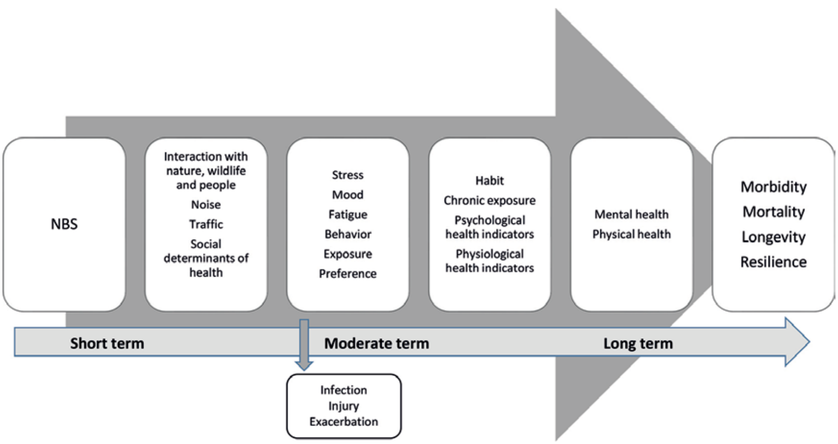

Figure 8.2 Model for temporal influence of NBS on health

NBS promotion or hindrance of the aforementioned exposures and health-promoting opportunities may affect numerous health outcomes, many of which were covered in the following section on "Nature-based solutions and mental health." Increased contact with nature may ultimately promote population health, as evidenced through mental and physical wellbeing, positive pregnancy and birth outcomes, and longer life expectancy. In addition, NBS may prevent physical and mental changes that increase vulnerability to disease

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and injury, whether through prevention, delayed onset, reduced symptoms, or improved outcomes such as more rapid recovery or higher probability of survival.

Figure 8.3 elaborates on Figure 8.2 to show the direction of influence on time use, resilience, and health outcomes. NBS are posited to increase time in natural settings and in associated activities, consequently decreasing time in settings where air pollution, noise, and other stressors are concentrated. Both the increased contact with nature and reduced harmful exposures advance more resilient physical and mental health through healthy lifestyle, functioning homeostatic systems, and psychosocial resources for responding to stressors. These benefits of shifting time toward natural settings accumulate to affect short- and long-term clinical health outcomes.

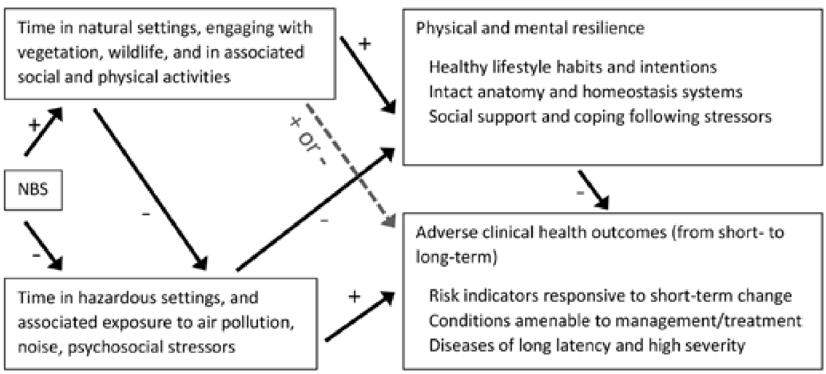

Figure 8.3 Model for direction of influence of NBS on time use, resilience, and health outcomes

Importantly, although it is generally presumed that NBS and nature exposure have positive effects on the whole, both models (Figures 8.2 and 8.3) shown allow for the possibility that contact with nature may have negative impacts for certain populations or circumstances. As an example, greater areas of tree coverage have been associated with reduced cardiorespiratory mortality. However, the evidence does not uniformly support a beneficial association between greater tree coverage and reductions in mortality (i.e., detrimental associations in some circumstances) (Donovan et al., 2013; Eisenman et al., 2020). Understanding intersecting pathways that together have a net positive or negative influence on health can inform environmental change strategies. For example, responding to the health evidence with a plan to maximize tree surface area (to optimize air quality benefits through particulate deposition) may be less appropriate than promoting visible and accessible greenspaces

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(relevant to pathways through human perception and behavior) and selecting a species mix with low allergen production (to limit unintended harms from NBS). Thus, continuing to learn about the mechanisms through which NBS affect health can (1) guide the design and implementation of future efforts to avoid harm and optimize benefits, (2) inform HIAs and engagement with stakeholders, and (3) ensure that evaluations are sensitive to the multiple ways that health could be affected by the NBS in question.

Factors Influencing the Effect of NBS on Health

The direction and extent to which NBS and resultant contact with nature are likely to impact human health will depend on multiple factors, including the type and qualities of the NBS (Figure 8.4). Park spaces may have different effects on health compared to NBS such as bioswales, green roofs, and private gardens. Greenspaces vary in their spatial extent, physical arrangement, density of vegetation, visibility, and accessibility, with implications for both physical exposures (e.g., air pollution) and engagement opportunities. Street plantings of large trees offering shade may be more likely to encourage neighborhood walking compared to plantings of shrubs and flowers. The salience of shade trees and thus the association of tree canopy with walking might vary. Street trees might support walking most strongly in selected conditions such as on warm days with minimal precipitation or in areas with other features to support walking (Lovasi et al., 2012).

The period, length, and mode of exposure to the NBS will also determine its influence on health. Although it is presently unclear how nature exposures accumulate throughout life to affect health, brief and infrequent encounters are presumably less likely to have long-term effects. Regular contact with nature during childhood may have significant early-life benefits to physical, cognitive, and motor development, which in turn could reduce risk for disease throughout the life course. The few available studies examining exposure to nature at various life stages have demonstrated associations with health over time (Cherrie et al., 2018; Pearce et al., 2016). While it is plausible that greater exposure to NBS over long periods of time will have a greater influence on health, relatively few long-term studies have been conducted, leaving gaps and uncertainty as to the validity of this supposition. The health impacts of the NBS exposure also may differ depending on the time of day of exposure and mode of exposure. If biophilia (natural affinity for nature) is an acting mechanism by which NBS exposure influences health, then walking in the park during the day will likely achieve more health benefits than nighttime walking. Similarly, walking or sitting in nature may provide more benefits than bicycling.

The association between NBS and health outcomes may depend on the characteristics of the individuals exposed and of their community. NBS

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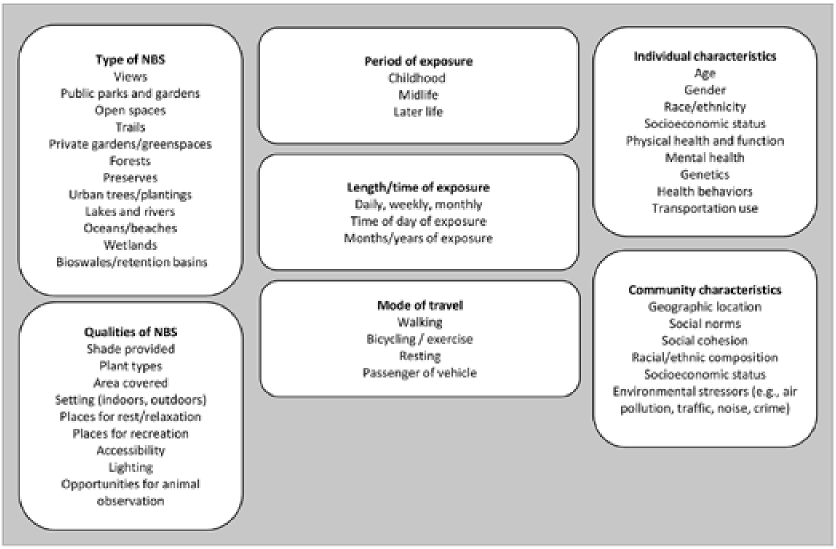

Figure 8.4 Factors that may affect the impact of nature exposure on health (effect modifiers)

will likely have different health consequences depending on population demographics and health status. The benefits of NBS to physical activity and social engagement may be enhanced for children and older adults compared to working-age adults who have limited time to spend in nature. Park spaces may have a greater effect on physical activity levels for individuals of lower socioeconomic status because they have limited or no access to commercial exercise facilities. Alternatively, parks may have an attenuated effect on physical activity in low-income or otherwise marginalized settings because of associated safety concerns (Weiss et al., 2011). NBS may be more likely to benefit individuals without functional limitations, unless accessibility and awareness for populations with health-related mobility limitations are specifically addressed. The characteristics of the underlying population of the target area of interest should be considered when evaluating the potential health benefits of an NBS. In addition, engagement with NBS will depend on human perceptions to activate behaviors like physical activity or processes like stress recovery. For instance, in the context where NBS is understood as part of a broader gentrification process (e.g., negatively impacting housing affordability (Anguelovski, 2016)), individuals may experience fewer stress recovery and lifestyle benefits or even unintended harm. Similar to the potential differences in health impacts by individual-level characteristics, the impacts from

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a NBS may vary depending on the characteristics of the community (e.g., social norms and socioeconomic status).

The specific qualities of the NBS and of the affected individuals and communities may amplify or attenuate the health impact of contact with nature. Examining these differential patterns may strengthen the evidence for specific causal pathways. For example, place-based stressors may have a greater effect on health outcomes among individuals with stress-pathway genetic susceptibility (Dick, 2011; Mooney et al., 2016). While prior work has considered area-based socioeconomic conditions, a parallel finding for a stress pathway gene–environment interaction with NBS would support the importance of NBS in removing or allowing recovery from stressors. Attention to such effect modification (i.e., differences in the strength or direction of association across exposure qualities, settings, or groups) can help identify where and how NBS can be deployed in order to maximize health benefits.

CONCLUSION

The scientific literature offers only modest support for the health-promoting benefits of NBS, although the evidence is still accumulating. Rigorous observational studies, natural experiments, and evaluation studies of NBS implementations are necessary to strengthen confidence in the positive associations observed thus far. As such, NBS plans and implementations should remain cautious regarding presumed positive impacts to human health, even as the broader array of ecosystem services is kept in mind. It is hoped that future studies will affirm the health benefits that are biologically plausible and that have been evidenced in a moderate number of published studies to date. Further, attention to the mechanisms through which NBS and contact with nature may affect health will inform HIAs and planning in ways that support continued progress toward understanding and acting upon the determinants of population health.

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9. Nature-based solutions and mental health

Nadja Kabisch, Sukanya Basu, Matilda van den Bosch, Gregory N. Bratman, and Oskar Masztalerz

MENTAL HEALTH IN CITIES

Poor mental health is a global pandemic affecting people of all ages. For instance, more than 280 million people worldwide suffer from depression as a mental disorder (WHO, 2023). Mental disorders further include anxiety, bipolar disorder, psychotic disorders, dementia, developmental disorders and other diseases. Beyond substantial suffering of the affected individuals, friends and family members, mental illness generates enormous social and economic costs (Trautmann et al., 2016). Poor mental health stresses health-care systems and adds additional pressures as mental diseases can increase the risk for a number of physical illnesses such as cardiovascular disease (Alvarenga and Byrne, 2016).

The urgency and severity of the global mental health crisis point to the need for innovative and holistic approaches that promote mental health and prevent mental disease. Following the definition of the World Health Organization (WHO), mental health includes far more than the mere absence of disease (see Box 9.1 for an overview of the WHO definition of mental health and its determinants). Remarkably, it involves aspects of self-actualization, mental resilience and social connectedness, all of which are acknowledged in this chapter. Yet the importance of mental illness is not disregarded.

BOX 9.1 DEFINITION OF MENTAL HEALTH AND DETERMINANTS OF MENTAL HEALTH

- A 'state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work produc-

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tively and fruitfully, and is able to make a contribution to his or her community'.
- Includes 'subjective well-being, perceived self-efficacy, autonomy, competence, intergenerational dependence, and self-actualization of one's intellectual and emotional potential, among others'.
- The 'promotion, protection and restoration of mental health can be regarded as a vital concern of individuals, communities and societies throughout the world'.
- 'Multiple social, psychological, and biological factors determine the level of mental health of a person at any point of time'.

Source: WHO (2018).

The aetiology of mental disorders is complex and only partly understood. It is known that interactions between internal and external factors such as genetic predisposition, social conditions, lifestyle and environmental exposures determine the risk of developing mental disease (Van Den Bosch and Meyer-Lindenberg, 2019). The interplay of these factors varies depending on population, context and setting. For example, recent research has found that depression and schizophrenia are more common in cities than in rural areas (Lederbogen et al., 2013; Reichert et al., 2020). While city living is associated with a number of benefits, urban areas can also be demanding and stressful (Tonne et al., 2021). Cities are often characterized by spatial divides and social disparities (Dye, 2008). Paradoxically, dense cities also tend to have fragmented social networks, which can be associated with a poor sense of community (Gruebner et al., 2017) and in turn may decrease mental resilience.

Other reasons for poor mental health in cities is the increased occurrence of environmental stressors (Bilotta et al., 2018). High levels of motorized traffic lead to air pollution and noise. Their negative effects on physical health have been demonstrated in the past, but recent research adds evidence for adverse influences also on mental health and well-being (Van Den Bosch and Meyer-Lindenberg, 2019). Among the many different types of pollutants, particular matter smaller than 2.5 µm ($PM_{2.5}$) seems to be especially harmful because it includes ultrafine particles that can enter the circulation and reach the brain (Rajagopalan et al., 2018). Exposure to high levels of $PM_{2.5}$ has been associated with significantly increased levels of anxiety, depression and suicide in a number of studies (Power et al., 2015). The presence of social stress may further intensify the association of air pollution and negative mental health outcomes (Olvera Alvarez et al., 2018). Noise can result in annoyance and other negative feelings which can induce psychophysiological stress reactions (Waye et al., 2002). Finally, people suffering from mental disorders may be less resilient to heat exposure and comorbidities of mental and physical

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diseases are common, all of which makes those persons particularly vulnerable to environmental change (Hancock and Vasmatzidis, 2003; Kabisch et al., 2021a). It is also important to note the aspects of mental health that are related to psychological and emotional well-being, flourishing and eudaimonic happiness – as the WHO definition highlights (see Box 9.1) – and the ways in which factors in urban life may contribute to (or detrimentally impact) these outcomes as well (Bratman et al., 2021).

Natural environments in cities can contribute to solutions to some urban mental health challenges. A large body of evidence demonstrates the mental health benefits that exist for adults from access and exposure to urban nature, including reduced risks of depression and schizophrenia (Van Den Bosch and Meyer-Lindenberg, 2019). Interactions with nature also reduce the risk of cognitive and developmental disorders among children and adolescents, such as Attention Deficit Hyperactivity Disorder. However, the presence of natural environments in cities may be generally scarce and their accessibility is often unequally distributed, all of which may increase vulnerability in disadvantaged populations. It has been shown that low exposure to natural environments may result in disconnection from nature with negative effects on mental health (Chawla, 2015). Further, a number of studies demonstrate that without daily access to nature, children are at higher risk of cognitive and developmental disorders (Amoly et al., 2015; Chawla, 2015; Dadvand et al., 2015; Zijlema et al., 2017). To improve evaluation and appreciation of the mental health benefits of nature experience, efforts are growing to incorporate them into ecosystem service assessments (Bratman et al., 2019).

NATURE-BASED SOLUTIONS AND MENTAL HEALTH

Actions that specifically protect, manage and restore natural ecosystems, use their provided services to address societal and ecological challenges and simultaneously provide benefits for biodiversity and human well-being are called nature-based solutions (NBS) (Cohen-Chacham et al., 2016). NBS include newly planned and implemented green infrastructure elements that specifically aim at coping with challenges such as climate change, water scarcity and food insecurity. At the same time, pre-existing green spaces such as long-standing parks and cemeteries may also qualify as NBS if the criteria are being met that the provided natural elements help in protecting ecosystems and support coping with societal challenges. In the following section we introduce models that link natural elements with mental health and describe pathways through which NBS may help to resolve the urban mental health crises – which may be regarded as a societal challenge. Acknowledging the holistic definition of mental health provided by the WHO, in this chapter, NBS for mental

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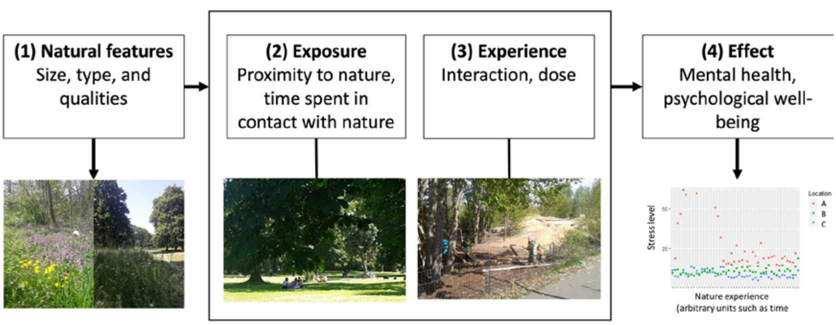
health are not limited to the reduction of disease, but include the support of self-actualization, mental resilience and social connectedness.

Models Linking Nature-Based Solutions and Mental Health

Potential mechanisms and pathways behind the positive mental health effects of natural environments are shown by the conceptual framework developed by Bratman et al. (2019). This provides a broad structure of a potential template with which the mental health benefits of nature contact might be considered, in support of efforts to put this science into practice (Figure 9.1) (Bratman et al., 2019). These include four main steps: the first is to characterize the nature itself, from species composition to vegetation structure and spatial configuration. These environmental attributes will affect the impacts of these elements on mental health, and will also influence the second step: opportunity for nature exposure. Here, residential proximity, accessibility (which is influenced by physical and social components of the environment), safety and quality of green space, and sociodemographic and cultural characteristics will influence the degree to which individuals are exposed to nature. With the third step comes a consideration of the experience of the nature interaction itself, which is open to a variety of perspectives and approaches, including a characterization of human–nature interaction (Kahn et al., 2010), or the use of exposure science metrics that often frame exposure in terms of 'dose' (Frumkin et al., 2017). Last, as more evidence is gathered regarding causal pathways and moderators (on the level of the environment and the individual), insight will grow into the ways in which steps 1–3 lead to relevant effects (step 4) that have repercussions for mental health and well-being, and the ways that these



Source: Adapted from Bratman et al. (2019); photographs by Nadja Kabisch.

Figure 9.1 *A conceptual model providing a template for the analysis of mental health benefits of nature contact along four main steps*

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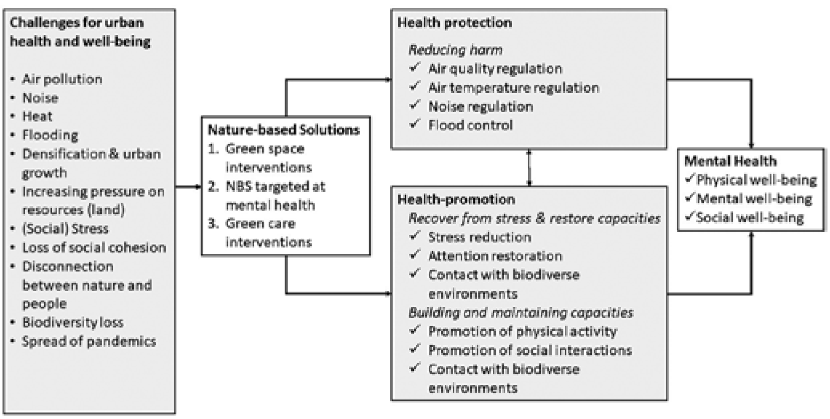
effects differ across individuals and populations depending on environmental and sociocultural contexts.
In line with the considerations of the Bratman model, Markevych et al. (2017) and Marselle et al. (2021) discuss major pathways linking green spaces and biodiversity to human health in general: reducing harm, restoring capacities and building capacities. Marselle et al. (2021) expand on a dimension describing potential adverse effects of biodiversity on human health. In the following, we apply these overarching pathways to the interactions of NBS and urban mental health by discussing three main hypotheses.

First, green spaces are NBS for many urgent challenges and provide co-benefits for mental health by reducing environmental stressors. Second, NBS can directly support mental health by providing resources for human–nature interaction and mental resilience. And third, NBS that are intended to support the treatment of psychiatric disorders (also called nature-based interventions) may provide advice for urban design and unfold beneficial effects for coping with societal and environmental challenges beyond the treatment of mental disease. Based on Markevych et al. (2017), Figure 9.2 also provides an overview of pathways on NBS targeted at mental health and green care interventions in their response to global challenges to mental health outcomes.



Source: Adapted from Markevych et al. (2017).

Figure 9.2 Nature-based solutions targeted at mental health and green care interventions to respond to global challenges to mental health outcomes

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Co-Benefits of Green Spaces for Mental Health

Green spaces can act as NBS as they generally address a broad range of socio-ecological challenges such as urbanization, environmental change and, in some circumstances, health inequities, through the delivery of various ecosystem services, i.e. the benefits people derive from nature (MEA, 2005). At the same time, they may contribute to reduced psychiatric morbidity. Several studies have delivered evidence for an association between access and exposure to green spaces and mental disorders: Engemann et al. (2019) examined associations between growing up surrounded by different environments and the rates of psychiatric disorders such as mood, depressive and stress-related disorders across Denmark. They found a reduced mental morbidity among people who grew up surrounded by higher shares of near-natural green spaces, particularly with high vegetation densities, compared to built-up environments. Maas et al. (2009) examined large-scale representative medical record data in the Netherlands and found reductions in the annual prevalence rates of depression and anxiety disorder related to an increasing proportion of green spaces in people's living environments. The associations were strongest among children and people of lower socioeconomic status, indicating particular benefits of green spaces for vulnerable populations. In a study from the United Kingdom, Sarkar et al. (2018) found that increases in residential greenness were associated with lower odds of major depressive disorder. The relationship was found to be particularly strong for women, participants younger than 60 years and participants residing in deprived or very dense neighbourhoods.

The reasons for these associations are not entirely elucidated, but several pathways have been suggested. The regulation of harmful exposures such as air pollution, air temperature and noise may play a role in prevalence reduction of mental disorders, following the models of Markevych et al. (2017) and Marselle et al. (2021) that we described above. If green spaces are properly planned in a NBS context, they can reduce ambient air pollution (Nowak et al., 2018), and since there is evidence that air pollution increases the risk of mental disorders (Van Den Bosch and Meyer-Lindenberg, 2019), it is plausible that green spaces hence reduce this risk. A study by Klompmaker et al. (2019) supports this hypothetical pathway.

This study also suggested that the noise-reducing impact of green spaces may be part of the explanation. Exposure to high noise levels has consistently been associated with increased risk of mental disorders (Klompmaker et al., 2019), thus noise reduction may be an important method for preventing mental morbidity.

Another example for how green spaces can reduce harmful environmental stressors is the regulation of the ambient air temperature. For instance, Basu et al. (2018) found that warmer temperatures in California increase the risk of

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emergency room visits for mental health disorders in both the warm and cold seasons.

Beyond ecosystem services that regulate the aforementioned stressors, NBS in the form of green spaces may provide safeguarding and improvement of biodiversity. This again may strengthen mental health. Marselle et al. (2019) delivered a comprehensive review of the mental health effects of biodiversity and concluded that there is evidence suggesting that biodiverse natural environments may be associated with improved mental health. Nevertheless, they emphasize that the data situation is still too insufficient to be conclusive and the evaluation of the role of biodiversity poses several methodological challenges to be dealt with in the future.

Nature-Based Solutions Targeted at Mental Health

As described above, poor mental health is strongly intertwined with several socioecological challenges. It has been associated with vulnerability to physical illnesses (such as cardiovascular diseases) that are further impacted by environmental factors such as increased heat stress and air pollution. These challenges may be directly addressed by NBS through a suite of salutogenic measures that promote mental health and well-being. This can happen through direct human–nature interaction, such as park or forest visits, by enhancing the recovery of mental resources that are strained by psychological stressors in urban areas. Kabisch et al. (2021b) found the highest restoration experience of their participants after exposure to a long-standing urban park with widespread and old trees compared to a highly artificial urban environment. They additionally found a positive correlation between restoration experience and the perceived level of naturalness in the respective environments. Another study by Gidlow et al. (2016) showed greater restoration experiences after exposure to green compared to urban environments. Furthermore, NBS such as the implementation and protection of parks and forests may improve mood and mental resilience and thus lower vulnerability to mental stress and disorders. Lee et al. (2011) demonstrated that the exposure to forest environments significantly increased positive feelings and decreased negative feelings compared with urban exposure. Chen et al. (2018) found that negative mood states and anxiety levels were significantly reduced and positive mood states were improved after visiting forests. Hartig et al. (2003) showed that positive affect increased and anger decreased after a walk in a nature reserve while walking in an urban environment resulted in the opposite pattern. Finally, Bratman et al. (2015a, 2015b) found that nature versus urban walks provided affective benefits and reduced rumination.

These restorative effects of contact with nature might be explained by the Stress Reduction Theory (see Box 9.2 for explanation). Additionally, it is plau-

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sible that strong mental resources may help people to generally cope with environmental change and its adverse health effects. Altogether, including mental health promotion in the set of objectives of NBS may unfold co-benefits for coping with environmental change, urbanization and social inequality and synergistic effects could evolve.

BOX 9.2 MAIN FEATURES OF STRESS REDUCTION THEORY AND ATTENTION RESTORATION THEORY

- Stress Reduction Theory postulates that improved health and well-being is the result of contact with restorative natural environments that stimulate stress recovery from the impacts of everyday life through parasympathetic nervous system activation (Ulrich et al., 1991).
- In Attention Restoration Theory certain (green) environments support restoration from mental fatigue caused by everyday life (e.g. through directed attention at work) (Kaplan, 1995). These particular environments help to relieve the overloaded individual through experiencing a sense of being away, coherence, fascination and compatibility in a specific environment. Green, natural environments may afford experiencing these restorative qualities (Marselle, 2019).

Nature-Based Interventions and Mental Health

Nature-based interventions, also referred to as Green Care, is an umbrella term for describing specific therapies and treatments that use natural elements to improve health and well-being (Annerstedt and Währborg, 2011). These therapies address for example psychiatric diseases and apply therapeutic settings and activities close to nature in the treatment of patients, e.g. by prescribed green exercise, prescribed group walks, horticultural therapies, care farming or animal-assisted therapies (Cook et al., 2019). By treating persons with mental diseases, nature-based interventions directly address mental health crises and hence can be considered NBS. Furthermore, lessons beyond the treatment of psychiatric disease can be learned from nature-based interventions, e.g. about mentally supportive city design.

Vujcic et al. (2017) performed a cohort study in which randomly selected psychiatric patients completed a special programme of horticulture therapy in the botanical garden of Belgrade, Serbia. Psychological assessments were conducted before and after the intervention and the outcome was compared to a control group. The research team found a significant reduction of stress in

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patients following the horticulture therapy. Pálsdóttir et al. (2018) identified qualities of natural environments that support the rehabilitation of persons with stress-related mental disorders. They examined the process of nature-based rehabilitation in a specially designed garden in Sweden and found several characteristics defining a mentally supportive environment. For example, the properties *Being away*, *Extent*, *Fascination* and *Compatibility* from Kaplan's Attention Restoration Theory were confirmed to be important aspects (see Box 9.2). Furthermore, the perceived sensory dimensions *Serene*, *Nature*, *Prospect*, *Refuge* and *Space* were identified in the therapeutic environment.

Green space characteristics such as size (therapeutic garden of 5 ha), the availability of secluded sites and escape routes and many trees were emphasized to be vital to promote restoration from fatigue and stress (Jiang et al., 2016; Pálsdóttir et al., 2018; Stoltz et al., 2016). García-Llorente et al. (2018) describe a multitude of green care interventions and discuss their potential to reconnect people with nature. They name, for example, outdoor activities including forest walks and green exercise, nature exposure, contemplation, relaxation, observing animals and plants, horticulture, gardening and agricultural activities. Those activities may be carried out by city dwellers in urban forests, parks and spaces of urban agriculture (which also plays an increasing role for urban food production and security). At the same time the authors stress that most of the existing green care studies only evaluate the direct therapeutic effects of the interventions rather than including co-benefits beyond mental health – studies assessing the relevance of green care in socioeconomic and environmental terms are identified as a future research topic.

Additionally, evidence from existing and future green care and nature-based intervention studies about mentally supportive environments may be translated into city planning to deliver urban and green space design directives that support people suffering from mental illness and prevent mental disease in general. A focus could be on the rising number of elderly people with dementia, as proposed by Andreucci et al. (2019). In addition, green care interventions may have direct beneficial ecological effects while also contributing to the promotion of sustainable lifestyles.

CASE STUDIES FROM THE GLOBAL NORTH AND SOUTH ON DIFFERENT SCALES

In the following section, two case studies are presented as exemplary applications of the conceptual model by Bratman et al. (2019). As a model always reduces complexity, the examples only relate to a subset of possible environmental factors and pathways that were described in the sections above. The first case study describes a newly developed park on a former brownfield site in a dense urban environment in the city of Leipzig, Germany, and the

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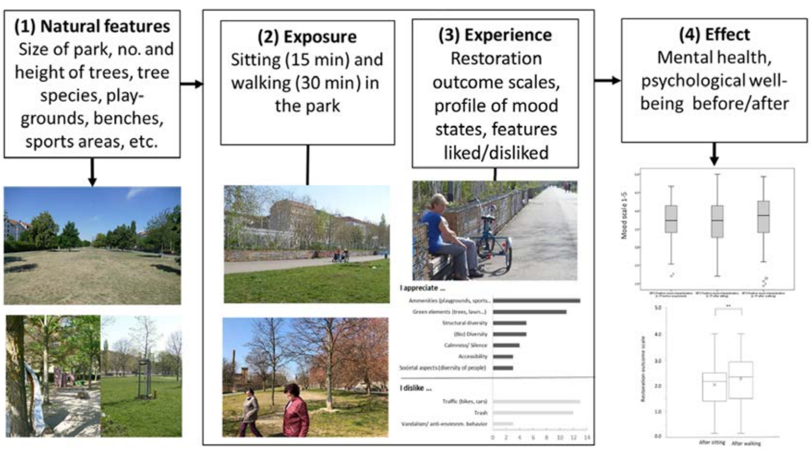
second case study works on impacts of urban nature and particularly trees in Hyderabad, India, which is faced by rapid urbanization and loss of green space.

Mental Health Impacts of a Park Regeneration Project in Leipzig

The Lene-Voigt-Park is a new park that has been developed on a former railway brownfield site and was opened for public use in 2004. It is part of the urban regeneration strategy 'Park-Bogen-Ost' in the city of Leipzig that is located in the eastern part of Germany (Figure 9.3). The aim of the regeneration strategy is to revitalize the local districts and neighbourhoods characterized by high population and building density and low green infrastructure, to create a green 'fresh air' corridor with several bicycle lanes connected to the city's cycling network, pedestrian routes, creative playgrounds, sports areas and urban gardening spaces along the former railway line. The redevelopment of the Lene-Voigt-Park can be regarded as a NBS, because it was meant to improve the environmental conditions (low air quality, intensive urban heat island effect due to a high percentage of built-up space) in the eastern part of Leipzig (Kabisch, 2019). At the same time, there are multiple benefits for human health and well-being.



Source: Adapted from Bratman et al. (2019); photographs by Nadja Kabisch.

Figure 9.3 Application example of the conceptual model by Bratman et al.: mental health impacts of visitation patterns to an inner-city built-up park on a former brownfield site in Leipzig, Germany

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A recent research project by Kabisch et al. (2021b) aimed to determine the mental and physical health effects of different urban green environments. One of the examined parks was the Lene-Voigt-Park in Leipzig. Applying the conceptual model by Bratman et al. (2019), in *Step 1 (natural features)*, information on park vegetation and infrastructure characteristics was collected and spatially mapped. This included the size of the park, number and height of trees, tree species, playgrounds, sports activity areas, urban gardening sites, benches, waste bins, etc. A multifunctional park was identified that mainly consists of lawns, a number of newly planted trees, paved trails, several playgrounds and sports facilities such as a table tennis area, a basketball court and four beach-volleyball fields. For *Step 2 (quantifying exposure)*, a sample of 33 older people was exposed to different urban green environments including the Lene-Voigt-Park. Participants were asked to sit and to walk for a specified amount of time in the park. They were asked to choose their seating location and walking route for themselves to simulate a realistic park visit. For *Step 3 (experience)*, the restoration experience was measured using the restoration outcome scale as an instrument. The values provided through the restoration outcome scale significantly increased with longer exposure time (Figure 9.3). When the participants were asked to describe which aspects they appreciated in the Lene-Voigt-Park, they mentioned the different built amenities such as the playgrounds and sports areas, but also referred to the different green elements and the overall high diversity of structures in the park. Some of the participants, however, also complained about the high traffic of bikes and the cars around the park as well as trash and vandalism on the site. These could be regarded as usage barriers for some residents. In terms of recommendations for urban planning and decision making, potential usage barriers may be considered in future park planning and maintenance (Hunter et al., 2019). This would also include adapting to local contexts and demands, e.g. the installation of sufficient lighting, sanitary infrastructure and drinking fountains which are particularly demanded by older people, women and families with children (Kabisch et al., 2021a). Finally, for *Step 4 (effects)*, mental and cardiovascular health effects were examined through well-being assessment scales and measuring physiological stress parameters such as blood pressure and heart rate variability (see Kabisch et al., 2021b for a full description of the study).

Urban Nature as Stress-Reducing Space: the Case of Hyderabad, India

Hyderabad is the sixth largest metropolis located in Telangana, a southern state in India. The city is situated in a part of the Krishna river basin, the Musi sub-basin. Hyderabad falls in a tropical savannah zone with an annual mean temperature of 26.6°C and low rainfall. The city has faced a rapid decline in green cover in the last 20 years from 2.71 to 1.66 per cent (Ramachandra et

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al., 2015), hence various initiatives and policies are considered to increase it. In the age of accelerated urbanization and drastic reduction of greenery, proximity to green space or wooded area is considered an important value for the people living in the city. The interaction with natural elements is a crucial influence factor on spiritual well-being (Irvine et al., 2019). In the following, exemplary results from interviews with adult park users, children park users and street vendors in Hyderabad are presented that highlight the value of experiencing nature in the city as a stress-releasing space (Basu and Nagendra, 2021). In this example, the particular importance of trees as NBS for mental health is demonstrated.

By applying the conceptual model by Bratman et al. (2019; see Figure 9.4), in *Step 1 (natural features)*, information on characteristics of four major parks and street trees was mapped and collected. This included size of the parks, species present (native versus introduced) as well as height, girth and canopy sizes of street trees in various neighbourhoods and biodiversity present within. In *Step 2 (understanding exposure)*, park visitors and street vendors formed the sample of the study. Long-term park visitors, frequent visitors, irregular visitors and vendors with and without access to tree shade were interviewed. For *Step 3 (experience)*, activities like walking barefoot on the grass and listening to birds chirping may stimulate good feelings (Ratcliffe et al., 2013; Riters, 2011). People in the parks of Hyderabad were found to express their state of feeling as a sense of 'calmness', 'meditative', 'solitude' and 'blissful'. Particularly information technology employees consider that the time spent in the park for a tea break is the best time of their day, because the fresh air and tree shade fade away their stress, leaving a sense of calmness which boosts their energy to work again. Street vendors with tree shade are found to be much happier than vendors without. After spending long working hours outdoors, trees become a sense of 'home' and 'sukoon' which holds a very deep emotional connection and sense of belongingness. Strollers in the parks find walking in green spaces therapeutic and anxiety-reducing. A middle-aged couple feels reluctant to wake up and spend time in an air-conditioned gym: 'We spend 9 am–8 pm in an air-conditioned closed office environment, we never felt like adding 2 more hours in a gym which is the similar environment.' But a park motivated them to exercise daily and spend some time in an open environment. While trees have direct impacts on the majority of the wealthy residents, the cultural beliefs and traditional uses of trees also indirectly influence the psychological well-being of socioeconomically disadvantaged city dwellers. Historically, the livelihoods of these people are intertwined with trees. Basu and Nagendra (2021) found that centuries-old trees that are present in the streets and parks of the old city of Hyderabad act as keystone species with a high population of urban wildlife. And they are also considered to be sacred. Many fruit vendors start their day by offering fruit to the tree under which they spend their whole

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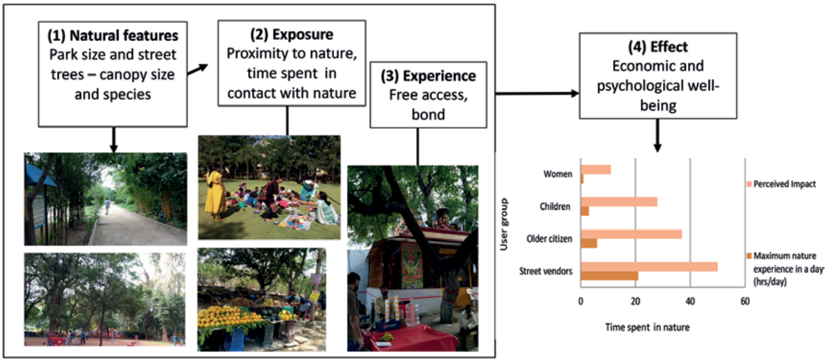
day, which is also shared by many birds, ants and even monkeys on some days. This offering is locally called *bohoni*.



Source: Adapted from Bratman et al. (2019); photographs by Sukanya Basu.

Figure 9.4 *Application example of conceptual model by Bratman et al.: stress-releasing impacts of urban nature in Hyderabad, India*

Finally, for *Step 4 (effects)*, the time spent in nature has various economic and psychological well-being benefits and has stress-releasing impacts on various user groups. Trees were found to stimulate nostalgia as a common feeling among city dwellers, especially in the older group, as interview results show. A huge mango tree in Indira Park in Hyderabad triggered childhood memories in many older citizens. A group of seven retired men became friends by reminiscing over the old days. Now their 5 pm–8 pm time spent together under this tree is their 'time of escape'. Therefore, trees not only stimulate memories but also promote socializing which may have a significantly positive impact on their mental well-being.

In terms of safety, interview results showed that lack of safety is a major reason for stress, especially among women. Parks may enhance social interactions, provide a 'sense of safety' and reduce anxiety. Park workers and street vendors with access to the wooded area find their work very satisfying, peaceful and physically secure. Female labourers often have to take their children to work and as they find their work in the construction sites life threatening, they rather choose to work in the parks for the safety and health of both themselves and their children: 'If we know our children are safe, we can work peacefully.' According to many street vendors, trees are the determining factor for selecting their work location to have a better workspace.

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Many parents in the parks indicated the need to have green spaces for the overall development of their children. They find spending time outdoors in green spaces decreases their children's time spent on electronic gadgets: 'Our child has developed its interest in painting after we started coming to the park every evening. Nature helps to enhance her imaginations.' Through the interaction with children during the research process, the research team found that they tend to develop a fondness for gardening as well as birds and animals. They expressed their engagement with gardening or animals as 'exciting', 'interesting', 'makes me happy' and 'fun'.

The street vendors sitting under a tree for several years symbolize trees as their protector and parental figure. Responses like 'My father used to sell fruits sitting under this same tree, I can strongly feel his presence even today' (58-year-old man) provide critical insights on the intricate bond in human–tree relationships. *Ficus religiosa*, also known as sacred fig, are canopy trees vital for hot climatic conditions and have the highest religious significance among most city dwellers. Earlier in history, forests provided a venue for several traditional events and as the forests shrunk in size, old trees in the streets and parks became highly valued. These trees facilitate many cultural events, are associated as sacred areas and also promote cultural values and morals that are passed on to newer generations in many communities.

Also, low-income groups depend on various parts of trees for treating common diseases, which reduces the stress of paying for medical treatment. For example, *Azadirachta indica*, commonly known as Neem tree, is widely used for medical purposes: twigs, barks, leaves, fruits – all parts of the trees are utilized for various purposes. Worship is an important feature for many vendors and park workers. From interactions with park workers and street vendors, we found that certain trees in the parks are perceived as providers, often called *annam-daata*. They believe that the well-being of their livelihood is linked to the blessings provided by certain trees. The findings of the study in Hyderabad emphasize the importance of non-material benefits or cultural ecosystem services obtained from nature for human well-being. Overall, these services have gained scientific attention in recent years (Ament et al., 2017; Kosanic and Petzold, 2020; Plieninger et al., 2015; Schaich et al., 2010).

CONCLUDING REMARKS AND TAKE-HOME MESSAGES

The two case studies from Germany and India impressively illustrate how NBS can improve mental health in quantitative and qualitative ways, including the prevention and treatment of mental disease, but also far beyond this. In this chapter we demonstrated that green spaces can be considered NBS for many urgent societal challenges and provide co-benefits for mental health

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by reducing environmental stressors. Additionally, NBS may target directly supporting mental health by providing resources for human–nature interaction and spiritual identification, enhancing social interaction and connectedness and strengthening mental resilience. Last but not least, lessons learned from nature-based interventions that are originally intended to support persons with psychiatric illness may provide counsel for the design of mentally supportive cities, parks and landscapes.

Access to nature provides important benefits for mental health, via multiple pathways, and with critical repercussions for many individual and social outcomes (Sangha et al., 2018). On the global scale, as an ever-increasing proportion of humanity moves to cities, with an associated decrease in contact with nature, it is important to account for what the effects of this changed experience entail for mental health. These impacts include a growing deprivation of the benefits that nature contact provides, as well as the independent pathway of increased risk for the onset of disease to which certain urban factors contribute. These impacts should be taken into account in urban planning efforts and decision-making contexts and in critical efforts to address health inequities (Jennings and Gaither, 2015). This includes working to rectify the effects of prior practices and planning decisions that have resulted in inequitable distribution of nature access within urban environments (Nardone et al., 2021) and directly addressing discrimination that can occur in natural spaces as well (Hoover and Lim, 2020; Silva et al., 2018). NBS have great potential to support urban mental health, and future interdisciplinary research and city planning may further support science on the topic and contribute to putting science into practice.

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PART IV

Nature-based solutions governance, planning, and value

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10. Planning and maintaining nature-based solutions: lessons for foresight and sustainable care from Berlin, Jakarta, Melbourne, and Santiago de Chile

Rieke Hansen, Judy Bush, Didit Okta Pribadi, and Emanuel Giannotti

INTRODUCTION

Nature-based solutions (NBS) in cities raise hopes that urban green spaces will be planned and designed with ecological aspects at heart, fostering natural processes for water management or temperature regulation while benefiting both human well-being and biodiversity (Maller 2021; Raymond et al. 2017). However, NBS that often receive media attention and are promoted in political contexts include complex plantings on facades or rooftops requiring intensive care, water supply, and resources such as concrete, steel, and geotextiles. For example, the recently proclaimed largest green facade in Europe on the Kö-Bogen II commercial building in Düsseldorf consists of 8 km of hornbeam hedges in metal planters with automatic irrigation and fertilization as well as regular pruning to maintain geometric shape and size (Kraft 2020). Urban greening that has already reached the intended size when planted undermines fundamental ecological processes such as plant growth. In general, biogeochemical cycles that sustain ecosystem services are often neglected (i.e. carbon sequestration in soils), and plantings with low diversity of functional traits provide limited support for urban biodiversity (Brunbjerg et al. 2018; O'Riordan et al. 2021; Parris et al. 2018; Ziter 2016).

Certainly, high-tech greening solutions provide more ecosystem services compared to urban areas with no greening, but the benefits might be overstated and even distract from causes that need to be tackled such as CO_2 or particulate matter emissions (Keeler et al. 2019; Pataki et al. 2021). With current greenhouse gas emission levels, all trees within a city likely contribute less than

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0.5 percent to climate change mitigation via carbon sequestration (Baró et al. 2014; Tang et al. 2016). It might take 26–33 years until trees reach the point of carbon neutrality and can be considered as carbon sinks (Petri et al. 2016). Moreover, the provision of ecosystem services often increases with age. Older trees provide a significantly higher amount of ecosystem services, yet urban trees are affected by high mortality rates (Rötzer et al. 2019). Thus, NBS need to be planned having the full life-cycle and required resource input in mind. Careful design and maintenance of NBS can enhance ecosystem service provision and influence sustainability. For example, maintenance intensity of green spaces and related energy use has a significant impact on the carbon footprint of these sites (Strohbach et al. 2012). Lawns represent the prime example of green elements that are often unsustainable. From an ecological perspective, lawns in their high-maintenance version, which can be found in almost any region of the world, are referred to as "green deserts" that consume ample resources yet have little habitat value (Ignatieva and Ahrné 2013). In contrast, alternatives adapted to the local climate and/or representing local biotopes, such as steppe or prairie vegetation, require fewer resources and contribute to biodiversity habitat (Ignatieva et al. 2020). The question of whether urban green space can be considered as NBS is thus very much a question of planning with natural processes and adapting to the local context.

The effects of climate change are putting increasing pressure on urban greening, reducing its ability to address urban challenges, and act as NBS. Droughts and consequently lack of access to water prevent urban vegetation from performing the intended cooling function via transpiration, or carbon sequestration via biomass growth (Gillner et al. 2014; Stratópoulos et al. 2019). Urban densification leads to additional pressure on green infrastructure by reducing available space and increased use intensities (Burgin et al. 2014; Daniel et al. 2016; Haaland and van den Bosch 2015). Green infrastructure is often not equally distributed within cities and deprived neighborhoods often suffer most from environmental pollution or the effects of climate change (Derkzen et al. 2017; Ward Thompson et al. 2016).

Efforts for planning and implementing NBS must therefore begin with basic questions: How can we preserve and/or restore existing urban green areas as well as urban trees so that they can function as NBS? How can we ensure that new NBS can actually provide the intended multiple benefits over the long term and in places where the benefits are needed most?

We shed light on these questions by sharing four case stories from different regions: major cities in Southeast Asia, southeastern Australia, Central Europe, and western South America, namely Jakarta, Melbourne, Berlin, and Santiago de Chile. We describe urban issues in these cities that have been or could be tackled with NBS, focusing on the most basic and common green elements: public green spaces and urban trees. Because of the differences in

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each city when it comes to green elements and whether they are considered as NBS, we refrain from a definition but try to describe the green elements in each case. We discuss how these green spaces are addressed in urban planning and the challenges of mainstreaming and maintaining NBS.

These four cases have been selected in a pragmatic approach based on contextual knowledge of the authors, aimed at providing examples for metropolitan cities in different geographic regions with different climate, planning systems, wealth, culture, and many other factors (information-oriented selection with maximum variation; Flyvbjerg 2006). For each city region major challenges of, as well as efforts for, planning and maintaining green spaces were discussed and focused on a specific topic: challenges of planning and implementing green elements in Jakarta, efforts in strategic park planning in Santiago, approaches to enhancing ecosystem service provision with blue-green infrastructure in Melbourne, and a strategy to improve maintenance in Berlin. Due to their differences, they should not be considered as comparative cases, but as examples that contribute different perspectives to the overall topic based on their local situation.

URBAN ISSUES AND POTENTIAL FOR IMPLEMENTING NATURE-BASED SOLUTIONS IN FOUR CITIES ON DIFFERENT CONTINENTS

The selected four cities from different global regions are all large metropolises with 3 to 11 million inhabitants (Table 10.1). Berlin is the only city from the Old World; it faced phases of rapid population growth already during the industrialization of the nineteenth century. Colonialization of the other regions spurred the development of settlements and cities, displacing and disrupting First Nations' and Traditional Owners' existing societies, ways of life, and custodial connections with their lands. For Jakarta, Melbourne, and Santiago, population growth strongly accelerated after the Second World War and is still high. In Berlin, after a long period of stagnation during the Cold War, population increase is a relatively recent trend.

Urbanization Pressure in Jakarta, Indonesia

Jakarta is the capital of Indonesia and drives the national economy. It is inhabited by 11 million people and deemed one of the most populous cities globally (World Population Review 2021). It contributes to 17.7 percent of the national gross domestic product (BPS-Statistic Indonesia 2020) and also plays a key role in the global economic network.

Jakarta is located in the tropical monsoon region and lies on the coast, and downstream of three watersheds, namely Citarum, Ciliwung, and Cisadane.

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Table 10.1 Comparison of the four city regions

	Berlin, Germany	**Jakarta, Indonesia**	**Melbourne, Australia**	**Santiago de Chile, Chile**
Climate zone (Köppen climate classification)	Marine west coast	Tropical rainforest	Marine west coast	Mediterranean
Inhabitants (2018)	3.6 million	10.5 million (metro area)	4.8 million (metro area)	6.7 million (urban agglomeration)
Population development (estimated average annual rate of change in percentage for 2018–30)	+0.1	+1.6	+1.5	+0.7

Source: Population data based on United Nations (2018).

Being sited on an alluvial plain, Jakarta is prone to flooding of its buildings and impermeable surfaces. The combination of high rainfall, land subsidence, sea-level rise, unmanaged waste and drainage, and the dominance of built-up areas increasingly raises the risk of flooding (Mishra et al. 2018; Riyando Moe et al. 2017). Based on Jakarta's land use map in 2019, vegetated areas made up only 12.3 percent of the city region (Provincial Government of Jakarta 2021).

Jakarta's hydrological cycle is mostly disrupted by urbanization and climate change effects as typically found in mega-urban Asia (Wang et al. 2020) and is progressively more threatened by flooding, drought, and land subsidence. Current planning focused on conventional engineering approaches fails in solving the issue. Despite an integrative approach to manage watersheds that involves upstream areas (peri-urban Jakarta), efforts to restore rivers, water reservoirs, and land capability to infiltrate water in Jakarta are still required. In this case, inter and transdisciplinarity of the NBS approach may offer an alternative solution. However, the concept of NBS is not yet used by urban planners in Southeast Asian cities, including Jakarta (Kooy et al. 2020; Lechner et al. 2020).

Conditions of the city's green infrastructure and lack of land accessibility

The Provincial Government of Jakarta aims to increase urban green space, as the Law of Spatial Planning Number 26/2007 mandates a minimum 30 percent of area in every city, of which 20 percent should be public and 10 percent should be private. However, until now the Government of Jakarta has only

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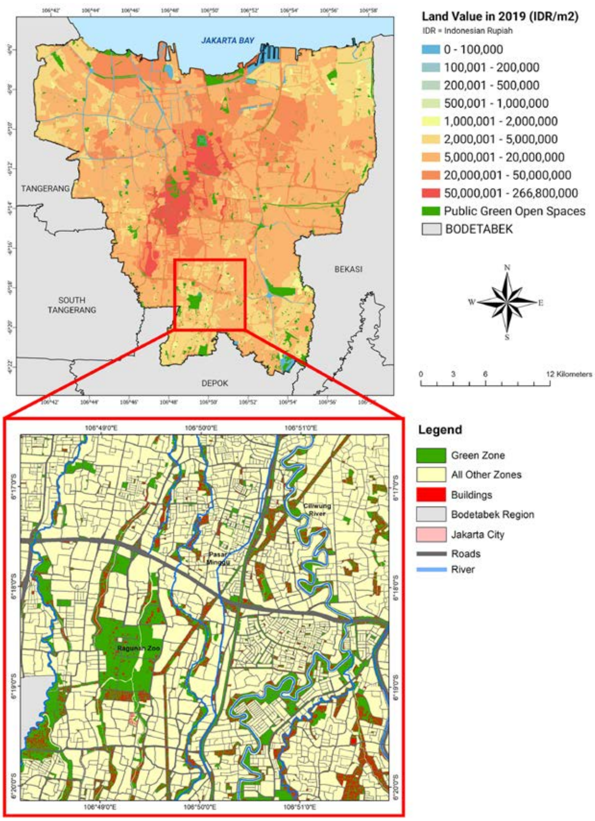
managed 5.7 percent of urban green spaces, considered public green spaces, consisting of urban forest, green lines (i.e. green open spaces along the road-side, river bank, railway side), nurseries, sports fields, cemeteries, parks, and gardens (Environmental Agency of Jakarta Province 2021). The rest is agricultural land and other green spaces managed by the private sector, which are difficult to preserve. Jakarta's public green spaces are fragmented, scattered in smaller sizes, and unevenly distributed (Figure 10.1, top).



Source: Top: Provincial Government of Jakarta (2021), Ministry of Agrarian Affairs and Spatial Planning, and National Land Agency (2021); bottom: Provincial Government of Jakarta (2021); layout: K. Saifullah.

Figure 10.1 The distribution of scarce and uneven public green spaces on different land values in Jakarta (top), and green space area lost by violation of spatial planning (bottom)

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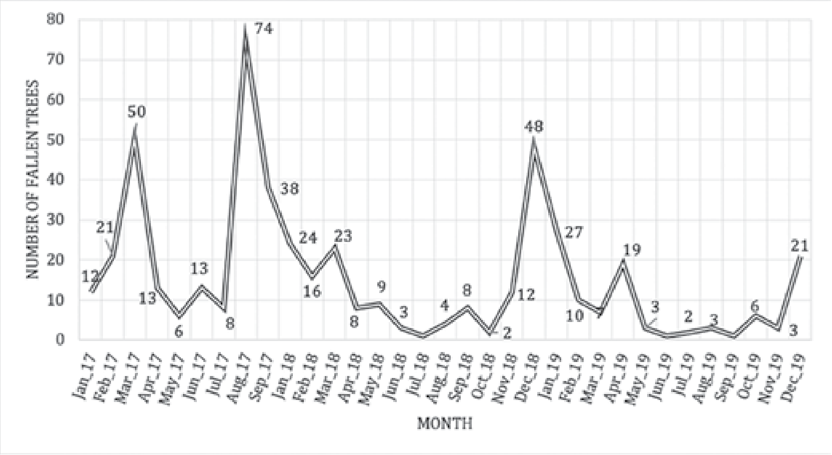
Adding green spaces is difficult as land prices and development pressures in Jakarta are high (Figure 10.1, top). According to Setiowati et al. (2018), total land acquisition for public green space in 2012–17 was only 111.53 ha or 37.18 percent of the total target of 300 ha set by the Provincial Government of Jakarta. Moreover, the area gained was small and scattered. At the same time, there are still violations of spatial planning due to construction on public urban green spaces, as can be seen in south Jakarta (Figure 10.1, bottom).

Besides encroachment of green space, other elements of green infrastructure in Jakarta are endangered. Trees have low life expectancy mainly due to reduced growing area, unsupportive environments, and frequent rain storms. Prasetya (2014) revealed that most of the trees along the roadside in eastern Jakarta have experienced serious damage compared to the trees in a compact urban forest area, which are mostly healthy (Safitri 2018). Figure 10.2 shows the number of fallen trees from 2017 to 2019 that mainly occurred in the rainy season (i.e. August–April). Instead of protecting people from climate change effects, trees that grow on limited land adjacent to human properties have caused a lot of damage and losses, exacerbated by an increased risk of falling (Provincial Government of Jakarta 2019). Nurseries have been prepared by the government to replace fallen trees. Nevertheless, new trees need a long time to mature enough to bring ecological benefits to the city.



Source: Provincial Government of Jakarta (2019).

Figure 10.2 The number of fallen trees by month, 2017–19

The policy to provide 20 percent area for public green spaces faces huge challenges in growing cities like Jakarta with high density and land development

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driven by economic motives. Lack of monitoring and law enforcement as well as available budget for maintaining and extending urban green spaces have become serious issues. NBS propose a better solution as they allow the integration of natural and engineering approaches in dealing with environmental problems in Jakarta. By this integration, the advantages of green spaces in urban agendas can be well defined and developed, thus they will gain wider public support. Kooy et al. (2020) suggested an NBS approach to incorporate natural processes via green-blue space development (e.g. wetland, green walls, roof gardens, vegetated infiltration, etc.) in managing stormwater and wastewater to increase water supplies and to decrease flood risk in lowland and coastal Southeast Asian cities, especially Jakarta. However, this effort is likely hindered by rapid urbanization, typical climate conditions, especially high rainfall intensity, and poor governance that is often found in these cities (Lechner et al. 2020).

Steps Toward Greening Strategies in Santiago de Chile, Chile

The Santiago Metropolitan Area (SMA) is located in a basin whose altitude varies between 450 and 1,000 meters. The climate is Mediterranean and the annual precipitation, concentrated in winter, is scarce and varies greatly from year to year. According to climate change projections, rainfall will decrease consistently, while temperature will increase (Magrin 2015). The urbanized area has constantly grown during the last decades, consuming mainly rural land but also affecting natural areas, such as wetlands or native forest in the Andean footsteps and coastal range (Puertas et al. 2014; Romero et al. 2012). Other environmental problems include poor air quality and exposure to socio-natural disasters, like earthquakes, flooding, and forest fires (GORE RMS 2017).

The SMA is subdivided into several municipalities and lacks a metropolitan authority. This administrative fragmentation, along with the weakness of Chilean territorial planning, is a major challenge to good governance (Barton and Kopfmüller 2016; Precht et al. 2016). Although the Santiago region is the only one in Chile that has a land use plan (Plan Regulador Metropolitano de Santiago), the ministries are the main bodies responsible for infrastructure planning and implementation, with sectorial views that are rarely coordinated with one another. Moreover, the local urban regulations depend on the municipalities, which also have responsibilities in providing various services, including waste collection and green space maintenance (Giannotti et al. 2021; Vásquez et al. 2016).

Many studies have highlighted the social and spatial inequalities of the SMA, which are also evident in the distribution of green spaces, although the results differ according to the definition of green space used by each study.

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The wealthiest municipalities, in the northwest cone, have a good amount of well-maintained urban forest and green space, while the rest of the city is characterized by less vegetation and poorer maintenance (Escobedo et al. 2016; Reyes and Figueroa 2010; Vásquez et al. 2017). Recent research found that municipal management is the most important variable to explain tree survival, which is consistent with the huge differences in the budget allocated by municipalities (Steinfort et al. 2020; see also Hernández and Villaseñor 2018; Reyes et al. 2015). Another relevant factor is the water requirement of trees, as drought-resistant species are more likely to survive in a semi-arid context where irrigation is required, especially during the dry season (Reyes-Paecke et al. 2019; Steinfort et al. 2020).

Investments in public green spaces

During recent years, the concern to improve the design of green spaces has grown, together with the commitment to ensure a more equitable access to them. In this regard, NBS and similar concepts, like green infrastructure, have emerged as useful approaches, but they have been mainly promoted by academic initiatives (Giannotti et al. 2021; Muñoz et al. 2019; Vásquez 2016). Within public institutions, only the Ministry of Environment (Ministerio de Medio Ambiente, MMA), has adopted these approaches, especially in the Plan for Adaptation to Climate Change and Biodiversity (MMA 2014).

The MMA is mainly concerned with peri-urban areas. In the Santiago region, the Global Environment Facility project deserves a special mention. Its primary goal is to protect biodiversity and establish corridors through the mountain ranges (https://gefmontana.mma.gob.cl/). Within the urban area, several initiatives have been promoted by the civil society, non-governmental organizations such as Fundación Mi Parque, and public institutions. Among the latter, the Ministry of Housing and Urbanism (Ministerio de Vivienda y Urbanismo, MINVU) has initiated various programs to improve the urban environments of poor neighborhoods and to realize new parks in municipalities that lack green spaces, with the aim of having more equitable access to them (Vásquez et al. 2017). MINVU can provide resources that are rarely available at the local level to design and implement new parks. Moreover, in the SMA, MINVU has also taken over their maintenance, through a specific department that now manages a network of 21 parks (Reyes et al. 2011; Figure 10.3).

In order to streamline these efforts, in 2019 MINVU began to elaborate a National Policy for Urban Parks (Politica Nacional de Parques Urbanos, PNPU). The main goals of the policy are: establishing coordination among the different stakeholders involved in the construction and maintenance of parks and securing new investments from different sources; defining criteria for a more sustainable design, especially regarding irrigation; differentiating the

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Figure 10.3 The "Brasil Park" in the municipality of La Granja is currently being regenerated thanks to the MINVU program for urban parks. It was designed by Cancino & Magrini and Harris & Illanes architects

uses of the parks and augmenting their safety; and concentrating investments in the municipalities with the greatest deficit of green areas.

The PNPU (2021), will probably help to advance toward a more sustainable design, better maintenance, increased participation of civil society, and more equitable distribution of green spaces in the SMA and other Chilean cities. Nevertheless, the PNPU only considers urban parks, which highlights the need to have better coordination among the many initiatives that exist today about the realization and maintenance of different green spaces and moving towards developing NBS.

Blue-Green Infrastructure Enhancement in Melbourne, Australia

Melbourne, a major city in southeastern Australia, has a population of almost 5 million and covers an area of almost 10,000 km^2 (DELWP 2017a). The city has developed from a colonial settlement in 1835 on the banks of the Yarra River. The area has been home to the Wurundjeri and Bunurong peoples, the Traditional Owners, for more than 60,000 years, and their custodianship nurtured a bountiful landscape of forests and woodlands, native grasslands, and wetlands (Presland 2008). While urbanization has decimated much of the

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urban area's biodiversity, Melbourne and other Australian cities continue to provide habitat to a diversity of species, including threatened species, some of which are only found in urban areas (Ives et al. 2013, 2016; Soanes and Lentini 2019).

Melbourne's green-blue spaces are located in a network of parks, gardens, nature reserves, golf courses, and waterways (Figure 10.4), as well as street plantings and private gardens (VEAC 2011). Melbourne's livability and sustainability is threatened by the urbanization pressures of densification (reducing open space) and expansion (with suburbs replacing the peri-urban forests and agricultural areas on the urban fringes) (TNC and RM 2019). In the competition for urban space, infrastructure provision such as transport is often prioritized, with green space and trees assumed to be easy to replace, relocate, or even "offset" (through land purchase outside the city boundaries). These challenges are exacerbated by climate change: increasingly severe and frequent heatwaves, drought, and extreme weather events (TNC and RM 2019). A record-breaking heatwave in February 2009, in which more than 370 people died from heat impacts, was the precursor to catastrophic bushfires that burnt into Melbourne's fringes, killing 183 people (Steffen et al. 2014).

As Melbourne's planners increasingly recognize the threats and impacts of urban heat, "cooling and greening" the city has become a key priority (DELWP 2017a). While the term "nature-based solutions" is not yet widely used by planners and practitioners in Australia (Moosavi et al. 2021), there is increasing recognition of the critical roles that well-watered landscapes play in both cooling urban areas and providing habitat biodiversity, treating air and water runoff, and providing opportunities for people's connection with nature (DELWP 2019; TNC and RM 2019).

Developing blue-green infrastructure

Melbourne's 2017 metropolitan strategic plan highlights the contribution to urban resilience provided by the cooling benefits of a greener city (DELWP 2017a). The implementation of the plan's greening policy includes mapping the trees and green spaces in the city, creating guidelines for streetscape planting and design and partnering with research institutions, local governments, and others to facilitate and support implementation of green roofs, and other urban blue-green infrastructures (DELWP 2021).

One of these implementation partners is Greening the West, a regional collaboration of state government, local governments, community organizations, universities, and industry bodies, initiated and facilitated by urban water utility City West Water (GTW 2020). The rapidly urbanizing western areas of Melbourne are significantly drier and hotter than other areas of the city. Greening the West formed in 2011, to increase the amount of urban greening as well as to improve the quality and use of green spaces. One of the key initiatives,

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Note: During Melbourne's COVID-19 pandemic lockdown, spaces such as golf courses, usually the exclusive domain for golfers (as well as an important habitat for biodiversity), were opened to provide valued "breathing space" for local residents and adventure space for children.
Source: Judy Bush (October, 2020).

Figure 10.4 Bracken Creek flows through a golf course in Melbourne's inner north

"Greening the Pipeline," aims to both revegetate and open up access to a 27 km decommissioned water pipeline easement.

While NBS, in the form of "green infrastructure" and "water-sensitive urban design," are increasingly highlighted by Melbourne's planners as priorities, key challenges remain for their implementation and maintenance at scale, including allocating space for NBS in a densifying city, and adequately resourcing ongoing maintenance. As the number and diversity of water-sensitive urban design and green infrastructure installations increase, there is also an increase in knowledge and information on maintenance requirements and techniques

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(DELWP 2017b; MWC 2013a), including provision of training courses and seminars for technicians, planners, and maintenance staff (Clearwater 2021). However, there are significant challenges associated with maintenance, particularly of water-sensitive urban design treatments if the installations have not been designed with a view to ongoing maintenance. For example, the sediment collection function of installations requires periodic sediment removal, which can be expensive and technically difficult, and which may involve disposal of contaminated waste if the stormwater has carried higher levels of pollutants (MWC 2013b). Furthermore, stormwater wetlands which have accumulated pollutants can create "ecological traps" for native frogs and fish, impacting their health and ongoing survival and further highlighting the need for a focus on effective design and maintenance regimes (Hale et al. 2019).

While guidelines and technical checklists emphasize the importance of ongoing, regular maintenance, policy officers have noted that although funding may be available for "capital expenditure" for new installations, operational budgets are often under pressure, and rarely increased, even with an increase in areas to be maintained (Bush 2020).

Green Space Maintenance Challenges in Berlin, Germany

Berlin is the capital of Germany and now the most populous city in the European Union. About 40 percent of the city consists of green and blue spaces including large forests, water bodies, and agricultural land in the peri-urban zone (GRIS 2020). The population in the central districts does not have adequate access to nearby green spaces (SenStadtUM 2016b, appendix). Continued population growth increases pressure to densify and develop new residential areas leading to higher intensity of use for Berlin's green infrastructure (SenUVK 2019). The effects of climate change lead to additional pressure on the urban vegetation. The city is expected to be more frequently exposed to extensive dry spells as well as cloudbursts leading to flooding (SenStadtUM 2016a).

The concept of NBS so far has received little attention in German city planning, although many practices such as decentralized rainwater management have a long tradition (Zölch et al. 2016). Moreover, Berlin builds on 150 years of green space planning, is frequently lauded for ecological planning approaches, and has a broad variety of plans and policies concerned with green infrastructure (Hansen and Pauleit 2020). Public green spaces of about 11,000 ha and 440,000 street trees are managed by 12 District Street and Green Space Offices, while protected habitats and nature reserves are managed by District Environment and Nature Conservation Offices (Ruddeck and Schahin 2017). Green spaces are often in poor condition and, compared to other major German cities, Berlin residents feel least safe and are least content with the

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maintenance of green spaces (Forsa 2014). Between 2012 and 2019, about 44,000 street trees were cut and only about 18,000 planted (BUND 2021). Issues with maintenance even concern relatively new green spaces, partly due to high intensity of use, but also due to climatic conditions, plant diseases, etc. For example, in the landscape park Johannisthal (see Figure 10.5) more than 500 of the 870 planted native trees died within the first ten years. According to the district administration, this is related to the low water storage capacity of the soil, high surface temperatures, and tree species not being adapted to the extreme site conditions. Irrigation, which is not automated, was applied but did not significantly stop the loss of trees and resulted in high costs. Therefore, replanting is not planned (BA Treptow-Köpenick 2018a, 2018b).

Note: While the park includes a nature reserve and is a biodiversity hotspot for grassland species, a large proportion of the newly planted trees died, despite irrigation, leading to a lack of shadow and cooling capacity.
Source: Rieke Hansen (2013).

Figure 10.5 Landscape park Altes Flugfeld Johannisthal in Berlin is a former airfield with extreme site conditions

Berlin's "Good care manual" as a pathway to improved maintenance
Berlin's city administration developed a manual for good care ("Handbuch Gute Pflege") which defines standards for different green elements such as street trees, ornamental plantings, or lawns (SenUVK 2017). The goal was to

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combine quality requirements for recreation, cultural heritage, and nature conservation, and the development processes of the manual involved both offices from streets and green spaces as well as environment and nature conservation. The manual links information on habitat management with maintenance data in Berlin's digital green space information system "GRIS."

Eleven "golden rules" for maintenance include step-wise mowing or pruning to create a habitat mosaic, planting of forage plants for pollinators, enhancement of structural diversity, or allowing succession. The manual's catalogue of green elements provides detailed information, including social, ecological and aesthetic functions, maintenance tasks, ecological information (i.e. relevance as a habitat for protected species), and a calendar with appropriate periods of the year for each task.

An overarching aim is to foster ecological maintenance approaches if in correspondence with recreational needs and historic relevance. For example, if a lawn is used less, the maintenance shall be reduced. The manual also refers to monitoring in order to ensure the long-term vitality of urban green elements, especially with respect to climate change effects. For restoration and replanting, measures are suggested that enhance the vitality such as selecting drought-resistant street trees or more robust plants for lawns. Currently, the applicability of the manual is tested with pilot projects that either have a social, ecological or historic-aesthetic focus in all 12 districts (SenUVK 2021). The manual represents a shared standard for all of Berlin's districts, shall help to consider maintenance requirements during the planning of new green spaces, illustrate the economic damage of poor maintenance and overall provide an argumentation base to argue for sufficient resources. Digital green space management helps to use resources efficiently and monitor maintenance activities. The manual is considered as an important first step in a path towards better green space maintenance in Berlin and will also be used for political and public communication in order to increase the awareness of the value of sustainable green space management (Ruddeck and Schahin 2017).

CHALLENGES ACROSS THE CITIES

Despite their differences in biogeographic, socio-economic, and cultural contexts, the four cities share a number of aspects relevant for implementing NBS, including barriers. It should be noted that the focus was not on the full spectrum of NBS but on public green spaces and urban trees as important elements of urban green infrastructure. Considering that NBS are supposed to provide a variety of ecosystem services and contribute to biodiversity, not all urban green spaces might qualify as NBS but they do represent an important spatial resource in cities that has the potential to be carefully developed to

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provide more and more diverse ecosystem services and to be sustained over the long term.

Pressures on and Maintenance Issues with the Existing Green Infrastructure

All cities face severe effects of climate change, which threaten human health and economic assets but also the health and survival of vegetation. Climatic change increases the need for NBS for cooling or flood retention yet at the same time increases stress on vegetation and drives failure rates. For example, fragmented small green spaces make trees vulnerable to storms in Jakarta. In Melbourne, with hot, dry summers and increasing exposure to severe droughts, ensuring adequate water for healthy vegetation is critical. Water scarcity leads to conflicts between water usage for urban vegetation and needs for drinking water. In Berlin, droughts require costly watering which is not standard practice, and conflicts related to water shortage are expected to increase. Maintenance, including irrigation, or lack thereof, is a crucial factor for the survival of trees in Santiago and leads to unequal distribution of green infrastructure in correspondence with municipal wealth. Besides, maintenance issues are expected to become more urgent with progressing climate change.

Overall, all four cities struggle to maintain existing green infrastructure, and their efforts in expanding green areas and planting trees are partly exceeded by loss, such as with street trees in Berlin or when (illegal) urban development happens in Jakarta. Moreover, public investments can be undermined by the loss of vegetation from private land as in Melbourne. All these issues can contribute to a gradual degradation and net loss of green infrastructure. Moreover, loss of mature habitats or large trees take decades to be compensated (Le Roux et al. 2014). Therefore, maintaining the existing green infrastructure is paramount.

Challenges for Implementing Sustainable Nature-Based Solutions

Barriers to implementing NBS relate to land accessibility, which becomes even more difficult when urbanization pressure is high. This concerns all four cities but is especially evident in Jakarta. Efforts to increase green infrastructure have been pushed to reduce flood risk, but are hampered by the lack of land availability and high land prices in Jakarta. Moreover, all four cities face pressure on green and open spaces due to urbanization. In newly developed areas as well as densified quarters, space for trees and other larger vegetation is usually limited (Erlwein and Pauleit 2021), leaving few options to design NBS that address societal challenges as well as biodiversity and/or those requiring

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NBS with a high level of technology, including related resource input and intensive maintenance such as high-tech green roofs (Snep et al. 2020).

In Santiago, Melbourne, and Berlin, programs are available for creating green and blue spaces, such as through regional partnerships like Greening the West in the Melbourne region, nature compensation requirements in Berlin, or the urban parks program in Santiago. However, if maintenance issues are not addressed such investments can prove to be unsustainable, providing opportunities for high-profile ribbon-cutting events but no long-term benefit. Moreover, without long-term financing, funding programs can only be accessed by municipalities and districts that are well off and can afford additional maintenance resources, as in the Santiago region, resulting in unequal distribution of NBS.

WAYS FORWARD FOR MAINSTREAMING NATURE-BASED SOLUTIONS

Mechanisms and approaches for mainstreaming NBS are highly context-specific, making it difficult to propose generalizable recommendations. Different contexts in different cities as well as different planning tasks require adapted measures (i.e. for conservation, restoration, or new development of urban green and blue spaces). In the four analyzed cities, the concept of NBS is not yet explicitly applied in planning but there is awareness of the benefits that could be provided by NBS and there are efforts to utilize these benefits. To support mainstreaming and maintaining of NBS, we can conclude the following.

Legal and Political Frameworks for Protecting and Implementing Nature-Based Solutions

Mainstreaming NBS requires effective planning instruments and regulations which ensure that pressure of urban expansion, densification, and economic interest do not outcompete interest in providing NBS. For cities like Jakarta, it is not only important to enlarge green spaces but also to monitor and control spatial violations on the reserved (public) green spaces. This requires political as well as legal support, i.e. via planning codes or regulations that require integration of NBS into the new developments such as green area factors (Climate ADAPT 2020; Juhola 2018). Moreover, it needs a public administration with capacity for monitoring to ensure that planned NBS are really implemented and maintained.

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Nature-Based Solutions Planning with Foresight

The environmental stress caused by increasingly frequent and severe drought and reduced water availability, rising temperatures, and catastrophic events (Kendal et al. 2018) has implications for plant suitability and conservation of endemic and threatened species. “Novel ecosystems” and “climate analogues” should be considered to develop NBS that are better adapted to future climate conditions at the same time as supporting local biodiversity (Parris et al. 2020). Strategic approaches to maintenance such as the “Good care manual” in Berlin help to promote green elements that qualify as NBS and provide guidance and foresight. If maintenance supported by life-cycle assessments is already considered during planning, NBS can be long-lasting and responsive to future change.

Considering Scale, Design, and Distribution of Nature-Based Solutions to Optimize the Benefits

Small green spaces and unequal distribution as in Jakarta and Santiago not only lower the benefits and just distribution but also, particularly in Jakarta, increase the risk of fallen trees and higher maintenance costs caused by limited spaces for tree growth. In Santiago, tree survival is difficult to ensure in municipalities with less vegetation and poor maintenance, usually related to lack of financial resources. NBS should be an important element of city master plans but also at district- and site-level planning to ensure strategic integration of NBS and reserving sufficient space. Also, the resource needs for maintenance and the economic-ecological benefits for the city need to be properly measured regarding scale, design, and distribution of NBS.

Prioritization of Nature-Based Solutions with High Social and Ecological Benefits and High Biodiversity Value

A priority should be given to NBS with long-term ecological functioning and contribution to biodiversity as well as providing benefits to citizens that need them most. The Berlin case is an example of how to consider aesthetics, usability, and ecological aspects of NBS. Part of investing in long-term well-being of green infrastructure is providing conditions for healthy vegetation growth, such as trees with adequate access to soil and water, as well as professional maintenance that ensure ongoing functioning, as in Melbourne. In addition, planners should prioritize districts with a lack of public green spaces, as in Santiago.

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Retrofitting to Create Sustainable Nature-Based Solutions

Many existing urban green or blue elements would not qualify as NBS because they provide only limited benefits or low support for biodiversity, and the required resource input or use of environmentally damaging materials might even exceed the benefits, such as with intensive lawns. However, these elements can be transformed into NBS by adapted maintenance or replanting to enhance habitat function and the provision of ecosystem services. Berlin's "Good care manual" shows a way towards a gradual transition by including rules for more sustainable and biodiversity-friendly maintenance that is supposed to be enhanced. Regeneration and restoration programs as described for Santiago and Melbourne can promote sustainable solutions and adaptation to climatic conditions by using locally adapted vegetation types that ensure longevity and low maintenance needs. Tree programs as in Jakarta should not only replant but also improve living conditions for mature trees such as enhancing root space, reducing soil compaction, and improving stormwater infiltration for supplying trees.

Resource Input Balanced with Nature-Based Solutions Benefits

For all NBS and in particular high-tech solutions including electronically monitored systems, costs and resource consumption should be checked against the benefits with life-cycle assessments in order to invest in the most sustainable NBS. As the climate changes, resource input may need to be reevaluated, such as with irrigation in Berlin. Drought-resistant trees can survive water scarcity but might provide limited ecosystem services, such as cooling via shading if growth is hindered by water shortages, so investments in irrigation systems may be warranted. In the context of water scarcity, conflicting demands for water need to be considered and, eventually, technical solutions for water access are needed (i.e. use of greywater from households) in cities like Melbourne that focus on water-sensitive urban design and emphasize the importance of blue spaces for cooling.

Sustained Commitment for Long-Term Care

The mainstreaming of NBS, as living dynamic systems, requires provision of ongoing operational funding for maintenance, not just construction funding. Long-term maintenance requires commitment to and investment in resources and skills (Bush 2020). Acknowledging the dynamic nature of NBS and landscape maintenance means that ongoing management must be adaptive, requiring careful monitoring and evaluation, as well as incorporating mechanisms to adjust with changing conditions, community priorities, and environmental

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factors as shown by the cases of Berlin and Melbourne. As can be learned from Jakarta, lack of maintenance, monitoring, and evaluation can undermine violations of public green spaces and increase the risk of fallen trees.

Enhancing Public Participation

In Santiago, Melbourne, and Berlin participation of public and non-government stakeholders enhanced the management of green-blue spaces. Both public and private green spaces are important for providing NBS. In cities like Jakarta, where land acquisition by the government is difficult, private landowners could be taken more into focus. This requires planning instruments that can range from incentives to obligations for private landowners. However, it needs to be considered that private persons might lack awareness or resources for proper maintenance and might have interest in urban greening not in line with professional motivations for implementing NBS. Thus, involving non-governmental stakeholders requires negotiation of different interests. Also, for NBS on public land, participation should be enhanced to ensure that citizens' needs are met.

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11. Governance of and with nature-based solutions in cities

Niki Frantzeskaki, Katinka Wijsman, Clare Adams, Nadja Kabisch, Shirin Malekpour, Melissa Pineda Pinto, and Paula Vandergert

INTRODUCTION

Cities are places where multiple systems, sectors, and actors come together, creating challenges and opportunities for urban sustainability and resilience. As such places, city governments are under pressure to keep services and the related infrastructures up to date and in good quality, while charting ahead to achieve sustainability and resilience goals. In doing so, city governments and other city actors seek and create opportunities to invest in solutions that strengthen their capacity to adapt to climate change, reconnect people and nature in urban environments, and improve social cohesion. Nature-based solutions (NBS) are proposed as an integrative concept and systemic approach, with the potential to address urban sustainability and resilience in a holistic way (Nesshöver et al. 2017). NBS deliver multiple functions and benefits beyond nature conservation, such as recreational opportunities, flood protection, urban cooling, etc., relevant for various urban infrastructure systems, sectors, and scales (Frantzeskaki et al. 2019). While these co-benefits and the multiplicity of NBS functions have been widely discussed in the literature, their implications for planning and governance is an emerging area of research and commentary (Frantzeskaki 2019).

NBS are a challenge to plan and implement in cities due to their systemic nature that requires the inclusion of multiple actors' perspectives, knowledge, and expertise, as well as acceptance by various groups (Frantzeskaki et al. 2020). Nature in cities has been a contested topic with some early writings seeing nature and cities as conflicting. The rise of ecological awareness and the acknowledgement of the interdependencies between people and nature in urban settings (McHarg 1998) has led to a growing interest in more-than-human understandings of people–nature relationships (Maller 2021). This is a critical

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turn for the way in which nature is valued in cities, impacting how cities are planned and governed, and how people live in cities. Nature provides unique services in cities that human-made technology and infrastructure cannot substitute (IPBES 2019). Therefore, the multiple functionalities that nature provides are increasingly seen as an inherent part of the city, rather than separated from it (Duvall et al. 2018). This evolution of how we value nature in cities has important implications for the governance of cities, in terms of the distribution of environmental goods, such as green spaces, and who is exposed to environmental bads (Mata et al. 2020; Tozer et al. 2020). This also ties into broader discourses on urban justice and social-ecological justice (Vandergert et al. 2015; Pineda Pinto et al. 2021; Sharifi et al. 2021).

As interventions in spaces in cities, the planning and governance of NBS requires an understanding not only of their technical and ecological characteristics, but also how they will be used, managed, and maintained over time, and how they connect with urban life and citizens (Kabisch et al. 2022). Understanding 'what it takes' to implement NBS in cities in an inclusive way requires recognising their systemic nature, and that their delivery of multiple benefits depends on the appreciation and valuation from urban citizens and other stakeholders with divergent interests. NBS implementation will often face contestation of values and interests, which requires co-production approaches that understand and incorporate people–nature relations from the onset. Additionally, NBS depend on living organisms and ecological processes requiring adaptation to the urban context (Ossola and Niemela 2018; Kabisch et al. 2022). Thus, their implementation is a collective action problem 'where … who should be responsible for taking action, cannot be limited to specific borders or boundaries' (Jon 2021, 11).

In this chapter, we present and propose a novel conceptualisation of inclusive governance relating to NBS in cities. It is important to understand that there are two different aspects of NBS governance. First, we will introduce the importance of governance *of* NBS as part of urban infrastructure. Simply put, governance of NBS takes NBS as a goal, 'how do we get NBS designed, planned, and/or implemented?' We discuss the important governance design characteristics and aspects, such as the importance of multi-actor engagement and the multi-level governance considerations in place. Second, we discuss governance *with* NBS, positioning NBS as governance instruments to complex societal challenges used to achieve diverse urban agendas. Simply put, governance with NBS takes NBS as a means, asking the question: 'What can we achieve using NBS in cities?' We show the ways NBS can be pivotal to locally achieve the Sustainable Development Goals (SDGs) and how NBS are a means to bridge governance across sectoral agendas in cities. After explaining these different dimensions of NBS governance, we present and propose that efforts from city governments need to be put in place to make the governance of and

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with NBS inclusive. To this end, we propose and present five dimensions of inclusive governance to guide the design and setting of NBS in cities in the future.

GOVERNANCE *OF* AND *WITH* NATURE-BASED SOLUTIONS

Governance is about the different processes in which policies, plans, and legislation are negotiated, discussed, contested, formulated, and implemented, and how they gain legitimacy and deal with accountability. It is thus about how various actors and their different interests are brought together in a dialectic space, and how their diverse expertise and knowledge are included in strategic and operational activities of steering towards commonly desirable outcomes. Governance is about 'the mechanisms of steering to guide societies towards outcomes that are socially beneficial and away from outcomes that are harmful' (Young 2008, 14).

With NBS seen as viable answers to deal with sustainability and resilience issues in cities (in particular climate adaptation), their governance requires inclusive approaches for their planning and implementation. The quest for inclusivity in planning, co-designing, and (co-)managing NBS stems from the recognition that all climate solutions need inclusivity and justice as core principles so as not to exacerbate existing inequalities and injustices and/or generate new unfair outcomes. We propose to think of inclusive governance as a multi-dimensional design and evaluation requirement for NBS in cities.

The notion of inclusivity stems from a concern about democratic norms in governance – especially those affected by decisions should have a say in them – and invites reflection on access, participation, and engagement as relevant to NBS decision making. Typically, inclusivity has been approached as an issue of remedying marginalisation in decision making on the basis of social difference (e.g. gender, race, ability, class), but we argue that it can be extended to the need to broaden perspectives and ideas more widely speaking. Inclusivity is therefore a concept helpful to pay systematic attention to diverse framings of problems and solutions from different stakeholders. Inclusivity in the governance *of* and governance *with* NBS can be further operationalised (see Figure 11.1) as inclusive to actors from multiple sectors (cross-sectoral inclusivity), as incorporating different origins and types of knowledge, including local and Indigenous knowledge holders (epistemic inclusivity), as considering more-than-human dimensions (multi-species inclusivity), as spatially distributing benefits and accessibility equitably (spatial inclusivity), and as bridging generational interests (intergenerational inclusivity).

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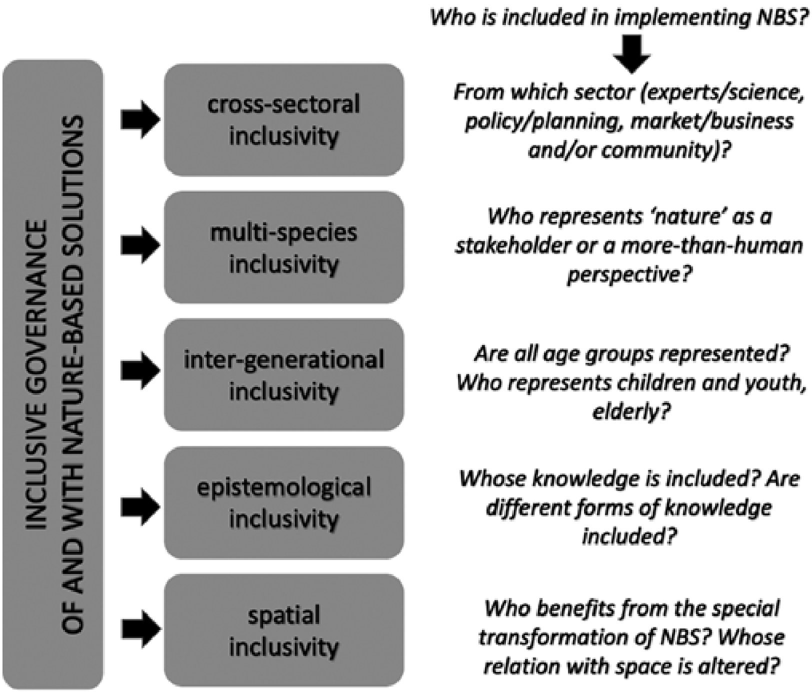

Figure 11.1 Operationalisation of inclusive governance of and with nature-based solutions in cities

Governance *of* Nature-Based Solutions in Cities

NBS are globally implemented through a range of governance models and a one-size-fits-all model therefore does not exist (Zingraff-Hamed et al. 2021). What is widely agreed, though, is that a reliance on urban grey infrastructures and fragmented governance – where benefits, risks, roles, and responsibilities are divided and siloed between different organisational and disciplinary domains – creates a significant barrier against the planning and implementation of NBS and thus against realising their co-benefits (Dorst et al. 2019; Fastenrath et al. 2020; Malekpour et al. 2021; Zingraff-Hamed et al. 2021). It is also widely understood that the complex relationships between technical, ecological, social, and economic dimensions of NBS means that governing NBS cannot reside with a single organisation, discipline, or sector, but requires collaborative governance shared between inter- and transdisciplinary urban actors (Frantzeskaki 2019; Malekpour et al. 2021). We here argue that it is

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helpful to approach this type of collaborative governance through the concept of inclusivity. This concept invites a reflection on the multi-dimensionality of the governance of NBS. We identify three types of inclusivity as relevant to the governance of NBS.

First, *cross-sectoral inclusivity* means taking into account multiple actors' perspectives, ideas, and interests in the design, planning, implementation, and management of NBS in urban environments. Ecologists, engineers, and social scientists, for example, have completely different ways of looking at NBS – emphasising either structural integrity, ecological connectivity, or social values – yet all are necessary for successful NBS applications (Wijsman et al. 2021). What is more, lay audiences offer different knowledge than experts do, for example on informal institutions and the memory of the system through experiential knowledge and historical references (Vandergert et al. 2021). What is challenging in ensuring this type of inclusivity is identifying who needs to be part of the governance process (e.g. how close in time and space does one need to be), in which way they can be included (e.g. which medium of engagement to be considered), and how such process needs to be organised (e.g. frequency, location, representation, reporting, and feedback registration or not), facilitated, and designed over time. Cross-sectorally inclusive governance of NBS can build from the long tradition and knowledge on participatory and collaborative (urban) planning (Puskas et al. 2021) and governance to ensure the active and genuine involvement of academic and non-academic stakeholders, ensuring representation, openness, and accountability (Cook et al. 2021). Eakin et al. (2021, 2) point out that 'increased efforts to include diverse actors in planning highlights the importance of actor network coordination and inter-organizational communication'.

This, however, is not a process to be taken lightly. It is important to understand what collaborative governance means and what it entails, given the evidence that 'stakeholder coordination is most challenging in urban projects, where many public and private land- and homeowners and initiatives interact' (Raska et al. 2022, 5). Collaborative governance through cross-sectoral inclusivity is about sharing information, capacities, resources, risks, and decision making among actors, in order to achieve a set of outcomes or to overcome a set of challenges that would not be achieved/overcome without such collaboration (Bryson et al. 2015). Collaborative governance is an integrative approach that brings together various disciplines, interests, values, and perspectives across existing conventional boundaries. The governance of NBS thus challenges different urban sectors (e.g. water, housing, transport), organisations (e.g. city councils, non-governmental organisations, private developers), and disciplines (e.g. urban planning, engineering, ecology) across various scales (e.g. city, neighbourhood) to look beyond narrowly defined remits and responsibilities and to innovate integrative collaborative approaches that can achieve holistic

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outcomes. Inter- and transdisciplinarity have been recognised as key principles underlying the governance of NBS (Dorst et al., 2019; Albert et al., 2021, Kabisch et al., 2022).

To create inclusive governance processes for NBS, procedural aspects of justice need to be taken into consideration. Scholarship in participatory planning as well as adaptive governance offers insight on fundamental aspects for such things as ensuring mutual respect, building rapport, and on the importance for facilitators or process convenors ‘to create supportive spaces to raise procedural and distributive justice concerns, and to ensure all stakeholders are recognised and empowered’ (Eakin et al. 2021, 2). Puskas et al. (2021) report that the majority of the literature on NBS governance and participatory engagement adopts a consultation and partnership model of engagement. According to them, ‘the dominance of consultation and partnership levels in urban planning and design may explain a trend towards a mix between maintaining the decision making process with experts and policy makers while allowing some level of public participation’ (Puskas et al. 2021, 7). There are two key points to keep in mind when considering how to progress collaborative governance through partnerships. First, the importance of partnerships as configurations employed to solidify collaboration, build trust, and engage in mutually beneficial exchange, as evident across the literature of NBS governance (see also Frantzeskaki et al. 2019, 2020; Midgley et al. 2021) and as a stepping stone for further mainstreaming of NBS (Xie et al. 2022). Second, the focus on consultation and partnerships as modes of governance requires attention to ensure that cross-sectoral inclusivity extends beyond engaging planners, policy makers, and experts to also include citizens/communities, especially those infrequently invited or partaking in the design and/or implementation of NBS. Also, consultation and partnerships are one approach to include and build relationships between different stakeholders, but inclusive processes need to go beyond consultation to truly bring multiple actors and knowledge to participate in and co-design NBS.

There are different ways to organise and ensure inclusive processes for bringing cross-sectoral stakeholders together. These include scenario-building processes (Pereira et al. 2020; Cook et al. 2021), envisioning and appreciative inquiry development, thinking of entry points for addressing justice considerations (Eakin et al. 2021), and multi-media participation methods (e.g. videos, virtual reality interfaces, serious gaming, interactive engagement technologies, design methods). Digital technologies and platforms also offer a way to bridge the procedural justice aspects, to make such processes more inclusive. As Puskas et al. (2021, 8) argue, ‘digital methods … can open up participation to a wider audience (more equal and diverse, removing barriers due to e.g. age, disabilities) as witnessed via the advancement of citizen science, open data and crowdsourcing platforms’. What is important is to choose methods and

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forms appropriate for the socio-cultural capacity of the engaged stakeholders as well as to the knowledge available to mediate/intervene in dealing with the social-ecological complexities that NBS are set to address.

As a second aspect of inclusivity, NBS require multiple and pluriform knowledge to weave in the aspects of envisioning, design, planning, implementation, monitoring, and evaluation. This dimension of *epistemic inclusivity* is often overlooked even though it is a crucial aspect to include in the urban governance of NBS in order to ensure epistemic justice. Epistemic justice (sometimes also called cognitive justice) challenges the idea that universal knowledge is possible and instead advocates the recognition of different social groups as producers of knowledge (Visvanathan 1997; de Sousa Santos 2007; Fricker 2007). Centring the plurality of knowledge, to consider epistemic inclusivity means to recognise knowledge practices other than scientific ones as legitimate and valuable, and to consider its bearers credible, for example by valorising the knowledge of women and Indigenous peoples (Wijsman and Feagan 2019). It requires a reflection on the concepts, practices, and frameworks used to analyse our worlds and interventions into it (Wijsman and Feagan 2019) and a conscious reconsideration of the organisation of knowledge systems to prevent Western scientific knowledge from overpowering alternative ways of knowing and understanding the world (Wijsman and Berbes-Blazquez 2022).

In this regard, Puskas et al. (2021, 4) point to the importance of utilising ‘a broader knowledge-base’ to design and implement ‘more democratic’ NBS. One way to ensure that there are fewer epistemic justice tensions – meaning that prominence of knowledge or expertise of one stakeholder group does not dominate the narrative or power over others – is to organise knowledge co-production processes as epistemic inclusive governance processes. Knowledge co-production has been advocated as a way to be inclusive in developing pathways for NBS implementation (Wickenberg et al. 2021) as well as ways to engage with social or technical pioneers/entrepreneurs (Fastenrath and Coenen 2021). Urban living labs are examples of settings that are place-based and that organise and allow for experimentation where co-creation and co-production of NBS occurs (Frantzeskaki 2019; Mahmoud et al. 2021). Co-production methods, however, are not one-size-fits-all approaches and institutional fitness to socio-cultural and socio-political contexts needs to be considered. In addition to inclusivity outcomes, governance processes for NBS that ensure/safeguard epistemic inclusivity can trigger new ways of thinking, and new innovations through the bridging of knowledge and ideas, such as the emergence of nature-based enterprises (Kooijman et al. 2021) or integrative thinking for nature-based solutions (Albert et al. 2021).

Third, governance of NBS needs to account for *multi-species inclusivity*. A multi-species approach brings to the forefront the lives of other organisms

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that are enmeshed in the worlds of humans and that recognises the creative, political, and affective capacities of these others (Kirksey and Helmreich 2010). The urban governance of NBS can play a key role in coordinating the biodiversity and climate change crises (Clement 2020) by building a shared understanding of working with and for nature to improve both social and ecological outcomes. Without recognising and including other species in some ways as co-participants in political and practical decision-making processes, it will not be possible to achieve legitimate and inclusive governance of NBS in cities.

When looking at NBS governance for multi-species inclusivity it is crucial to examine the needs and capabilities of the species that co-inhabit our cities, as well as future city dwellers. While scientific disciplines like ecology provide valuable observations, knowledge on the ecology of species, their interactions, and relations to the environment and people can also be fragmented and biased, and thus challenging to include in appropriate ways. However, diverse insights can be gained through alternative ways of being and relating with urban nature, for example through citizen science, Indigenous practices and worldviews, the perspectives of children, and through non-traditional planning and governance methods. These can bring attention to the lives of other species by visualising or making visible these others through storytelling, art installations, and experimental visual communication that can reveal recombinant ecologies, or ‘hidden’ assemblages of species and interactions with people and the landscape (Vanni and Crosby 2020).

Exploring and bringing together multi-species knowledge then raises the question of how we can incorporate the needs of other species when envisioning, planning, designing, and implementing NBS. A first task includes making injustices visible in order to rectify existing inequities. It is also important to recognise different value systems or assumptions, such as recognising nature’s intrinsic value (Clement 2020). For multi-species justice considerations to become central in NBS, we need to find different ways of encountering other species through empathy, responsibility, and political processes that can nurture an ethics and politics of care, solidarity, and respect (Steele et al. 2019; Tschakert 2020). Multi-species inclusivity thus means that, at a minimum, governance for NBS needs to account for the multiple species that through their lives enrich and populate urban environments, and that have a right to flourish through their own experiences, agency, and capacities. Ideally, however, this needs to go beyond consideration of individual species and expand into a relational paradigm that sees people, other living beings, landscapes, and ecosystems as a model to inform NBS governance. Through the development of two ontological models of water, Laborde and Jackson (2022), together with Aboriginal Australians and state planners, developed the *Living Waters* paradigm, in which there is no separation between people, water, and other living

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beings, contrary to the modern water management paradigm. Importantly, this model – and others that challenge dualistic underpinnings – can inform current planning and governance practices in terms of exposing blockages and obstacles for enacting a more relational governance (Laborde and Jackson, 2022). This shifting paradigm also influences and includes new actors that can bring a multi-species understanding for NBS governance to decision-making spaces. A multi-species inclusivity approach has the potential to steer a vision and direction through NBS governance that addresses the combined challenges of climate change and biodiversity loss.

Governance *with* Nature-Based Solutions

NBS have been discussed as a means for urban transformation (Frantzeskaki et al. 2017) and achieving multiple global policy agendas, such as the United Nations SDGs (Faivre et al. 2017; Seddon et al. 2020). The 17 goals agreed upon by United Nations member states in 2015 provide a framework for transformative planning, policy making, and investment to achieve economic prosperity, human wellbeing, and environmental protection. As opposed to mainstream biodiversity conservation approaches that predominantly focus on ecological benefits, NBS can be integrated into a suite of technologies and infrastructure solutions, as well as a portfolio of planning interventions, in order to deliver multiple environmental, social, and economic benefits that align with various SDGs (Cohen-Shacham et al. 2019). For example, NBS can increase access to green spaces in urban settings which improves human health and wellbeing (SDG 3), biodiversity (SDG 15), water retention and natural stormwater treatment (SDG 6), and provide opportunities for green investments (SDG 8, SDG 9) and urban regeneration (SDG 11), making cities more liveable, sustainable, and resilient (Faivre et al. 2017).

While there are clear synergies between multiple functions of NBS and the co-benefits they can deliver, there are also trade-offs. For example, NBS can increase the value of properties in the area in which they are implemented, exacerbating social inequalities and inhibiting inclusive access to urban amenities (negative impact on SDG 10 and SDG 11). The non-linearity and interconnectedness of social-ecological systems within which NBS is implemented makes the assessment of synergies and trade-offs a complex endeavour. Moreover, NBS systems themselves change over time due to dynamic alterations in their natural components, or under external pressure (e.g. under the impacts of climate change). This may result in changes in the relationship between different functions and co-benefits over time, making the assessment of synergies and trade-offs even more difficult.

To address these challenges and ensure that governance with NBS delivers on its intended transformative outcomes, we need frameworks and tools

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that allow for integrated assessment of co-benefits, synergies, and trade-offs prior to the design and implementation of NBS (see for example Raymond et al. 2017; Gómez Martín et al. 2020). Furthermore, NBS need to be governed through adaptive planning using scenario approaches, monitoring and ongoing assessment, and the design of adaptation pathways and strategies that can respond to changing circumstances (Albert et al. 2021) and keep the synergies and trade-offs in check in the long term. Even if we broaden the topic to include nature-based thinking as an approach to wilding or renaturing landscapes (Randrup et al. 2020, 921–922), it is highlighted that this needs to be socially inclusive and have landscape-scale considerations.

In the same line, governing with NBS also needs to be inclusive, first and foremost spatially. What we conceptualise as *spatial inclusivity* is the transformation of place and space that NBS bring about by reconnecting people and nature in cities. As spatial interventions, NBS can be the means to ensure that connection to nature in cities is accessible and available equitably to all urban citizens. Spatial inclusivity is contested in the way land uses are allocated and distributed in cities as well as shaped through zoning, and that through gentrification processes this can exacerbate disadvantage in the availability and accessibility of nature in cities (Kronenberg et al. 2021; Mabon and Shih 2021).

Governance configurations and spatial organisation can enable the adoption of NBS in cities to transcend jurisdictional barriers. This is important for bridging the ongoing gap in governance between the ecological scale and the jurisdictional scale, as well as how this plays out across different jurisdictions (Borgström et al. 2006; Macdonald et al. 2021). NBS is an essential concept to attain transformative change, as it has the capacity to create hybrid (grey-green) infrastructure solutions (Eggermont et al. 2015). Interaction among multiple levels of governance is important in the context of the city, as local, national, and global interests and policies play out in the governance of NBS. For example, prescriptive and top-down agendas need to be coupled with bottom-up initiatives (Zölch et al. 2018), such as urban experimentation which is an enabling process for transformations (Fuenfschilling et al. 2019) and further ensures that these transformations are contextualised to place (Frantzeskaki et al. 2018).

Place-based localism could be isolationist, but when considered in the context of a region there are opportunities for higher-level coordination (Cowell 2015). However, there are still conceptual gaps and practical governance and jurisdictional barriers to a metropolitan level of governance. For example, in the Australian context, there is a stark mis-match of governance for the metropolitan level. This can be illustrated by the three-tier government system in which there is an ongoing absence of federal-level urban policy (Gleeson 2007; Burton 2017; Hu 2020) and an urban planning structure that

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is fragmented between state and local competencies (Davidson and Gleeson, 2018). A deeper understanding of the city-level and metropolitan-level governance attributes, influences, and enabling institutions is integral to the implementation of transformational urban nature initiatives such as urban forestry across Greater Melbourne (Bush et al. 2020; Coenen et al. 2020; Fastenrath et al. 2020; Moloney and Doyon 2021).

Another dimension of inclusive governance with NBS is *intergenerational inclusivity*, that centres around how justice happens between generations. Integrating an intergenerational justice perspective is pivotal to creating sustainable benefits for the long term. In the context of pressing societal challenges with long-term implications, such as climate change, urbanisation, land cover changes, biodiversity loss, etc., environmental justice communities increasingly engage in temporal discussions on who bears the brunt of these challenges, forging intergenerational views. Typically, generational justice relates to sustainability and the responsibilities of the current generation to allow future generations to live in a safe and healthy environment (Bolte et al. 2011). It thus considers the 'transgenerational respect for the rights of and the fulfilment of duties vis-à-vis future and past generations' (Meyer 2017, 1).

Integrating an intergenerational justice perspective into NBS governance starts with co-designing NBS where multiple actors from a diversity of stakeholder and beneficiary groups need to be considered. To have socially inclusive and just outcomes for current and future generations, such a NBS co-governance process needs to include different population age groups with an intragenerational perspective including younger and older generations to be addressed and heard. Older people, children, teenagers, and adults may all have different needs and demands on a NBS to be implemented. Older people may demand specific infrastructure elements to be installed together with NBS. When new green spaces such as parks or new retention areas are planned as a potential NBS to mitigate extreme weather events, for example, they may be accompanied with the creation of particular benches to rest for older people, with areas serving as shelter in times of extreme events, with paths that are safe and accessible (Enssle and Kabisch 2020). Children may also demand nature areas to experiment and play, green spaces with trees for shading, accompanied with benches, to allow friends and family members of all age groups to be socially active (Kabisch and Kraemer 2020; Kabisch et al. 2020).

DISCUSSING IMPLICATIONS OF THE INCLUSIVE GOVERNANCE OF AND WITH NBS

To progress the inclusive governance of and with NBS there are two core principles that should underpin it: intersectionality and inter- and transdis-

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ciplinarity. These two concepts elucidate the inclusive governance of NBS governance.

Intersectionality

A way forward to more inclusive governance of NBS across all identified considerations (cross-sectoral, multi-species, epistemic, spatial and inter/intragenerational) is to take an intersectional approach to identify, engage, co-design, and co-create as well as empower communities to connect with NBS when in place. The concept of intersectionality draws attention to the interactivity of and interconnections between categories of difference, and how interlocking systems of power and oppression shape experiences in the world (Crenshaw 1989). Feminist scholars use intersectionality as a key analytical tool to discuss how inequalities are produced, paying attention to identities of race, gender, class, and sexuality, as well as experiences of species difference and living in dangerous environments. It has since become a research methodology centring on going beyond essentialisms, for example showing that climate change is not singular but instead experienced as a different kind of problem to different individuals and groups (Kaijser and Kronsell 2014) and highlighting the unequal impacts of pollution on differently situated people with intergenerational effects through contaminated breast milk, triggered miscarriages, and chronic childhood illnesses (Sze 2017). The key lessons from intersectionality are that the experiences that concepts try to capture are not necessarily stable (e.g. the experience of blackness is versatile over different geographies and different times) and that ‘the whole is larger than the sum of its parts’ (e.g. understanding the experience of black women requires more than adding an understanding of women to an understanding of blackness). It reminds us that climate change is not simply an environmental or technical issue, but instead that it is shaped by and shaping social difference. In the words of Naomi Klein, ‘racism is what has made it possible to systematically look away from the climate threat’ (2014, n.p.).

In cities where populations are in flux due to migration, location mobilities, and regeneration dynamics, an intersectional approach needs to also guide the management, maintenance, and stewardship of NBS. It is an oversight to only focus on the design and planning phases of NBS implementation and neglect their full policy and planning cycle. In considering policy and planning cycles, it is important to understand how such intersectionality unfolds and how the different dimensions build upon each other to create spaces for inclusive governance to be transformative. For example, intergenerational justice for NBS governance also speaks to multi-species inclusivity and asks us to extend our notion of NBS governance not only for future generations of humans, but also for those multiple living beings that will be co-inhabiting cities with

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future human generations. Intragenerational inclusivity can also be viewed as interspecies inclusivity, where the needs and relationality between humans and the many other species inhabiting cities is deliberated and considered. Intersectional approaches are fundamental to also plan and manage – govern overall – NBS in urban areas, especially when and where Indigenous communities, knowledge, and practices are contested. The path towards reconciliation is an ongoing process of interrogating and re-evaluating the values systems and assumptions that govern cities.

Interdisciplinarity and Transdisciplinarity

Inter- and transdisciplinarity in the context of the governance of NBS may be understood as the purposeful and systemic involvement of diverse holders of knowledge, capacity, resources, and decision-making power for the co-design and implementation of NBS (Albert et al. 2021). This does not imply that all actors should be involved at the same level, in all stages of planning and implementation and in all contexts, but that phases and types of inter- and transdisciplinarity should be strategically designed over the planning and implementation process to make the best use of complementary contributions (Albert et al. 2021; Malekpour et al. 2021). Through the inclusive governance conceptualisation presented in this chapter, a deeper understanding and appreciation of diverse influences, actors, and voices is essential for driving and co-producing NBS governance for cities. Inter- and transdisciplinarity is particularly important when considering the city as a whole. This is critical, first, for understanding the spatial reach, in terms of responsibilities, of NBS governance (e.g. neighbourhoods, municipalities, metropolitan regions). Second, in regard to whose interests are being served, whether within or across generations of people or broadening the scope to be inclusive of non-human species. Thus, inter- and transdisciplinarity are essential for understanding and including the appropriate stakeholders, in the appropriate ways, to enable an inclusive governance for cities to emerge.

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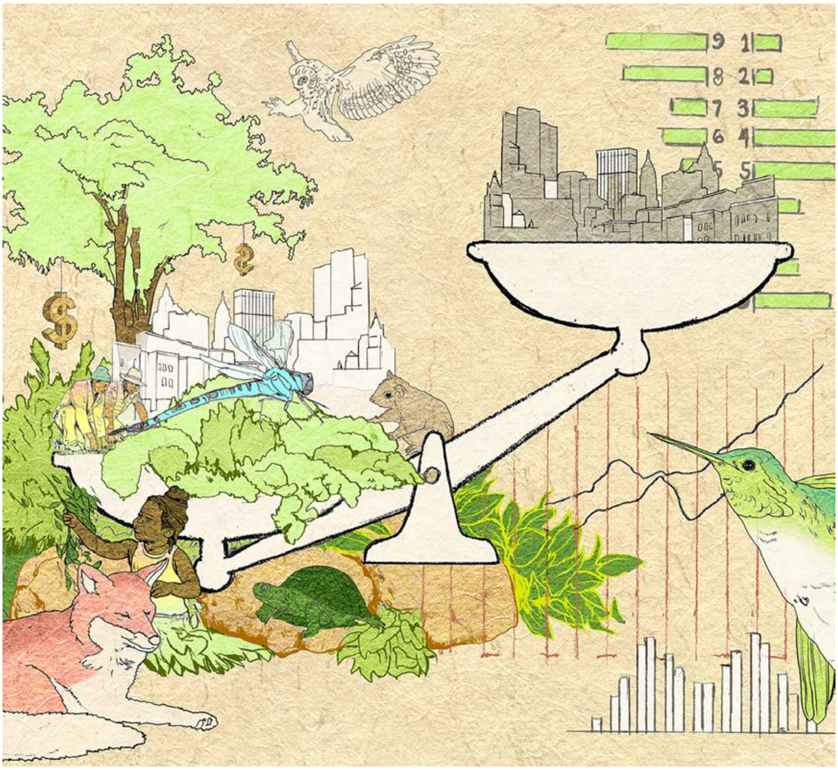

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12. Mapping, measuring, and valuing the benefits of nature-based solutions in cities

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INTRODUCTION

Cities must manage multiple, interacting challenges simultaneously—climate change, air and water pollution, flooding, heat waves, affordable housing, public health, and socio-economic and environmental inequities, just to name a few. Solutions to urban problems will necessarily come from a range of interventions that include gray or built infrastructure, green or natural infrastructure, and combinations of the two. Urban development that defaults to gray infrastructure risks inefficient use of resources and lost opportunities for synergies. Nature-based solutions can help cities address many of the challenges they face, breaking down artificial conceptual and policy barriers between urban problems by offering solutions to one problem that can concurrently deliver multiple co-benefits via the services that nature can provide people.

Nature-based solutions can provide a broad range of benefits to people in cities, i.e., ecosystem services—sometimes referred to as nature's contributions to people (Díaz et al., 2018). For example, they can help reduce the risk of flooding, attenuate water, noise, and air pollution, mitigate the urban heat island effect, and provide attractive spaces that promote physical and mental health (Depietri & McPhearson, 2017; Haase et al., 2014; Keeler et al., 2019; van den Bosch & Ode Sang, 2017). Information about how much, where, and for whom investments in natural infrastructure yield benefits can improve urban planning and decision-making and direct limited budgets to projects most likely to provide critical benefits to people (Cortinovis & Geneletti, 2020;

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Hamel et al., 2021; Keeler et al., 2019; Lafortezza et al., 2018). Ultimately, understanding the link between urban nature and human wellbeing can guide the design and redesign of more sustainable, livable, equitable cities. In theory, the approach to evaluating the ecosystem services that nature-based solutions can provide should not differ in rural versus urban landscapes. The "ecosystem service cascade" is a conceptual framework that maps the flow of services from ecosystems to people (Haines-Young & Potschin-Young, 2010; Tallis et al., 2012). It integrates two key components: a biophysical model that describes how a landscape or seascape supplies a specific ecosystem service and a valuation function that translates how the service contributes to human wellbeing. This integration allows decision-makers and stakeholders to evaluate how potential changes in land cover (such as a nature-based solution) affect the amount of the service being provided. Areas of greatest importance for nature-based solutions will be places that have (1) a high density of people using services combined with (2) a supply of ecosystem services that are sensitive to changes in land cover. In practice, however, fine-scale biophysical and socio-economic heterogeneity in urban landscapes make mapping and assessing the equitable distribution of services under alternate scenarios a more challenging endeavor than it is in more expansive, "simpler" rural landscapes (Li et al., 2020; Liu et al., 2017; Lonsdorf et al., 2021; Steele & Wolz, 2019).

Here, we introduce key aspects of assessing nature-based solutions in cities—understanding the supply of services, quantifying their value (i.e., how they impact human wellbeing), and exploring how value depends on context. We then use two case studies to put these concepts into practice. The first highlights approaches and tools for mapping and quantifying multiple benefits of urban green infrastructure, and the second focuses on how benefits flow to different beneficiaries. We conclude with future directions exploring how more information about the values of urban nature-based solutions can lead to better decisions for people and nature in cities.

ASSESSING NATURE-BASED SOLUTIONS: FROM SUPPLY TO VALUE

Ecosystem services provided by nature-based solutions include provision of material goods (e.g., food, feed, materials), regulation of ecological processes that provide benefits to people (e.g., regulation of hazards, climate, air quality, and water quality, provision of pollination, and pest control) and non-material (intangible) services (e.g., improvements in physical and mental health, opportunities for recreation, bolstering belonging and sense of place). See Table 12.1 for some commonly assessed urban ecosystem services.

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Table 12.1 Common urban ecosystem services and their supply of benefits to people living in cities, along with examples of potential metrics to value those services and methods for quantifying those values

Ecosystem service	Supply metric	Value metric(s)	Valuation modeling approach
Climate change mitigation*	Carbon stored or sequestered	Social cost of carbon	Net present value of change in damages from carbon emissions
		Carbon market price	Change in total revenue from sale of carbon credits
Urban cooling*	Air temperature	Productivity	Loss of workplace productivity as a result of temperature and humidity
		Climate emissions	Increased emissions from cooling (and heating) Cost of carbon (e.g., social cost, market price)
		Private cost of cooling	Cost of cooling (and heating) as a function of temperature
		Mortality or morbidity risk	Relative risk of mortality or morbidity as a function of temperature and region
Stormwater retention*	Stormwater volume and mass of pollutants retained by the landscape	Avoided water pollution	Cost of management practices to remove pollutants to meet water quality standards or regulations
		Groundwater replenishment	Cost of groundwater for irrigation and drinking water
Flood mitigation (coastal and pluvial*)	Flood volume or inundation extent, depth, or duration in extreme storm events	Avoided flood damage	Economic damage of crops and of buildings and other infrastructure estimated via repair cost
		Averting behavior cost	Change in costs associated with changing flood risk at the household or community level
		Mortality/injury	Risk of death/injury; number of people affected; value of a statistical life
Coastal hazard mitigation*	Ranked vulnerability of coastline to erosion and flooding	Role of coastal habitats in reducing vulnerability	Compare the number of people, demographics of people, value of property, type of infrastructure, etc. at increased risk in scenarios with and without habitats
Recreation*	Access (distance to parks), park attributes	Number of visitors to parks	Entry or use fees; willingness to pay; travel cost
		Housing prices	Hedonic pricing

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Ecosystem service	Supply metric	Value metric(s)	Valuation modeling approach
Physical activity and health	Access to urban nature (e.g., distance to parks, tree-lined streets, urban gardens, trails, etc.)	Physical activity (e.g., metabolic equivalents)	Relative risk of mortality or morbidity
		Quality of life/years of life	Disability-adjusted life years or quality-adjusted life years
		Avoided cost of treatment	Change in costs associated with treatment to restore original physical health level
Mental health	Access to urban nature (e.g., views of greenery, distance to parks, amount of trees in neighborhood)	Mental health indices (e.g., GHQ12[a], MHI5[b])	Relative risk of mental illness; change in subjective wellbeing
		Avoided cost of treatment	Change in costs associated with treatment to restore original mental health level
Biodiversity	Ensuring continued presence of a species through protection effort	Option value	Bioeconomic modeling of net social welfare as an option value

Notes: * Addressed in the InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) software suite (Hamel et al., 2021; Natural Capital Project, 2023). Not all models provide the full suite of valuation modeling approaches. While it is not an ecosystem service, we include "biodiversity" in the table because many practitioners are interested in exploring biodiversity alongside ecosystem services to inform decisions.
[a] General Health Questionnaire (12 items).
[b] Mental Health Inventory-5.

On Supply: Translating Landscapes into Ecosystem Services

Biophysical models are used to estimate the supply of ecosystem services arising from the landscape. A biophysical model shows the full potential of ecological functions to provide a given ecosystem service, regardless of whether humans recognize or value that function or service (Tallis et al., 2012). Most of the biophysical models underlying ecosystem services translate land use and land cover inputs into the supply of a service using two steps: the site-specific production of a resource and a spatial process that illustrates how that resource flows through a landscape. Realized ecosystem services flow to people when there is supply and demand for the service generated by the interaction of people with the ecological system (Brauman et al., 2020; Burkhard et al., 2014; Cortinovis & Geneletti, 2019).

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On Value: Translating Ecosystem Services to Impact on Human Wellbeing

Value is a complicated word, taking up over a foot of tiny text in its entry in the *Oxford English Dictionary*. Pascual and colleagues (2017) lay out four key meanings important in the context of valuing nature's contributions to people: value is "a *principle* associated with a given worldview or cultural context, a *preference* someone has for a particular state of the world, the *importance* of something for itself or for others, or simply a *measure*." The authors go on to describe the ways in which these meanings are linked, "for example when ethical *principles* lead one to assign *importance* to different aspects of nature's contributions to people, and to have a *preference* for a specific course of action, which in turn can be *measured* by an appropriate valuation tool" (Pascual et al., 2017, p.9, italics in the original).

Realized ecosystem services provide benefits to people; assessing (or measuring) their value is one way to describe the magnitude of their contribution to human wellbeing. There are a number of ways to do so. Economic methods can be used to generate estimates of benefits in monetary metrics, while other methods report estimates of benefits in non-monetary metrics (e.g., impacts on health, livelihoods, or environmental improvements). In sum, a person's or community's values (principles) lead to different assignments of values (importance and preference) and can be valued (measured) in different ways.

In the simplest framing, there are two broad categories used to discuss the values of nature: intrinsic and extrinsic. Intrinsic value is the value that something has *in itself* or *for its own sake* (Zimmerman & Bradley, 2019). Thus, the intrinsic value of nature includes the ways in which it has value irrespective of any relationship to humans. Extrinsic value (also called instrumental value) is the value that something has for the sake of something else to which it is related in some way (Zimmerman & Bradley, 2019) and includes the multiple ways in which nature provides goods and services to people. While Pascual et al. (2017, 2021) argue for "value pluralism" to better incorporate multiple worldviews and values in the identification and implementation of policy, in many cases it is important to recognize the broader context of value pluralism while focusing on individual types of value. Therefore, without denying the importance of intrinsic value, the concepts of ecosystem services and nature's contributions to people focus on extrinsic values of nature in its contribution to human wellbeing (Díaz et al., 2018; Guerry et al., 2015).

In some cases and contexts, monetary valuation of ecosystem services is useful. Monetary values allow aggregation of values into a common metric that can enable comparison of the value of ecosystem services to other goods and services, facilitating benefit–cost analysis of policies or management options. Expression in monetary value can also facilitate application and

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communication in policy, business, and financial sectors that traditionally use monetary measures as key metrics for decision-making. The provision of nature-based material goods sold in markets as commodities (e.g., agricultural crops, animal products, fish, timber) are relatively easy to value in monetary terms. Statistics on quantities and prices are routinely collected and readily available for many nature-based commodities.

Most ecosystem services, however, are more difficult to value monetarily. Most ecosystem services are not traded as commodities, have no observable price, and data on provision of the services may be sparse or missing altogether. Biophysical models can be used to generate estimates of the flows of ecosystem services and then combined with non-market valuation methods from economics to generate estimates of the monetary value of the flows of these services. Non-market valuation methods have been widely used to value environmental improvement (Freeman et al., 2014) and the provision of ecosystem services (Bateman et al., 2013; Committee of Experts on Environmental-Economic Accounting, 2021; National Research Council, 2005; Ouyang et al., 2020; Van der Ploeg et al., 2010).

There are three main types of non-market valuation applied to ecosystem services: (1) revealed preference methods; (2) stated preference methods; and (3) cost-based methods. Revealed preference methods use data on choices to infer values about non-marketed ecosystem services. For example, the premium price for houses on clean lakes or near nature preserves is evidence of the value that people have for nearby recreational opportunities and scenic beauty. Stated preference methods use survey responses to estimate the value that people hold for various ecosystem services. Cost-based methods use estimates of the costs of replacing ecosystem processes, such as the cost of providing clean drinking water with a water filtration plant instead of naturally provided clean water (Chichilnisky & Heal, 1998; National Research Council, 2000).

Where monetary valuation lacks robustness, feels wrong to key stakeholders, or is not relevant to decisions, it is often preferable to report outcomes of ecosystem service assessments in non-monetary terms. Non-monetary measures include biophysical metrics of environmental quality (e.g., whether lakes and rivers meet water quality standards), along with measures directly related to human wellbeing, such as measures of human health or livelihoods (Díaz et al., 2018; Keeler et al., 2012; Myers et al., 2013; Olander et al., 2018; Ruckelshaus et al., 2015). To be good measures of the value of ecosystem services, these measures should fairly directly connect nature to human wellbeing.

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On Context: How Socio-Economic Factors Mediate the Importance of Ecosystem Services

Regardless of how value is measured—in monetary terms, as impacts on human health or livelihoods, or using other metrics—the measure of value will depend on both the ecological and socio-economic context (Nelson et al., 2009; Tallis and Polasky, 2009). For example, the same amount of physical cooling provided by urban vegetation to mitigate the urban heat island effect will be of much greater value to urban residents in regions where hot weather is common compared to those in regions where it is rare. The population density and the size of the "serviceshed," the area in which people benefit from a particular service (Mandle et al., 2015), will determine the number of people affected by a given change in the availability of a service.

Dependence on ecosystem services also varies widely. For example, low-income urban residents who lack air conditioning are more vulnerable to heat stress and more dependent on physical cooling provided by urban vegetation than are high-income residents with access to air conditioning. Careful attention to the vulnerabilities of beneficiaries allows not only for more accurate estimates of the values of services, but also for the addressing of inequities in the flows of services. Characteristics (e.g., age structure, race) and assets (e.g., income) can also affect the vulnerabilities of beneficiaries and vary across groups and with different contexts (see Figure 12.1). As the amount of ecosystem service provided by the urban landscape increases, human wellbeing increases for all people, regardless of vulnerability, but the most dependent would benefit the most and thus receive the greatest value from the increase (Figure 12.1, right). The least dependent on the service receive less value because their wellbeing is already high, regardless of the service supply.

CASE STUDIES

To demonstrate the utility and details of modeling, mapping, and valuing urban ecosystem services we explore case studies from two cities: Guangzhou, China, and Minneapolis, United States (US). These two cases illustrate key elements that make the evaluation of ecosystem services in urban areas uniquely challenging. In Guangzhou, we focus on the impact of fine-scale heterogeneity in land use on the flows of ecosystem services and their values. The Guangzhou case study exemplifies an approach to articulating the ecosystem services provided by a large green space in both biophysical and monetary terms. In Minneapolis, we explore whether the supply of ecosystem services is equitably distributed with respect to socio-economic factors. The Minneapolis case highlights the importance of exploring how different demographic groups benefit from urban ecosystem services, with particular attention on marginalized groups. Together they highlight the linked nature of biophysical processes

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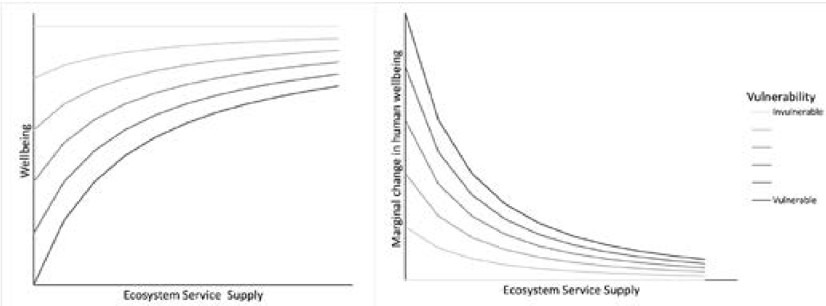

Notes: We expect that increasing supply of an ecosystem service improves human wellbeing but we also recognize that other social factors, e.g., education, access to health care, wealth, and technology or gray infrastructure, can all play mediating roles (left). For example, a neighborhood with high capacity and well-functioning and maintained stormwater infrastructure may be less vulnerable to a heavy rainfall event compared to a neighborhood with poor infrastructure and thus less dependent on the ecosystem service of stormwater retention. The importance of decisions that lead to changes in the supply of the service, i.e., the marginal value, thus depend on the interaction of vulnerability factors and the current supply (right). We expect diminishing returns on investments in ecosystem services for human wellbeing (regardless of vulnerability) as the current supply increases, and that the wellbeing of vulnerable groups continues to be enhanced more than that of less vulnerable groups.
Source: Authors' own.

Figure 12.1 Conceptual illustration of how social vulnerability may mediate the contribution of an ecosystem to human wellbeing

producing benefits, the social dimensions directing their distribution to people, and the data required to quantify them both.

Haizhu Wetland, Guangzhou, China

Guangzhou, China, is part of one of the world's largest metro areas, the Guangdong–Hong Kong–Macao Greater Bay Area, with a population of 72 million at the end of 2019. At 11km^2, the Haizhu wetland in Guangzhou is the largest wetland located in the downtown core of a Chinese megacity (Figure 12.2). Known locally as the "Green Heart" of the city, the wetland is highly accessible from the Central Business District and other densely populated areas, making it a key component of green space access for locals (Figure 12.3). From 2012 to 2020, the wetland received over 60 million visitors. It is also an important area for biodiversity in the city, home to a documented 177 bird and 325 insect species (compared to 72 bird and 66 insect species documented in adjacent urban areas). In 2020, the World Bank partnered with the local planning agency in Guangzhou and our team from the Natural Capital Project to quantify several ecosystem services provided by the wetland—in both biophysical and monetary terms—and to make those benefits explicit

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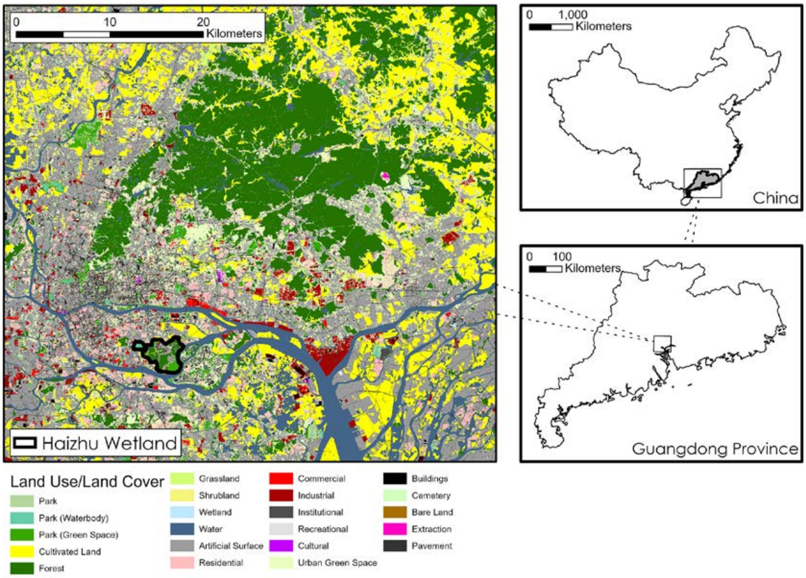
to decision-makers to help protect the wetland from future development. We modeled three services provided by the wetland: climate change mitigation (carbon storage and sequestration); urban cooling; and improvements in health (through both mental health and physical health pathways). We then calculated the provision of those same services in a future without the wetland to estimate marginal values.



Source: Land use/land cover is from GlobeLand30 and OpenStreetMaps data (see methods).

Figure 12.2 Location and land use/land cover of the Haizhu wetland region in Guangzhou, China

Land Use and Land Cover in Urban Environments

In urban areas, all ecosystem services are influenced by the interaction of land cover and land use. Land cover describes what the surface is, while land use provides information on how that cover is being used and thus how it might be managed. For example, turf grass is a common land cover type in urban areas. However, differences in management (e.g., mowing frequency and fertilizer application regimes) can vary dramatically with use (e.g., as residential lawn, recreation area, golf course, cemetery, etc.). These differences in land use within the same land cover type can affect biodiversity as well as services

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Source: Guangzhou Haizhu District Wetland Protection and Management Office (2020).

Figure 12.3 The Haizhu wetland and nearby Guangzhou Central Business District

such as nutrient runoff and retention, and carbon storage and sequestration. If one only used land cover, these differences would not be captured. Thus, it is critical that assessments of urban ecosystem services include both land cover and land use to accurately assess the impact of nature-based solutions.

Unfortunately, single land use and land cover (LULC) data sets that can account for this degree of heterogeneity are often unavailable, requiring creation by combining information from two or more data sets (Lonsdorf et al., 2021). For Guangzhou, we generated a new LULC dataset for the Haizhu wetland by combining land cover from GlobeLand30 (Chen et al., 2017) with land use from OpenStreetMaps (OpenStreetMap Contributors, 2021) and a Normalized Difference Vegetation Index (NDVI) dataset for 2019, derived from Copernicus Sentinel-2 using Google Earth Engine (World Bank, 2022).

Our partners from the planning department in Guangzhou were interested in comparing benefits provided by the wetland to a "no wetland" scenario—most likely one of residential development, given population growth. To create a residential scenario consistent with local patterns of land use and land cover, we applied the "wallpapering" method (Lonsdorf et al., 2021), which takes a small local LULC sample that best represents the future of interest and replicates it across the selected portion of the study area. We sampled an area

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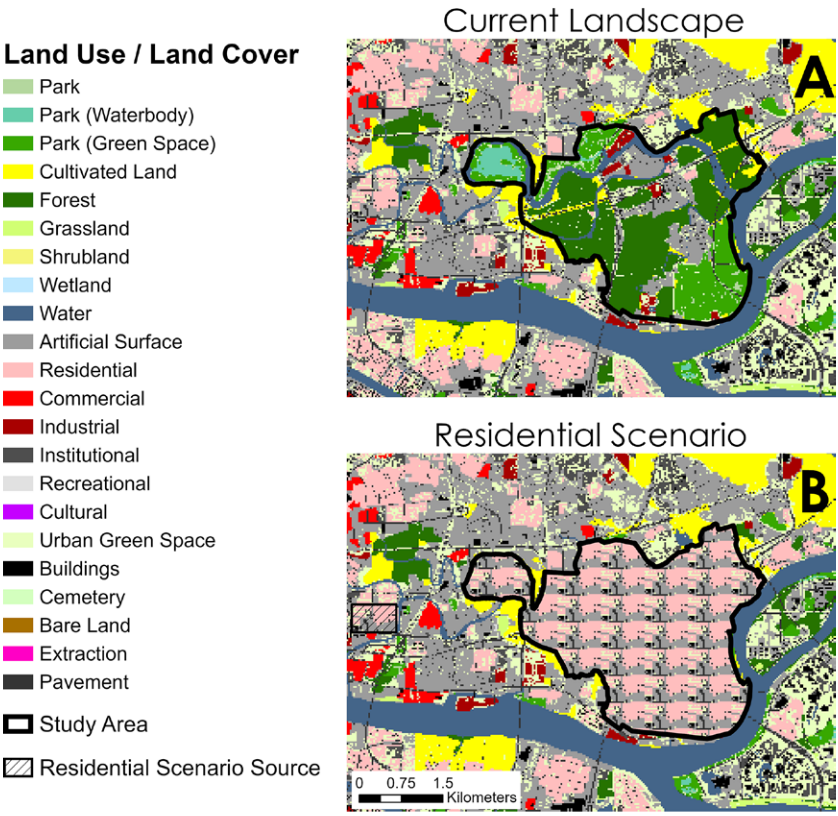

Source: Courtesy of Authors, based on data from World Bank, 2022.

Figure 12.4 *(A) Current land use/land cover in the Haizhu wetland in Guangzhou, China, and (B) alternative residential land use scenario*

of residential housing near the wetland to create a residential scenario (Figure 12.4B), which forms the basis for our marginal value calculations for each of the following ecosystem services. We repeated this process for NDVI using the same sample location as for LULC.

Climate Change Mitigation (Carbon Storage, Sequestration, and Avoided Emissions)

Overview

Climate change mitigation is an important goal for communities and decision-makers in urban areas. Two key mitigation pathways are the reduction

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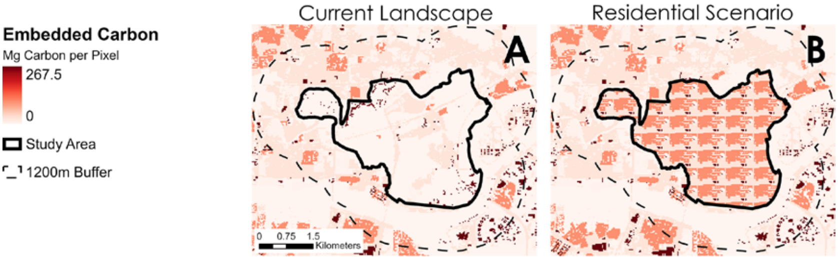
of emissions and sequestering of carbon on the landscape through natural lands and green infrastructure. Traditional methods of estimating landscape carbon storage and sequestration often focus on land cover in mostly natural systems and center on four pools of carbon: above-ground biomass, below-ground biomass, soil carbon, and organic matter (Natural Capital Project, 2023). These pools have analogues in the built environment—soil carbon still persists underneath buildings and pavements (Edmondson et al., 2012), urban green spaces have abundant vegetative carbon stocks above and below ground, and we can even account for organic matter stored in the built environment (building materials, furniture, books, etc.) (Churkina et al., 2010). However, a full carbon accounting in urban areas must include emissions: *flux carbon*, or annual emissions from energy use and land management, and *embedded emissions*, the CO_2 generated during the manufacture and construction of built infrastructure (Kuittinen et al., 2016).

Methods

Supply

We reviewed the literature to estimate parameters needed to reclassify the LULC types into each carbon pool (Mg C/ha), flux (Mg C/ha/year), and embedded emissions (Mg C/ha) (World Bank, 2022). We used the parameter table detailed in World Bank (2022) to reclassify the LULC map into each of these categories of carbon (Figure 12.5).



Note: Similar spatial patterns exist for landscape carbon and annual emissions.
Source: Courtesy of Authors, based on data from World Bank, 2022.

Figure 12.5 Carbon in embedded emissions (from the manufacture and construction of built infrastructure) with (A) and without (B) the wetland

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Value

We translated the carbon storage and sequestration results into monetary value using the social cost of carbon (Nordhaus, 2017). We report monetary value for the average value of the social cost of carbon with a 5 percent discount rate currently in use by the US government, as a conservative estimate of value (Interagency Working Group on Social Cost of Greenhouse Gasses, 2021).

Results

Replacing the wetland with the residential scenario adds 3,700 Mg (3.2 Mg/ha) of carbon to landscape pools, primarily from carbon stored in wood and other building materials. This is equivalent to US$52,500 (US$45 per hectare) in sequestration value. However, the residential development scenario generated significant embedded emissions from manufacturing concrete, steel, and other components of the built environment, increasing embedded emissions by 763,000 Mg (659 Mg/ha), at a societal cost of US$10.7 million (US$9,200 per hectare). Annual emissions similarly increased with transition to the residential scenario by 213 kMg CO_2-e/yr (184 Mg/ha/yr) at a societal cost of US$3.0 million per year (US$2,600 per hectare per year). Using a net present value approach with a discount rate of 5 percent and a 30-year time frame to estimate overall damages of annual emissions, we found the combined climate impacts from landscape carbon and annual and embedded emissions under the residential scenario amount to US$89.7 million of damages.

Urban Cooling

Overview

The urban heat island (Deilami et al., 2018; Oke, 1973; Rizwan et al., 2008) arises in cities due to a combination of heat capture and radiation by the built environment. Buildings and pavements capture solar radiation as excess heat, releasing that stored heat slowly and, if arranged in a dense enough urban fabric, raising the city's baseline ambient air temperature. This process can exacerbate extreme heat waves and increase the risk of mortality and morbidity among vulnerable populations, a pattern likely to worsen under human-induced climate change (Santamouris, 2020).

Methods

Supply

We used the InVEST Urban Cooling model to calculate the effect of the residential land use scenario on the local urban heat island (Natural Capital Project, 2023). In addition to LULC maps, this model requires data for reference evaporation (Trabucco & Zomer, 2019), reference air temperature for each month

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(Kenji & Willmott, 2018), the maximum urban heat island magnitude (2.07°C, from https://yceo.users.earthengine.app/view/uhimap) (Chakraborty & Lee, 2019), the air temperature blending distance (600 m) (Lonsdorf et al., 2021; Oke, 2006; Schatz & Kucharik, 2014), and the maximum distance from which large contiguous green areas (> 2 ha) contribute additional cooling (100 m, as per InVEST recommendations). The model also relies on a parameter table linking each LULC category with five primary drivers of the urban heat island: shade, evapotranspiration potential, albedo, green area inclusion, and building intensity. To inform the selection of values, we reviewed the global literature on each of these parameters as they related to each of our LULC categories (see more detail in World Bank, 2022).

Value

We assessed the monetary value of the wetland using a marginal value approach, calculating the projected loss of workplace productivity and increased energy cost of heating and cooling buildings in the surrounding areas. We used the Wet Bulb Global Index to inform changes in workplace productivity (Kjellstrom et al., 2009), using an average relative humidity of 71.1 percent (Ou et al., 2014). As data on workplace location and intensity of work (e.g., outdoor labor versus indoor office work) were unavailable for the study area, we assumed that commercial and institutional areas were "light work" and industrial areas were "heavy work" as per the InVEST guidelines (Natural Capital Project, 2023).

We translated the increased air temperature from the residential scenario into the increased energy consumption necessary to cool residential and commercial buildings using heating and cooling degree days (Roxon et al., 2020), assessing monetary value using the typical costs of energy per building type in Guangzhou (World Bank, 2022).

In addition to monetary value, we also estimate the avoided mortality provided by the wetland. Epidemiological literature reports that relative risk of heat-induced mortality increases above a "minimum-mortality" threshold temperature, which varies regionally due to the acclimatization of local populations but generally hovers around the 75th percentile of a region's temperature range (Guo et al., 2014). While this relationship between relative risk and temperature is non-linear, changes in risk are only reported at certain thresholds in the literature (i.e., 90th and 99th temperature percentiles) so we assumed a linear relationship to convert temperature maps into risk maps.

Results

Average August air temperatures surrounding the wetland vary between 30.7 and 31.5°C (Figure 12.6A). Under extensive residential development, the surrounding 600 m buffer would experience an average 0.25°C increase in air

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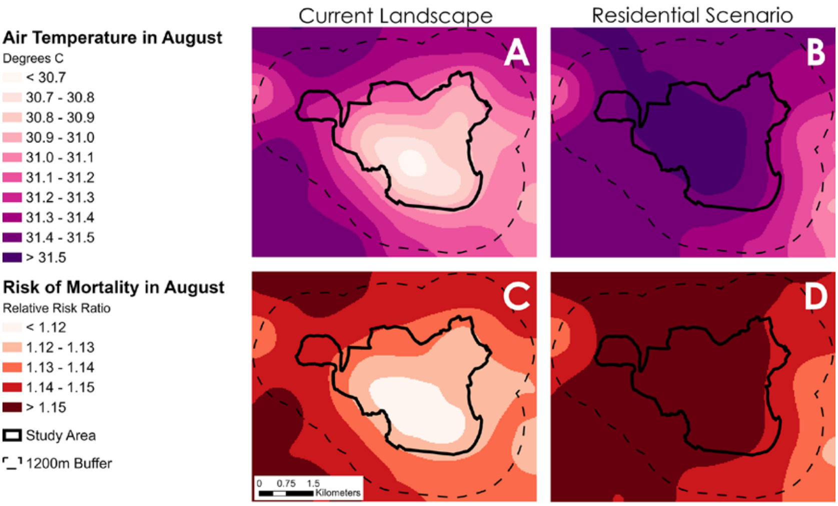
temperature on a typical day, a figure that increases to more than 1°C within the wetland area itself (Figure 12.6B). This represents the typical summer urban heat island effect—during an extreme heat wave, we can expect the loss of the wetland to further exacerbate temperature rise.



Note: Under the residential scenario, temperatures increased by an average of 0.25°C within the 600 m buffer surrounding the wetland (dotted line), corresponding with a 1.23 percentage increase in mortality risk.
Source: Courtesy of Authors, based on data from World Bank, 2022.

Figure 12.6 *Modeled air temperature in August under (A) the current landscape and (B) residential scenario and the associated relative risks of mortality (C, D)*

Without the wetland, workplace productivity in nearby heavy work environments fell during May and October (2.5 and 16.1 percent, respectively), while light work environments saw no change (World Bank, 2022).

The increase in air temperature under the residential scenario increased cooling energy demand during the summer months but decreased demand for heating energy during the winter months. As Guangzhou sits in a generally tropical climate with an average annual temperature of 22.4°C, the cooling demand outstrips heating demand over the course of a year: annual energy consumption by buildings within 600 m of the wetland increased by 1.1 million kWh at an annual cost of US$119,800. Using a net present value approach with a discount rate of 5 percent and a 30-year time frame, this represents US$1.9 million.

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For Guangzhou, the 75th, 90th, and 99th temperature percentiles are 28, 30.1, and 32°C, respectively; the relative risk of mortality at each of those thresholds is 1, 1.08, and 1.18 (Guo et al., 2014). Linear interpolation between these points allows us to convert temperature to relative risk, which we use to compute the difference in relative risk of mortality between our two scenarios (Figure 12.6C, D). The surrounding 600 m buffer will experience between 1.23 and 1.27 percent increase in mortality risk each month between June and September, a pattern likely to worsen during extreme heat events (World Bank, 2022).

Improvements in Physical Health Through Increased Access to Urban Green Space and Resulting Increases in Physical Activity

Overview

Access to urban nature and green spaces can affect people's physical health by increasing physical activity, which leads to multiple positive health outcomes (Remme et al., 2021; Warburton, 2006). We adapted an approach from Vivid Economics (2017), where the value of green space for physical health is a function of the "catchment area" (or area of influence of a park on people's physical activity), the contribution of green space to physical activity provision, population, and the costs of physical inactivity.

Methods

Supply

Liu et al. (2020) determined that the catchment area was 2,230 m from a park boundary for Guangzhou. To incorporate the effect of other parks beyond the Haizhu wetland catchment on the population in the catchment, we doubled this buffer size and included any parks larger than 2 ha in that area. Given a lack of local data on the relative importance of green space to physical activity, we assumed that green space could contribute up to 11 percent of an individual's total physical activity, a conservative estimate from a study in Seattle, US (Stewart et al., 2018). We used a population dataset created by Liu et al. (2020) for central Guangzhou to scale the benefit of activity by each person.

We assumed that the contribution of green space to total physical activity declines with increasing distance from green space throughout the catchment: for the first 300 m that contribution remains 11 percent (Labib et al., 2020), followed by a linear decay towards 0 percent at 2,230 m from a park.

Value

To estimate the avoided health-care costs due to physical activity in green spaces, we calculated the costs of physical inactivity, based on the valuation

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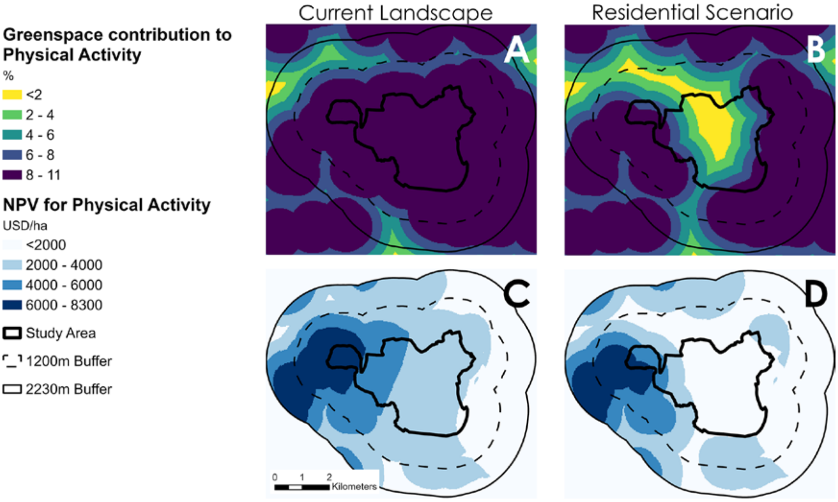
done by Zhang and Chaaban (2013) for China: US$44.2 billion in 2007. We extrapolated these costs to 2017 based on health expenditure figures for China (World Bank, 2021) and corrected those to 2020 US dollars: US$215.6 billion. With a population of 1.386 billion in 2017 this results in physical inactivity costs of US$23.58 per capita. We applied a net present value approach with a 30-year time period and a discount rate of 5 percent to calculate the difference in value between the current and residential scenarios.

Results

If the Haizhu wetland were developed into a residential area the average contribution of green space to physical activity would drop from 9.3 to 7.0 percent in the 2,230 m buffer zone (Figure 12.7), affecting about 230,000 people. The Haizhu wetland is of particular importance for the population living in and to the northwest of the wetland where there are few alternative sizable urban green spaces that could sufficiently support physical activity (Figure 12.7). In monetary terms, the development of the wetland could cause a loss of at least US$3.0 million in net present value over 30 years from declines in physical activity.



Note: In the 2,230 m buffer zone, the net present value loss is US$3.0 million under the residential scenario compared to the current situation.
Source: Courtesy of Authors, based on data from World Bank, 2022.

Figure 12.7 The percentage contribution of green space to physical activity for (A) the current landscape and (B) the residential scenario, and the corresponding net present value (NPV) of green space for physical activity in the Haizhu wetland and surroundings (C, D)

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Improvements in Mental Health Through Access to Urban Green Space

Overview

Mental health has been linked to access to green space in urban areas (Bratman et al., 2019; Gascon et al., 2015; Houlden et al., 2018). Here we use a dose–response relationship where mental health outcomes and changes in expenditures on those outcomes at the population level are derived as a function of natural area within a given distance from urban populations.

Methods

Supply

We linked the WHO-5 index value, a commonly used survey-based index measuring psychological wellbeing (Topp et al., 2015), to natural areas in Guangzhou based on Liu et al. (2019). Liu et al. used multiple regression methods to relate WHO-5 scores in Guangzhou to a variety of neighborhood characteristics, including demographic variables and importantly an indicator of green space—the mean NDVI within a 1 km buffer around the neighborhood. The mean observed WHO-5 score (out of 25) was 12.081 in Guangzhou, and the WHO-5 goes up by one point for every 0.136 increase in mean neighborhood NDVI (baseline 0.097), all else being equal, i.e.

$$W = 12.081 + ((NDVI - 0.097)/0.136) \quad (12.1)$$

Unfortunately, we did not have the required data to apply this as a functional value transfer approach, where we adjust neighborhood estimates based on variation in other covariates besides NDVI, so we use this unit value approach. While unit value transfer approaches generally perform poorly compared to function transfer (Kaul et al., 2013), in this case the value estimates were derived in the Guangzhou case study area and are more likely to be representative of the population than if they were transferred from elsewhere.

Value

We linked changes in population-level expenditures on mental health in the Haizhu wetland area in Guangzhou to natural areas using the following equation adapted from Vivid Economics (2017):

$$\text{Change in expenditures}_i = \text{Pop}_i * \text{Exp}_i * \left((-1) * \left(W_i^R - W_i^C\right)/W_i^C\right) \quad (12.2)$$

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where

Pop_i = population in raster cell ("neighborhood") *i*
Exp_i = per capita mental health expenditures in neighborhood *i*
W_i^j = score (index value) on the World Health Organization five-question wellbeing survey in neighborhood *i* for scenario *j*, where *j* *{Current, Residential}*.

WHO-5 scores range from 0 to 25, with larger values indicating greater quality of life. The (−1) establishes an inverse relationship between expenditures and WHO-5 score.

The linkage between change in WHO-5 survey score and change in per capita mental health expenditures is assumed to be 1:1. The actual relationship is likely to be more nuanced than this ratio suggests (Buckley et al., 2019), though there is insufficient data to parameterize it in Guangzhou.

We treated per capita neighborhood expenditures on mental health as constant across neighborhoods. We derived this value from Xu et al. (2016), who estimated an annual burden in China (total social expense) of US$88.1 billion (2013) for those that elect for treatment, and US$484.1 billion if all who suffered mental health issues were treated. This latter figure is more appropriate as a social welfare metric. The population of China was 1.357 billion in 2013, so this comes out to US$356.74 per person per year, or US$389.54 in 2020 US dollars.

We calculated the expected change in expenditures for a given neighborhood between scenarios *Current* and *Residential* by substituting equation (12.2) into equation (12.1) for WHO-5 values calculated at *{Current, Residential}*. Total change in expenditure is equal to the sum of the change in neighborhood expenditures, for neighborhoods within 1 km of Haizhu wetland. Neighborhoods for this analysis are defined as population cells (~ 90 m^2) from the 2020 WorldPop global population map.

We reflected the difference between the *Current* and *Residential* scenarios through a change in NDVI within the Haizhu wetland boundaries, holding all else equal. We extracted the mean NDVI within a 1 km buffer for all neighborhoods from the baseline NDVI map, derived from Copernicus Sentinel 2/ Google Earth Engine at 10 m resolution. For the *Current* scenario, we calculated a neighborhood's mean NDVI and then used a NDVI "wallpapering" approach consistent with the land cover wallpapering (Figure 12.3) to calculate the NDVI for the *Residential* scenario. The analysis does not account for the wellbeing of any new residents that accompany a developed Haizhu wetland.

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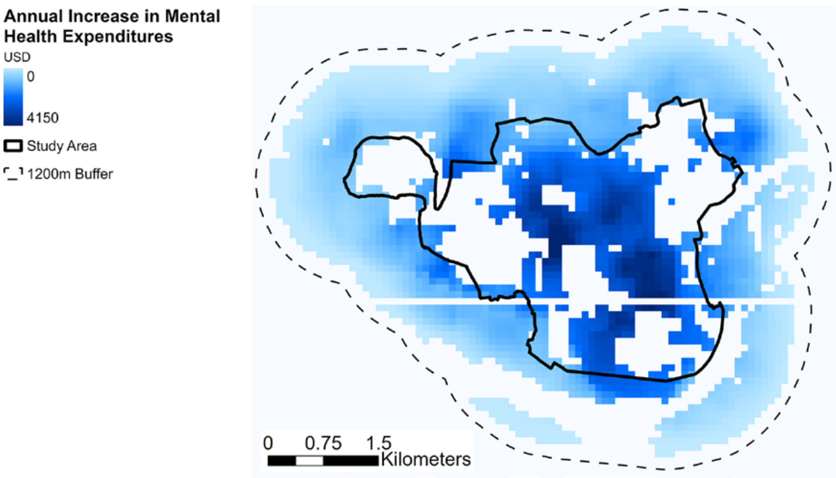
Results

Residential development leads to decreases in the value of the Haizhu wetland for mental health (Figure 12.8). Aggregate population in neighborhoods inside or within 1 km of the Haizhu wetland equals 238,000 people. Mean NDVI across neighborhoods in the *Current* scenario is 0.21; in the *Residential* scenario it is 0.15. This loss in natural areas leads to an annual increase in mental health expenditures of US$2.90 million, with a net present value of US$44.6 million over 30 years at a 5 percent discount rate.



Source: Authors' own.

Figure 12.8 Annual increase in mental health treatment expenditures expected without the wetland

Synthesis of the Haizhu Wetland Assessment

Analyzing the supply and consequent value of ecosystem services allows decision-makers to fully understand the externalities of development decisions. To examine the change in the total value of the four services examined here, we excluded the value of physical health. This is a conservative approach, recognizing that the value of physical health is theoretically incorporated within the mental health valuation methods. When viewed in aggregate, the marginal value of the explored ecosystem services provided by the Haizhu wetland totals US$146.8 million over the next 30 years (Table 12.2), in addition to reduced mortality risk and increased workplace productivity in

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Table 12.2 *The marginal value of four ecosystem services generated by the Haizhu wetland when compared to a residential development scenario*

Ecosystem service	Value metric(s)	Marginal value of the Haizhu wetland (net present value using 5 percent discount rate unless otherwise noted)
Climate change mitigation	Social cost of carbon	US$100.3 million over 30 years
Urban cooling	Productivity	2.5 to 16.1 percent increased workplace productivity within 600 m (May and October)
	Private cost of cooling	US$1.9 million over 30 years
	Mortality risk	1.23 to 1.27 percent decreased risk of monthly mortality within 600 m (June through September)
Physical health	Avoided cost of treatment	US$3.0 million over 30 years
Mental health	Avoided cost of treatment	US$44.6 million over 30 years

Note: The value metrics and ecosystem services presented are not exhaustive, and thus this is an underestimate of the marginal value of the ecosystem.
Source: Courtesy of Authors, based on data from World Bank, 2022.

the surrounding landscape. Crucially, this is an explicit underestimate of value because wetlands, in addition to mitigating climate change, cooling the urban fabric, and bolstering mental and physical health, also improve water quality, enhance biodiversity, and mitigate flood risk, among other services (Maltby & Acreman, 2011).

While this case study succeeds in articulating the ecosystem service supply and value of an urban green space, it does not explicitly identify those who benefit most from these services. For instance, the urban cooling benefit of the Haizhu wetland will be of greatest benefit to households lacking air conditioning or individuals at greater risk of complications due to excessive heat exposure. Socio-economic status can intersect with ecosystem services to ameliorate—or exacerbate—existing vulnerabilities (Keeler et al., 2019). We must, therefore, expand our effective definition of value to include not only the services rendered, but the relative needs of the recipients as well. In short: Who benefits the most from nature?

Multiple studies have demonstrated dramatic inequities in the distribution of green space and other types of green infrastructure throughout individual cities (Gerrish & Watkins, 2018; Landry & Chakraborty, 2009; Nesbitt et al., 2019). This affects the delivery of multiple different urban ecosystem services, including urban cooling. For example, canopy cover, percentage of impervious surface, and poverty level were all strong correlates of extreme heat in Richmond, Virginia, US (Saverino et al., 2021), and the Urban Heat Risk Index and proximity to green space are associated with many indicators of social

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vulnerability in Delhi, India (Mitchell et al., 2021). In the second case study, we build on the themes of mapping and valuing urban ecosystem services explored in the Guangzhou case to sharpen the focus on beneficiaries by exploring the flow of benefits to different groups in Minneapolis, Minnesota, US.

Minneapolis, Minnesota, United States

Minneapolis is a city of nearly 430,00 people (United States Census Bureau, 2020b) in the Great Plains region of the US. Previous work has been done to detail methods for applying urban ecosystem service models and valuation techniques to the city (Hamel et al., 2021; Lonsdorf et al., 2021), similar to the Guangzhou case study. We present this case study here to demonstrate how an assessment of the benefits provided by urban green space and nature-based solutions can and should go beyond valuation to take into account existing socio-economic disparities and vulnerabilities, which can temper or enhance the benefits urban nature provides (see Figure 12.1).

Rather than analyzing the benefits of any one urban green space in Minneapolis, we focused instead on the beneficiaries of urban ecosystem services across the city—mapping one service (urban cooling) and exploring how its benefits flow differently to different groups, with particular attention on marginalized groups. The first step in understanding disparities in the distribution of benefits from nature-based solutions is identifying who is marginalized and why marginalization occurs in a given local context. Schemata or mechanisms of historic and/or ongoing marginalization in a particular area can include processes as broad as colonization, settlement, land seizure, racism, and classism—or they can be narrow and place-specific, such as racially restrictive housing covenants placed on properties for sale. Minneapolis has a history of seizure of Indigenous lands, racist housing and land tenure policies through "redlining" programs like the Home Owners Loan Corporation, and housing covenants disallowing sales to non-white prospective owners (Delegard & Ehrman-Solberg, 2017). Given high disparities along racial lines in Minneapolis, we focused on race and poverty as mechanisms of marginalization to analyze disparities in urban nature's contributions to human wellbeing.

Methods

To reveal the impacts of structural inequities, we analyzed whether the distribution of impoverished or Black, Indigenous, and People of Color (BIPOC) residents in Minneapolis is related to the distribution of ecosystem services. We analyzed the distributional impacts of Minneapolis' urban heat island using the InVEST Urban Cooling model (Natural Capital Project, 2023) following prior work in the study area (Hamel et al., 2021). Assessing whether the

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risks of urban heat island exposure correspond to the locations of vulnerable populations is of paramount importance for municipal decision-makers interested in addressing inequities in urban green infrastructure (e.g., Hoffman et al., 2020; McDonald et al., 2021). While techniques exist to analyze and detect spatial patterns of inequality for different socio-economic groups (Roberto, 2016), relatively few studies have examined patterns of distributional inequity in urban ecosystem services (but see Liotta et al., 2020; McDonald et al., 2021; Nesbitt et al., 2019).

Similar to Nesbitt et al. (2019), we use a simple measure of correlation between two variables summarized at the US Census block group level—air temperature in degrees Celsius and either the percentage of the population that is BIPOC or the percentage of the population deemed impoverished in the 2018 American Community Survey (United States Census Bureau, 2020a). We mapped out how each block group contributed to the overall correlation to identify areas that are either (1) relatively cool and socio-economically privileged (white or not impoverished) or (2) relatively hot and socio-economically vulnerable (BIPOC or impoverished). This technique maps potentially uneven distributions of ecosystem services or vulnerability to environmental hazards and thus can help to highlight areas with a greater need for nature-based solutions.

Results

Areas of the city with higher poverty rates are hotter than average. High-poverty neighborhoods do not benefit as much from nature-based urban cooling (Figure 12.10A–C). The correlation between the poverty rate and air temperature was 0.57 ($r_s = 0.57$, $p < 0.01$; Figure 12.10D). A similar but less stark relationship exists for areas of the city with predominantly BIPOC residents ($r_s = 0.17$, $p < 0.01$).

Synthesis of the Minneapolis Inequalities Assessment

Urban cooling is distributed unequally in the city, particularly with respect to poverty. Revealing inequities like this can help encourage city officials to prioritize investments in poorer neighborhoods. This is especially important when the value of the services is higher for people with lower incomes. For example, more economically vulnerable people could lack air conditioning or be more dependent on publicly provided benefits as compared to privately provided (e.g., Figure 12.1). We suggest caution, however, in only using this kind of analysis to guide action. Distributional inequity often results from deeper, structural inequities and actions to improve services provided through nature-based solutions without addressing these could contribute to gentrification and displacement (Amorim Maia et al., 2020; Zhao et al., 2018). Overall, these types of distributional equity maps of ecosystem services add needed

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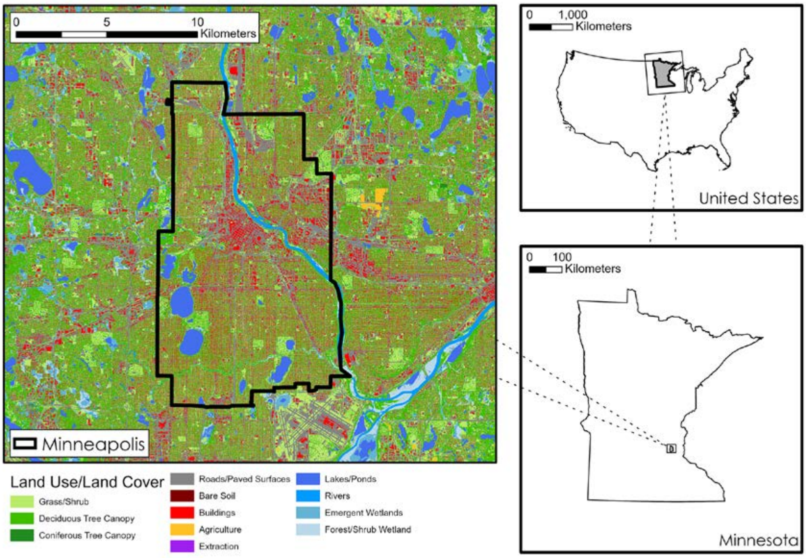

Source: Courtesy of Authors, based on data from Host et al., 2016.

Figure 12.9 Location and land use/land cover of Minneapolis

context for decision-makers who may need to determine whether policies are improving equity and locating the most inequitable areas.

FUTURE DIRECTIONS AND CONCLUSIONS

Using Ecosystem Services to Inform Urban Decisions at Different Scales

Here, we explored two case studies in which information about urban ecosystem services can inform specific land use decisions within a city. In the first, we explored how multiple ecosystem services might change in a future scenario with a significant loss of urban green space. In the second, we examined how attention to the beneficiaries of a single ecosystem service can expose inequities and ultimately inform plans and policies that address them. Both of these examples are from roughly the same scale—exploring how LULC within a city affects the flows of benefits to people. However, decision-makers interested in incorporating the benefits provided to people from nature in the city ask different types of questions at different scales and varying levels of specificity.

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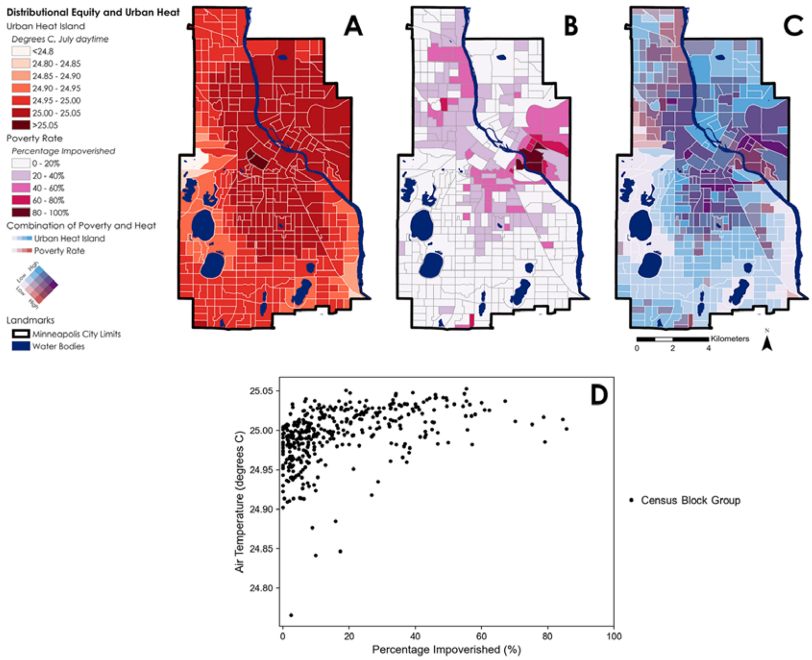

Source: Authors' own.

Figure 12.10 *Maps of (A) modeled air temperature in degrees Celsius and (B) the percentage of the population per census block group below the federal poverty line in 2018, alongside (C) a bivariate map highlighting areas with high levels of both heat and poverty and (D) a scatterplot showing the city-wide relationship between heat and poverty (Spearman's r = 0.57, p < 0.01)*

At the finest scale, such as our examples from Guangzhou and Minneapolis, municipal governments, private landowners, community associations, development agencies, and public–private partnerships ask questions about how nature-based solutions can inform particular land use decisions within a city. Asking and answering these questions and those like them take place daily and cumulatively shape the future of cities. These are questions such as: What benefits do urban residents get from this natural area within the city and does it make sense to maintain it as it is? What use of this parcel will best satisfy diverse objectives? 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

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programming that targets those with greatest need? As with the city-scale questions, these parcel-scale questions also require the exploration of alternative future scenarios and their likely impacts on the delivery of ecosystem services to people.

At a larger scale, questions that focus on a city as a whole can be used to prioritize investment in nature-based solutions and to create zoning plans within the city. These questions help explore opportunities and challenges in the city, such as stormwater management or resilience to intensifying temperature extremes. Illustrative questions include: Where does urban nature provide the most benefits to people in this city? Where are more trees, wetlands, or other nature-based solutions 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 can we improve equity in the delivery of nature's benefits to residents? These questions are being asked by city governments, planners, utilities, non-governmental organizations, environmental justice groups, and public–private partnerships. Answering these questions often requires the exploration of alternative development scenarios and their likely impacts on the delivery of ecosystem services to people.

Similarly, municipal decision-makers in a single city can examine their city as a whole, comparing it to peer cities or working to meet urban, national, or international targets for urban nature and biodiversity. In this type of enterprise, urban leaders can use peer cities to spark inspiration for the development trajectory of their city. Questions such as these are often asked principally by city governments and planners, in consultation with national governments and international organizations to guide urban design at the highest levels. They can help lenders such as multilateral development banks and non-governmental organizations prioritize investments in particular cities—or help those cities argue for such investments. Some example questions include: Is our city a good candidate for a water fund (e.g., Tellman et al., 2018)? Which cities have pioneered approaches for incorporating nature-based solutions into urban planning that my city could adopt? Here, as with questions at the global scale, understanding broad patterns of biodiversity and ecosystem service provision helps to provide context. Assessments of biodiversity and ecosystem services of particular regions or cities can help to answer these questions (e.g., Heris et al., 2021; PBL Netherlands Environmental Assessment Agency, 2021).

At the broadest scale, international organizations, national governments, and non-governmental organizations are interested in identifying cities of particular significance in achieving stated goals. Questions at this scale can help target partnerships and investments in particular municipalities. Example questions include: Which cities have globally significant levels of biodiversity either within the city or in the hinterlands that might be at risk from urban growth (e.g., McDonald et al., 2018)? What cities are good candidates for

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upstream or upwind investments in ecosystem restoration to improve water or air quality (e.g., Tellman et al., 2018)? Understanding global patterns of biodiversity and ecosystem service provision is a critical piece of information that can help answer these and other broad-scale questions (Brauman et al., 2020; Chaplin-Kramer et al., 2019; Díaz et al., 2018). No matter the scale of question asked, approaches to mapping, measuring, and valuing the benefits provided by nature to people can inform the strategic use of nature-based solutions in cities in ways that improve the livability, sustainability, and equity of the cities of today and tomorrow.

Improving Assessments of Beneficiaries

An important aspect of nature-based solutions that has not received as much attention to date as it deserves is the distribution of benefits across different groups in society. Disadvantaged and marginalized groups often are more dependent on their local environments but have less say over the policies that influence their environment. The Minneapolis case study examined the distribution of urban cooling benefits across both income and BIPOC groups. We found that neighborhoods with low income and minority groups that had less green space were exposed to higher temperatures than high-income and predominantly white neighborhoods.

Addressing the imbalance in benefits, however, is not so straightforward. Investing in nature-based solutions in a neighborhood increases the relative attractiveness and value of the neighborhood, an effect often referred to as "green gentrification." Approaches like ours do not (yet) predict how people may move in response to changes in ecosystem services. Community engagement around fears of gentrification and green gentrification (Ehrman-Solberg et al., 2020) suggests that adding nature-based solutions to areas of the city that house historically marginalized communities can inadvertently lead to displacement and therefore may not end up helping the people that the policy intended to benefit. Improving outcomes for marginalized communities may require addressing deeper structural inequities that go beyond investing in nature-based solutions in currently disadvantaged neighborhoods. A model that could identify when projects may lead to green gentrification due to a large influx of capital or green infrastructure investment in vulnerable communities would help decision-makers. The ability to quantify equity and the distribution of ecosystem services is critical to the equitable use of nature-based solutions in urban planning. We hope to engage the research community—and urban communities—in the creation of tools that help integrate ecosystem services and equity into urban planning.

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Improving and Disseminating Models of Supply and Value

As we have shown in the two case studies, we have useful models for mapping and valuing ecosystem services in urban areas. However, the urban models in InVEST are very new (Hamel et al., 2021) and will, over time, benefit from improvement as they are applied in real decision contexts in cities around the world. Over time, we expect that there will be improvements in the breadth of coverage of benefits (and costs) from investing in nature-based solutions, as well as the accuracy and reliability of our ability to estimate the supply of ecosystem services and their value. In many cases, general models of the supply of ecosystem services are easier to create in one context and apply in others, lending themselves to inclusion in flexible, global tools such as InVEST. General models for the value of ecosystem services tend to be more context-specific and thus require more detailed site-specific information that goes beyond what can be taken from an off-the-shelf globally applicable model. Models that address issues of distribution of benefits also tend to be context-specific, requiring more detailed information about different groups within the urban area and how dependent they are on ecosystem services. Further innovation connecting global and local data sources to valuation approaches such as those outlined in Table 12.1 will allow for broader inclusion of valuation in accessible tools such as InVEST.

Urban planners use a wide range of approaches to connect today's cities with visions of the future. Lowering barriers to including information about the multiple benefits of green infrastructure in cities can help integrate knowledge of ecosystem services into urban planning, but only if tools are actionable and easy to use. Tools such as InVEST are currently accessible only to those with GIS skills and basic modeling experience. Gathering the relevant local data can also be a barrier to using these approaches in urban planning. Lowering barriers by including relevant data sources with models and enhancing the user-friendliness of the software will increase the uptake of these approaches and tools.

Ultimately, a deeper understanding of the multiple benefits provided to people by urban nature can inform smarter targeting of investments in urban nature-based solutions. Creative solutions for more sustainable and equitable cities of the future can emerge from better, more accessible models of the supply of those services coupled with better, more nuanced understanding of their values to people.

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PART V

Engaging art and design for and with nature-based solutions

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13. Urban designs as social-natural resolutions

Brian McGrath, Danai Thaitakoo, Nithirath Chaemchuen, and Tommy Yang

INTRODUCTION

This chapter presents an integrative notion of urban design as an array of small-scale practices that "trigger" (Merwood-Salisbury and McGrath 2013) regenerative social-natural processes towards achieving a just transition from extractive to regenerative economies (https://climatejusticealliance.org/just-transition/). Our perspective is that equitable and sustainable urban designs are only achieved through the material resolution of the dynamics between socially produced spaces and natural processes, rather than exclusively as modern nature-based solutions (NBS). Good urban designs achieve not only the right to the city (Harvey 2008), but also the right to nature (Apostolopoulou and Cortes-Vazquez 2018). Since its mid-twentieth-century origins, however, urban design has had a troubling authoritarian, anti-social and anti-natural history, tied to the misuse of bureaucratic power based on Western ideas of modernization (Berman 1981; McGrath 2020) and the misuse of natural metaphors to describe urban social processes (Light 2009). Based on this troubling history, we argue against uncritically adopting modern NBS to the already overly technocratic disciplines of centralized urban design planning, and advocate for the cooperative formulations of continually evolving social-natural resolutions (SNR) negotiated through diffuse but nested consensual management and governance practices. Social-natural *resolutionary* processes can continually advance both new frontiers in ecological science as well as advancements in design justice (Costanza-Chock 2020). The growth of low- to medium-density urbanization across the globe is a pressing issue today with urban land consumption outpacing population growth (McGrath et al. 2017). We offer here indigenously based designs through the practice of "spatial ethnography" (Sen and Silverman 2013) in Chiang Mai, Thailand, as an example of designing for the new complex, connected, diffuse and diverse global urban realm (McHale et al. 2015).

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This chapter is structured around two critiques of modern NBS as applied in urban design, followed by alternative examples of urban designs as SNR using the case study of Chiang Mai. The first section outlines the emergence of the technical and specialist subfield of urban design, created by architect-planners in the United States in the face of the massive funding for urban renewal following the Second World War. The second section discusses how a second technical subfield for regional planning, named landscape ecology, grew out of environmental concerns around suburbanization from the new perspective afforded by aerial imagery. The third section examines the case study of Chiang Mai, where we test integrative practices of urban designs as SNR. Chiang Mai, an ancient and until recently small and remote city/territory, is currently witnessing rapid urbanization and development following the construction in the 1980s of an international airport and a super highway connected to Bangkok. Mid-twentieth-century planning models based on central business cores surrounded by satellite towns, linked by radial and circumferential traffic planning and controlled by land use zoning, were introduced to direct speculative growth (McGrath et al. 2017). These North American-based bureaucratic practices ignored the architectural and landscape patch matrix of indigenous, village-based social-natural and hydrological systems. This chapter concludes with a discussion of the *metacity*, a framework developed between ecology and urban design to conceptualize the integration of social justice movements with design as a model for new expanded and integrated forms of urban design practices (McGrath and Pickett 2011; McGrath 2018; Pickett and Grove 2020).

MODERN PLANNING AS SOCIAL-NATURAL DISTURBANCE

On April 9 and 10, 1956, the first Urban Design Conference was convened at Harvard's Graduate School of Design by the school's dean, architect Jose Luis Sert. Sert was also the last president of CIAM (Congrès Internationaux d'Architecture Moderne), the highly influential organization founded in 1928 by the Swiss modernist architect and urban planner Le Corbusier. CIAM was dedicated to the idea that cities should be radically transformed by the master architect-planner, employed by the state, to improve the crowded living conditions of the urban population globally (Mumford 2009). The conflicts inherent in the transformation of this European utopian technocratic movement with the post-Second World War American city continued to be debated in 2006 at the 50th anniversary of the founding of urban design (Krieger and Saunders 2009), and more recently considering urbanization at a planetary scale (Brenner 2013).

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While CIAM previously had advocated for a modernist vocabulary of widely spaced concrete and glass housing slabs set in greenery as a sanitary alternative to the dense matrix of traditional urban form, the Urban Design Conference in 1956 focused on creating new designs for urban cores in both older city centers scarred by urban renewal and for new car-based suburbs. Sert argued that these new urban cores "were the only places where civic culture could continue and be able to resist the centralizing and undemocratic forces of mass media-based politics" (Mumford 2009, 18). The conference conjured the new figure of the urban designer, combining the role of the planner, architect, and landscape architect, in the design and development of cities (Marshall 2009, 45). The tone emphasized the authoritative and "directive" role of this new professional figure embodied by the powerful chief planner of Philadelphia, Edmund Bacon. Urban design for Bacon was the physical fulfillment of the willful direction of power through a master plan, modeled on papal Rome or imperial Beijing (Bacon 1974). The conference's motives were inadequate to the demands to dismantle the social and environmental waste inherent in the new car-based suburban/city center commuting society. Not present were the voices of the displaced residents of the actual neighborhoods that had been historically marginalized by segregation, redlining, highway construction, urban renewal, and mass incarceration, nor the small farm owners whose greenfield land was converted to new subdivisions (Rothstein 2017; McGrath et al. 2019).

At the time of the 50th anniversary of the first Urban Design Conference, the politics of neoliberalism left few federal resources for cities. According to Jonathan Barnett, who created the Urban Design Group within the New York City Department of City Planning, "cities today are designed by an intricate interplay of private investment, public subsidies and incentives for development, government regulations, public participation, and public protest" (Barnett 2009, 103). The grand master plans of Bacon gave way to contested micro-zoning strategies through the design of new contextual urban fragments mimicking historical urban patterns (Rowe and Koeter 1978; Rossi 1982; Shane 2005). In New York City, form-based contextual codes developed for special zoning districts, such as around the Broadway theaters and the design guidelines for Battery Park City, were copied by developers worldwide, both in existing city centers and emerging edge cities.

Of the participants at the 50th anniversary conference in 2006, Michael Sorkin was the most vocal critic of the neoliberal legacy of urban design since the 1980s. "This nexus of special districts and overlays, bulk bonuses, tax subsidies, BIDs, preservation, and gentrification has now coalesced to form the primary apparatus for planning in New York and most other cities in the United States" (Sorkin 2009, 162). The result was to turn Manhattan into "the world's largest gated community" enabled by urban design technocrats. "The role of design as the expression of privilege has never been clearer … the city

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seems to everywhere sacrifice its rich ecology of social possibilities for simply looking good" (Sorkin 2009, 163). While Sorkin uses New York City as his example, the neoliberal, public/private, design/development model has been dutifully followed in cities around the world, and describes well the situation in Chiang Mai today, where new gated communities, commercial strips and shopping malls dot the verdant valley.

European architects had previously faced the problem of rebuilding historical cities following the Second World War, after having lost all consciousness of pre-modern social processes of civic design. Italian architect Saverio Muratori (1960) developed a deeply researched "operative history" of Venice, which we might call an "architectural ethnography" (Kaijima et al. 2018). For a decade he and his students documented the historical transformation of Venice from the scale of individual rooms to building blocks and neighborhoods. His work formed the basis of seeing the successional transformation of the architecture of the city as an organic-like process consisting of "cellular tissues" that adapt and change in relation to social-economic events over time. Muratori's architectural ethnography is a model for our approach to Chiang Mai (McGrath and Lei 2021). The radical rediscovery of Muratori's research is that the pre-modern city is designed and adapted from the inside out through the individual rearrangement of rooms and small-scale building alterations within the restricted footprints of a walking city. He does not mention landmarks, monuments, or great architects, nor master planners, but the continuous transformation of the common and ordinary city of daily life.

The view of a city being produced from the inside-out is echoed by feminist architect Susana Torre's concept of "space as matrix" (1981). Matrix is derived from the Latin word for pregnancy and the womb. It has generative connotations in both embeddedness in geology and the array of recombination of values in mathematics. For Torre it is a working concept for achieving spatial design justice:

> A matrix space is a critique of the traditional division of space into enclosed rooms which, in their size and location within the house, establish a rigid hierarchy of importance among certain members of the household. It is also a critique of the usual distinction between enclosed rooms for private activities and corridors for circulation – a spatial setup originally designed to separate household members from their hired servants. (Torre 1981, 51)

In a language that harkens to Muratori and Torre's polemics, Sorkin advocates for a more inclusive notion of urban design globally:

> Questions of the relationship of city and country, of the rights of citizens to space and access, of the limits on their power to transform their environments, of zoning and mix, of the role of the street, of the meaning of density, of the appropriateness

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> of various architectures, of the nature of neighborhoods, of the relations of cities and health, and of the epistemological and practical limits of the very knowability of the city, have formed the matrix of urban theory from its origins, and its constant evolution is not easily repressed. (Sorkin 2009, 166)

We have employed the techniques of architectural ethnography and space as matrix to study Chiang Mai as a regional river basin, structured from the inside-out by micro-scale extended family live/work compounds. This constitutes an urban "tissue" and city/territory as examples of urban designs not in service of modern city development but in support of the communities in its path (Figure 13.1).

LANDSCAPE AS URBAN BALM

In the introduction of *Design with Nature*, landscape architect and planner Ian McHarg regards the vineyards of the Rhone River valley from a train leaving Lausanne Station. For him, the farmer is the greatest landscape gardener, and while appreciative of Italian and French garden traditions, for McHarg the eighteenth-century English pastoral landscape is the "greatest creation of perception and art in the western world" (1969, 72). In the United States, McHarg saw the capacity in parkway design, such as the Bronx River Parkway and the Skyline Drive of Blue Ridge Parkway, for landscape architecture to create new public values around an "improved" nature, through the ability of the profession to apply a "balm" to landscapes scarred by traffic engineers (1969, 43–44). McHarg's design methodology began with an inventory of climate, geology, hydrology, soils, vegetation, and wildlife to inform human intervention and adaptation (Spirn 2000, 107). He developed seminal methods of mapping trophic layers analyzed through a graphic matrix that visualized compatible land uses, which determined where to build new subdivisions and what landscapes to preserve (Spirn 2000, 105, 108). For example, his firm, Wallace, McHarg, Roberts and Todd, planned a regional framework for the Green Spring and Worthington Valley Planning Council, Baltimore County, Maryland. Without any regrets expressed for the former farmers, they designed a total landscape vision based on protecting stream corridors in an elite former plantation area of horse farms called "The Valleys" (McHarg 1969, 91).

While McHarg's professional work, based on his love of the landscapes of the English gentry, was often limited to the planning of greenfield suburbs, his former students Michael Hough (1984) and Ann Winston Spirn (1985) employed his methods towards a new social-ecological understanding of cities. Hough argued for an alternative language for urban design that was critical of the aesthetic values and formalized pedigree of landscape architecture celebrated by his teacher. His "tale of two urban landscapes" contrasts the highly

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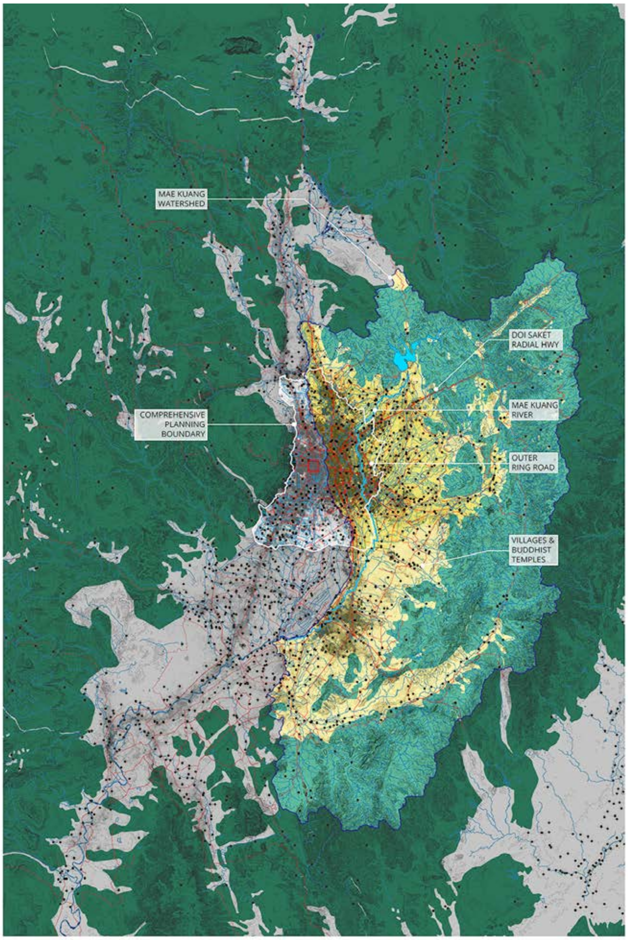

Note: This indigenous architectural and landscape patch matrix is confronting urban sprawl following newly constructed radial and ring roads. The historical center of Chiang Mai is the small, moated square near the bank of the Mae Ping to the west, and the older moated city of Lamphun is at the lower part of the basin at the mouth of the Mae Kuang to the south.
Source: Tommy Yang and Brian McGrath.

Figure 13.1 *A tale of two urban landscapes: to the west, the planned growth of the highway-based expansion of the historical city of Chiang Mai, and to the east, the Mae Kuang basin, encompassing a landscape matrix of forested mountains, canal-fed wet rice agricultural areas and villages indicated as black dots*

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maintained landscape of manicured parks, gardens, and lawns with volunteer urban plants found in poor neighborhoods, vacant lots, and derelict sites. The formal landscape fights with natural processes and is dependent on high energy inputs, while the volunteer landscape provides shade, groundcover, and habitat "at no cost or care, and against all odds" (Hough 1984, 10). Hough's theories are echoed in the community plan developed by William Burch for the Baltimore City Parks and Recreation Department (1991). Spirn calls the city a "granite garden" (Spirn 1985, 26), and in the West Philadelphia Landscape Project, established in 1987, she led an effort which became a model of the SNR of landscape design, community development, and urban stormwater management (https://wplp.net/).

Ecologist Richard Forman redefined the word landscape as a scientific rather than aesthetic concept to integrate various types of ecological studies proliferating in the 1970s. His definition of landscape was formulated from the views he enjoyed from the window of an airplane, where he could observe human disturbance, geology and soils, climate and water, vegetation patterns, as well as plant and animal communities traced in land patterns viewed from above. Forman redefined landscape as a recognizable kilometers-wide ecological unit where clusters of interacting ecosystems are repeated. Referencing the Byzantine mosaics in St. Mark's Basilica in Venice, he metaphorically referred to flattened aerial landscapes as ecological mosaics (Forman 1979). The field of landscape ecology was thus established for regional planners to address critical ecosystem questions spatially at coarse regional scales, identifying, characterizing, and cataloging structure and function as composed of two-dimensional patterns of patches and corridors within a larger land mosaic (Forman and Godron 1981).

In the introduction to Forman and Godron's textbook *Landscape Ecology*, Carl Steinitz, an architect and planner teaching at Harvard, describes himself as a "disturber" of landscapes. Steinitz saw both human and natural disturbance as normal, and landscape ecology was "a way to understand the structure, function and dynamics of those landscapes which are altered by design" (Forman and Godron 1986, v). Forman joined Steinitz at Harvard's Graduate School of Design, where landscape architecture and regional planning students could benefit from new GIS technologies to quantify the new scientific meaning of landscape for design (Forman and Godron 1981, 733). Several decades later, working with designers at Harvard, Forman developed an influential book illustrating ecological principles of landscape architecture and land use planning through simple diagrams (Dramstad et al. 1996), from which architects and designers developed the new theories of "infrastructure urbanism," "landscape urbanism" and "ecological urbanism" (Allen 1999; Waldheim 2006; Mostafavi and Doherty 2010; Reed and Lister 2014).

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Ecologist Steward Pickett's view of landscape is not a picturesque walk in the English countryside, a train ride in Switzerland, a pastoral parkway view from the car, nor a flat spatial pattern from an airplane. Instead, he developed landscape theories based on patch dynamics and succession through carefully observed multi-dimensional analyses of the complex dynamics of continuous adaptational ecosystem responses to disturbance gradients in time. At the start of his career, he formulated a spatially heterogeneous three-dimensional, and dynamic, temporally based view of landscape succession as composed of randomly generated and periodically disturbed habitats (Pickett 1976, 107). Critical of a linear reading of evolutionary succession leading to a single climax, Pickett's gradational and dynamic view of landscape ecology is based on genetic recombination and patch dynamics, balancing disturbance, maintenance and change, as adaptations to a species' position on spatial and successional gradients (Pickett and Thompson 1978). This complex reading of landscapes in space and time correlates to contemporary urban theories in architecture such as recombination in urban design (Shane 2005), and the complex spatial layering of urban succession (McGrath 1994). The twenty-first-century metacity comprises a non-linear, social-natural matrix consisting of successional patches of wilderness and urbanity which have been produced within various social, political and technological regimes (McGrath and Shane 2012).

As part of the Baltimore Ecosystem Study, Pickett and McGrath, Mary Cadenasso, Morgan Grove, Victoria Marshall and Joel Towers collaborated on integrating architecture, landscape and ecology over many years beginning with urban design studios at Columbia University in the early 2000s (McGrath et al. 2007, 2017; Pickett et al. 2013). The Baltimore Ecosystem Study remains the first example of a truly integrated approach between the architecture and ecology of the city based on patch succession and urban designs as SNR (Pickett et al. 2013, 2019; McGrath 2018). Urban patch dynamics can be designed as a self-diversifying social-natural process in both the architecture and landscapes of cities (Marshall et al. 2020). The multi-scaled as well as multi-dimensional frameworks of watershed, patch, neighborhood and block serve as a model for the study of the urbanizing territory of Chiang Mai, where patches of forests, villages and new subdivisions dynamically interact within a landscape matrix of river weir-/canal-fed rice paddies.

CHIANG MAI, THAILAND: URBAN DESIGNS AS SOCIAL-NATURAL RESOLUTIONS

The forested mountains of northern Thailand embrace furrowed valleys, annually flooded by flashy, monsoon-fed rivers. These isolated watersheds historically sustained wet rice-growing kingdoms governed by a polycentric

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religio-political system constituting a social-natural “galactical polity” that afforded relative autonomy to villages and lesser tributary polities (Tambiah 1976). The Kingdom of Lanna (“million rice field”) was ruled by the Lord of the Forest and the waters from the moated royal enclave of Chiang Mai (“new city”) at the foothills of Doi Sutep, at a careful distance from the Mae Ping River, a major tributary to Bangkok’s Maenam Chao Phraya. “Mae” refers to “water as mother” by the Tai Lue people (Ng et al. 2015, 2249), whose wet rice cultivation flourished for centuries through an intricate community-managed canal weir irrigation system called *muang-fai* (Tanabe 1994). Within this hydrological matrix, the architecture of the villages was structured around matrilineal/matrilocal intergenerational live/work compound houses (Potter 1980), corresponding to Torre’s feminist notion of space as matrix. The village-based canal weir and compound house spatial matrix and landscape patch structure of Chiang Mai valley serves as an example for an integrated model of practical and adaptable community-based indigenous urban designs as social-natural resolutions.

Approximately half of the “million rice fields” in Chiang Mai valley spread across the Mae Kuang basin, a major tributary east of the Mae Ping. Along with the airport and highway infrastructure improvements, the Mae Kuang Dam was constructed from 1986 to 1990, and Bangkok’s Royal Irrigation Department instituted a “people’s irrigation program” downstream. Department officials collaborated with farmers on replacing an annually reconstructed bamboo weir system with permanent concrete structures to enable dry-season multi-cropping in addition to the long-established wet-season subsistence farming. Now, after being released from the dam, water flows through a locally adjustable system of concrete weirs and canals, passing under the new radial and ring road-based urban sprawl. Although there is a Comprehensive Plan for Chiang Mai and its surrounding towns and villages, beyond locating highway infrastructure, this is only a paper plan, without any operational mechanisms to actually preserve agricultural land (McGrath et al. 2017).

We illustrate here the product of ten years of field work, spatial ethnographies and academic design research projects within the Mae Kuang basin as a site that integrates landscape patch dynamics and architectural space as matrix. The projects exemplify urban designs as SNR by integrating work from farming village compound houses to the regional irrigation system. Designs for urbanizing landscapes and villages in the Mae Kuang basin have been realized with students from Chulalongkorn University in Bangkok and Parsons School of Design in New York in conversation with villagers annually over multiple iterations. Examples include the Master of Landscape Architecture design thesis project by Nithirath Chaemchuen under the direction of Danai Thaitakoo at Chulalongkorn (Figure 13.2), and three years of architectural projects proposed by BFA Architectural Design students from Parsons, under

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the direction of Brian McGrath as the lead instructor and Tommy Yang serving as a teaching and research assistant in 2020.

Tambiah's image of a galactic polity captures the nested social-natural orbits that scale up from extended family compound houses in villages centered on temples, to the annually renewed community irrigation *muang-fai* landscape matrix overlorded by the King at a regional scale. We can read this polycentric nested system through the contemporary urban ecosystem concepts of patch dynamics and the metacity in direct contrast to the currently operating methods of modern urban planning and design (McGrath et al. 2007; McGrath and Pickett 2011). Such a diffuse and mutable territorial polity challenges both the fixed and centralized bureaucratic hierarchy of modern urban design and planning and the landscape balm of designed and managed "green" leisure products served as marketing tools for new developments.

Working north of Doi Saket Road, Nithirath suggests an alternative design for community landscape infrastructure management located between historical villages and new developments (Figure 13.3). The *muang-fai* matrix of Mae Kuang basin consists of irrigated rice fields with patches of new developments with manicured lawns, interspersed with volunteer vegetation, orchards, ponds and fruit tree-shaded village settlements, including cultural centers, temple festivals, schools and markets. Working with the indigenous *muang-fai* social-natural matrix, he proposes restoration of riparian zones along the distributary river, canal and weir network, where rice paddies serve as flood water retention zones. Sustained for centuries, the *muang-fai* patch matrix provides evidence of adaptive resolutions to historical pressures from climate and demographic change in a semi-tropical monsoon climate of annual droughts and floods, and daily temperature fluctuations of extreme midday heat and cool evenings. The design strategy also maintains the narrow road network and a trail system, connecting local villages through community, economic and cultural corridors as well as mixed-use neighborhood *kad* and *kuang* (roadside markets and common spaces). The narrow winding roads are most suitable for two-wheel vehicles, protecting their traditional way of life, while a new generation enters the newly accessible urban economy, a mobile geography named "desakota" by Terrance McGee (1991).

After the Mae Kuang and its distributary canals pass under the four-lane Doi Saket Highway from the northeast, it then flows under Chiang Mai's Outer Ring Road at a recently completed cloverleaf intersection at their junction (Figure 13.4). The lower half of the site, captured within the ring road, extends across the old "Handicraft Highway," where craft factories comprise a ribbon of development, relocated from villages in the 1980s for easier access for tourist coaches (Cohen 1995). From there the Mae Kuang passes again to the southeast under the Outer Ring Road before reaching the ancient, moated city of Lamphun further south. The focus of the architectural design studios was

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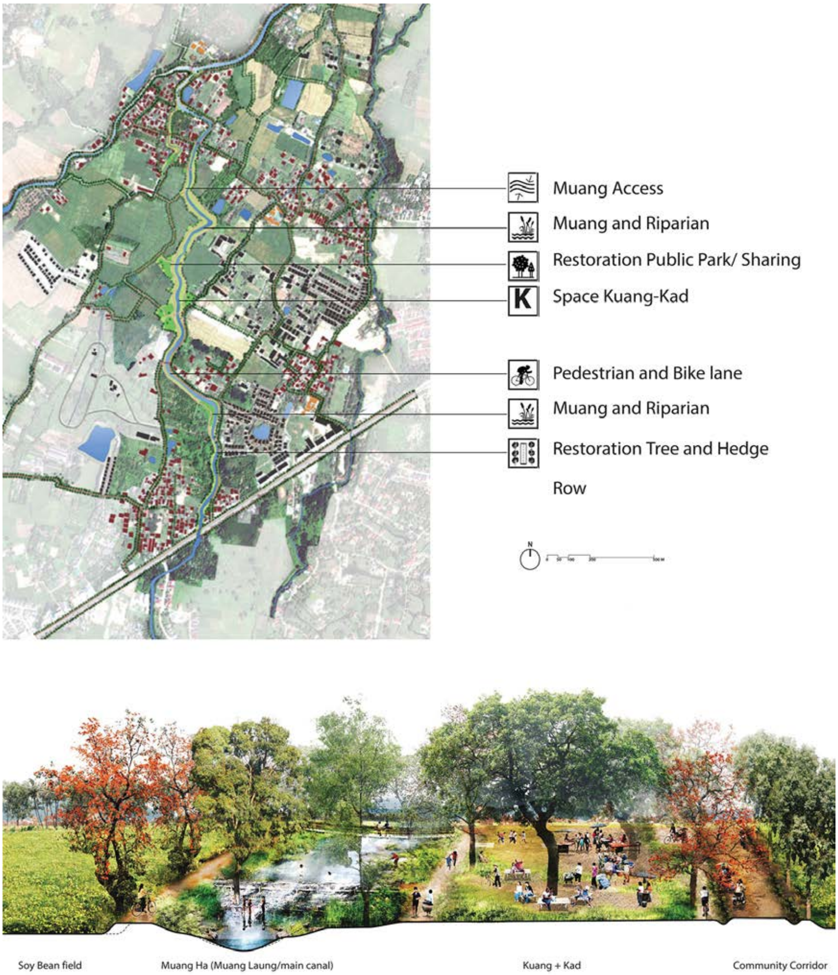

Source: Nithirath Chaemchuen and Danai Thaitakoo.

Figure 13.2 Study of landscape patch matrix framework of integrating indigenous villages and the weir canal and paddy structure with new highway-based developments through community and cultural corridors and public space networks; sectional drawing is cut through the canal and riverside riparian landscape, including community spaces and cultural corridors

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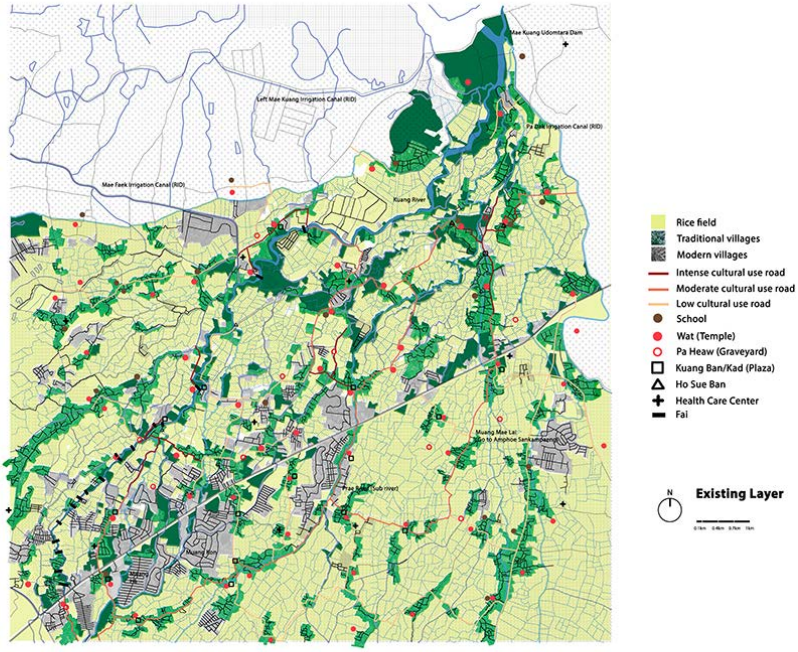

Figure 13.3 *Detail of the first design study area along Doi Saket radial highway showing the patch structure of the existing distributary* muang-fai *(canal weir) landscape matrix of the Mae Kuang basin, flowing under the highway, where new gated subdivisions have been developed in an area designated for agricultural preservation*

to work with the residents within the four villages along the river in this area. There have been multiple iterations of student designs in consultation with villagers over the years, with the aim to maintain the mixed-use extended family compound house structure of the villages, where covered common areas are used for craft production, including embroidery, wood working, basket weaving, indigo dying and for eating and socializing. The Lanna villages themselves combine the ecological logic of patch dynamics and the architectural logic of the compound house as spatial matrix.

The most recent project by Luis Urribarri and Jakob Denham is for a *kad/kuang* plaza that integrates many of the villagers' initiatives (Figure 13.5). Their design proposal furthers the river restoration project initiated by the elder headman, with a proposal for a small-scale water and septic treatment facility. At the riverside *sala* they propose an expansion of the elder's fish hatchery

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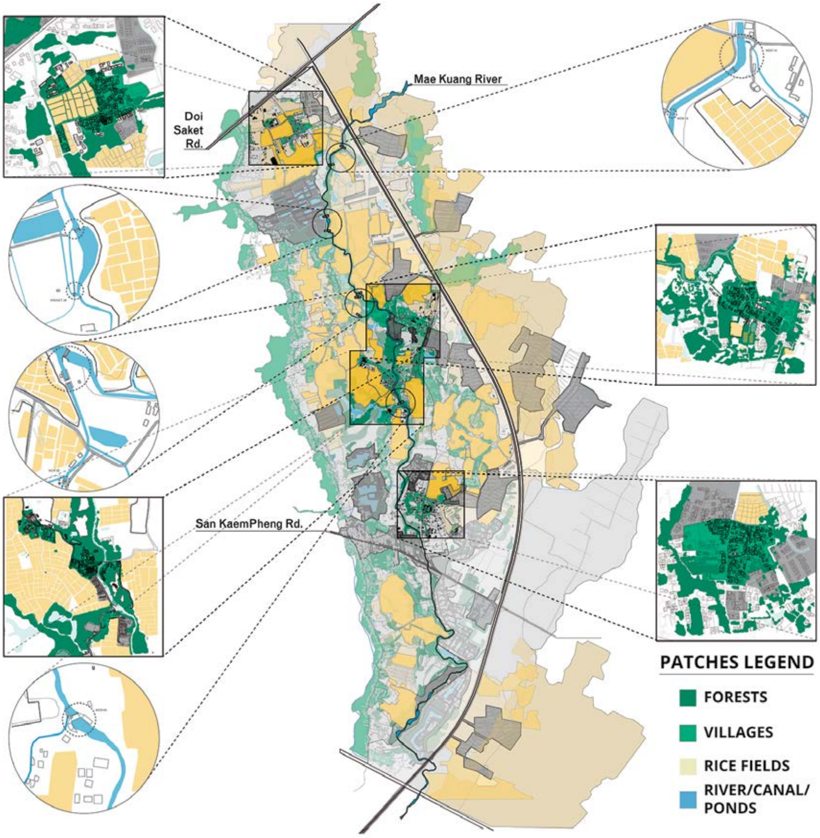

Note: This comprises a large area containing four weirs, four villages and four large rice fields, which have been studied and where we have conducted multiple design workshops with the same villagers over a number of years.
Source: Nithirath Chaemchuen and Danai Thaitakoo.

Figure 13.4 Our second design study area stretches for 7 km from north to south and is defined by the two spots where the Mae Kuang River passes under the Outer Ring Road

and water hyacinth-harvesting dock to establish a more direct connection between village residents and the river (Figure 13.6). A new weir and fishpond lined with covered pavilions house multiple entrepreneurial efforts: a plastic recycling hub, digital lab and handicraft workspace and an open-air pavilion for community meetings and educational demonstrations. The open walled, covered, wood-framed workspaces benefit from the microclimate provided by the pond under shade trees. With most activities outdoors, the design pro-

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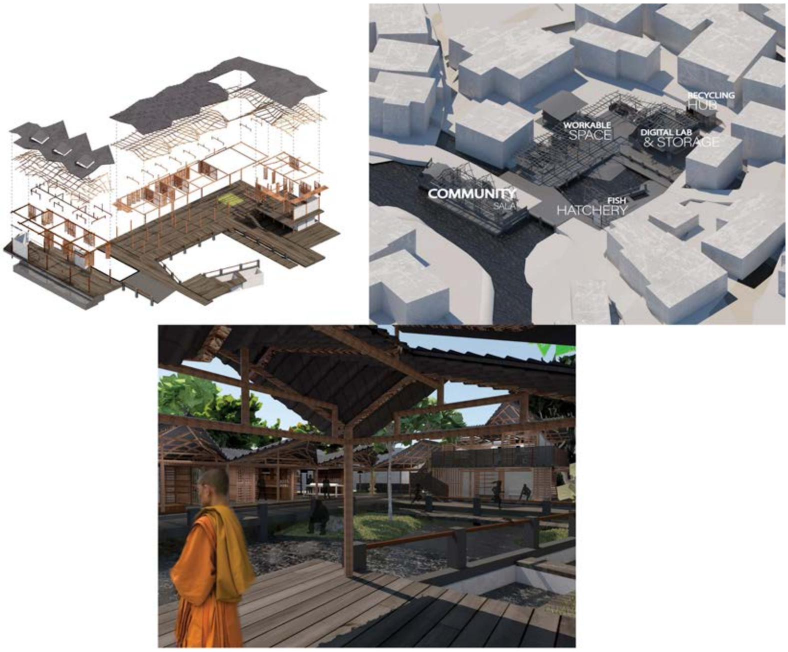
vides both a mode for sustainable infrastructure and passively cooled "green" healthy architecture.



Note: The proposal integrates the canal weir path dynamics as well as space as matrix logics. A new weir brings water into the central plaza of the town, where a spatial matrix of workspaces consolidates several local entrepreneurial initiatives.
Source: Luis Urribarri and Jakob Denham.

Figure 13.5 Luis Urribarri and Jakob Denham's proposal for a new community center for the village shown in Figure 13.1

These design research projects align with many other small-scale ecological, craft and food-based initiatives that are currently proliferating around Chiang Mai in direct contrast to the top-down approach from the planning ministries in Bangkok. The compound houses and *muang-fai* landscapes we surveyed are living examples of ecological patch dynamics and architectural space-as-matrix. Traditionally, flexible houses supported extended subsistence-farming families, while today they combine new homes, dormitories for workers and students commuting to the city, craft centers and covered common outdoor areas for meals and activities. The metacity, based on metacommunity and metapopulation theories in ecology, also suggests

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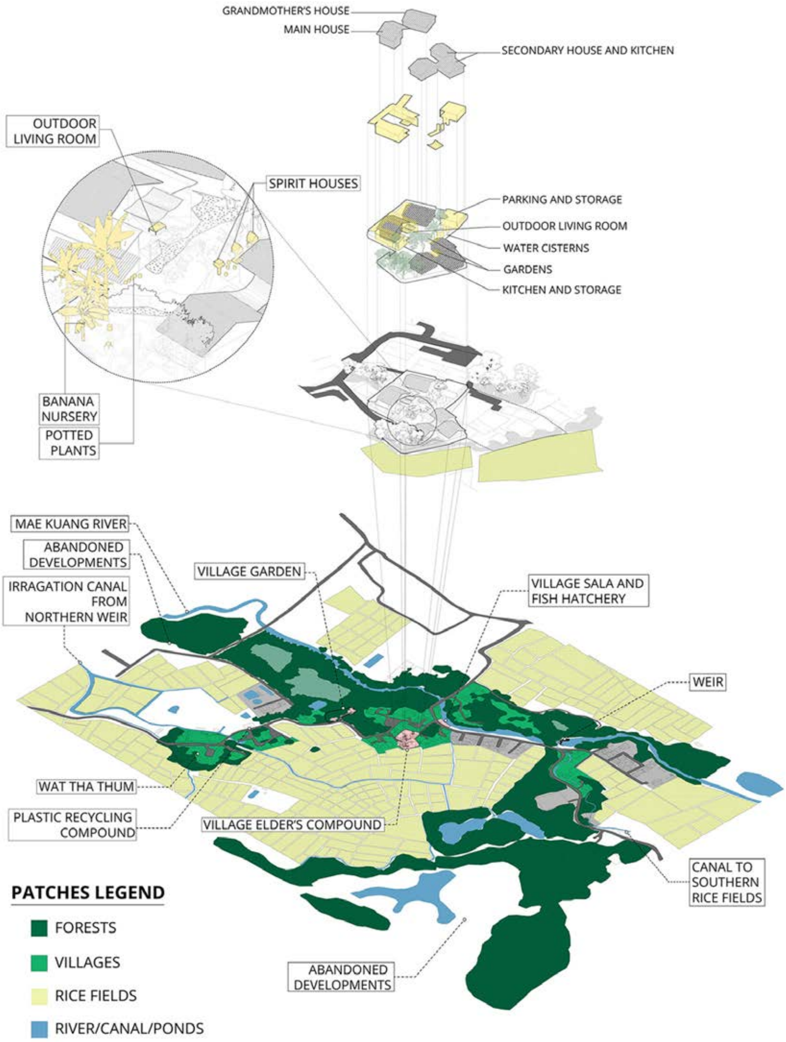

Note: The elder village headman initiated a village community garden to the north, and a covered community space – a "sala" at the waterfront – as a center for a fish hatchery and water hyacinth-harvesting project. Within the headman's compound is a space for fermenting bananas as part of an indigenous method of purifying the river water.
Source: Tommy Yang and Brian McGrath.

Figure 13.6 The architectural and landscape matrix of one village illustrates the compound house and rice paddy modular cellular unit

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a decentralized polity as the basis to build social movements that revalue the original *muang-fai* hydro-social system. The metacity provides a framework to scale up these social movements around justice, food, health and crafts in the simple villages of the valley, connected to the larger cultural value of Chiang Mai as a whole.

Before concluding, we offer an outline of lessons from Chiang Mai:

1. As designers we follow the Jemez principles for democratic organizing that incorporate inclusive, bottom-up practices, listening to relevant voices and solidarity in building just relations with a mutual commitment to self-transformation (www.ejnet.org/ej/jemez.pdf).
2. Our role as designers incorporates spatial ethnography, chronicling the ordinary and temporary social-natural practices that are unmapped and unrecognized by planning bureaucracies.
3. Our qualitative data is multi-scalar, multi-sensorial and temporal, focusing on the erasure and misrepresentation of marginalized groups (Caswell et al. 2016).
4. We focus on how ecological infrastructures and flows act as groundworks that create and support socio-cultural infrastructures and socio-cultural flows that coevolved as foundations of community.
5. In turn, socio-cultural infrastructures and socio-cultural flows are drivers and motivations in transforming landscapes and communities.

CONCLUSION

The disciplines of architecture and ecology, since their inception, have been troubled by structural sexism, racism and classism. While Jane Jacobs was present in the initial urban design conference, her voice was marginalized, most notably in Lewis Mumford's sexist review of *The Death and Life of American Cities* in the *New Yorker* titled "Mother Jacobs home remedies" (1962). Steward Pickett overcame institutional racism when he became the first known African American president of the Ecological Society of America in 2011, nearly a century after the founding of the organization, and he maintains a keen eye on developing an ecology of segregation (Pickett and Grove 2020). Michael Sorkin's critique of urban design argues that the city is infused with the political and is a "field of struggle for an equitable and just society" and "an ecological understanding of urban dynamics can promote stewardship, community, and responsibility" (Sorkin 2009, 159–160). In this volume on *modern* NBS, it is worth considering Marshall Berman's expansive notion of modernism as the cultural aspiration that binds people across sex, class and race. For Berman, modernity is not scientific advancement nor a style of

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architecture and planning, but the act of becoming modern subjects; to make ourselves at home in a constantly changing world (Berman 1981, 6).

The modern architects of CIAM deployed science and technology, unleashing the "ravages of motorized modernization" (Berman 1981, 171) to construct an ideal perfect world that was imagined extending across the globe, but could never develop from within (1981, 6). Berman imagines instead design expertise employed to develop visions and paradigms that could enable people to explore their own experience and history in perpetual self-critique and self-renewal. For Berman, Jane Jacobs played a crucial role in the development of this kind of modernism. Like Pickett's successional ecology unfolding around him, Jacobs observed the complex dynamics of life on her block in Greenwich Village from a point of view inside of what she calls an ecological system (1981, 315). Her celebration of vitality, diversity and fullness of life is the urban equivalent of the heterogeneous gradients and diversity of successional landscapes described by Pickett. Torre and Jacobs' radical feminism as well as Pickett's vision as a black ecologist are both distinctively modernist in Berman's subjective sense.

Our expansive notion of urban design aligns with the life-enhancing notions of *Wild by Design* (Ruddick 2016) and *Design by Radical Indigenism* (Watson 2019). The *muang-fai* system, what Tanabe has called *Ecology and Practical Technology* (1994), is design by radical indigenism. Urban designs as SNR fully engage the notion of design justice as a framework for analysis that "aims to ensure a more equitable distribution of design benefits and burdens; meaningful participation in design decisions; and recognition of community-based, indigenous, and diasporic design traditions, knowledge and practices" (Costanza-Chock 2020, 23). Urban designs as SNR, as demonstrated with the case study of Chiang Mai, offer lenses into the intersecting successional gradients of social and natural processes through the ability to read the spatial ethnographies of the forms, patterns, meanings and processes in the collective enterprise in constructing a sustainable built environment. A radical expansion of urban design presents ecological patch dynamics and architectural space as a matrix of consensual social resolutions within a continuum of successional social-natural gradients. The metacity framework connects the imagination to be within and outside a social-natural system across scales that are changing in space and time, where local decisions have effects that can be understood within and actively affect larger ecosystems.

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14. Ecological art in cities: exploring the potential for art to promote and advance nature-based solutions

Christopher Kennedy, Ellie Irons, and Patricia Lea Watts

INTRODUCTION

Throughout history, artists have explored the natural environment in their work and practice, from large-scale earthworks and conceptual propositions to performative and community-based projects worldwide. Since the 1960s, many artists have increasingly embraced interdisciplinary approaches to address the impacts of urbanization, climate change, and social inequity. Commonly referred to as ecological art, these practices often utilize or take inspiration from the principles of ecosystems and employ site-specific, socially engaged, and participatory practices. In many cases, ecological artworks aim to complement, examine, and advocate for nature-based solutions (NBS) or actions that leverage nature or natural processes to address social-ecological challenges (Matilsky 1992; Wallen 2012). As ambitious visions for NBS become both necessary and possible, ecological art plays a critical role in advancing its utilization, while also raising key questions about how to effectively support and integrate artists' visions and practices into urban planning and governance.

This chapter explores ecological art histories and future potentials, focusing primarily on examples of artists working in urban areas. The aim is to critically examine the role art can play in advancing NBS and to highlight the range of innovative and creative approaches artists are experimenting with across the globe. How effective can and should art be in promoting NBS? What aesthetic considerations are relevant for artworks that address environmental issues and urban life? And how can planners, municipal stakeholders, and others effectively integrate ecological artworks and artists into decision making and planning?

The artworks described across these sections emerge largely from a North American context, a reflection of the positionality and expertise of the authors.

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However, the impulse to integrate art, science, and ecological thinking is a global phenomenon. As we discuss how ecological art provides a host of benefits to both human and more-than-human communities, it is critical to reflect on the limitations of these practices, especially given enduring concerns around power, exclusion, and equity in the field of art. For example, Indigenous practitioners have been historically excluded from mainstream contemporary art venues and narratives, despite a wealth of knowledge systems and cultural practices (Ash-Milby et al. 2017). It is crucial to identify the diverse contributions of Indigenous practitioners (McMaster 2020) and to acknowledge how Indigenous ways of knowing inform approaches and practices now commonplace in ecological art (Todd 2016). Additionally, in the North American context, Black, Indigenous, and non-white immigrant communities have been excluded from mainstream environmental narratives and spaces (Finney 2014; Seymour 2018), and many white-led environmental movements have long failed to effectively integrate social justice concerns (Schell et al. 2020). While the authors are less familiar with contexts outside North America, we recognize the need for intersectional analysis and action is relevant in many contexts around the world, including in the Global South where issues of exclusion and the impacts of Western imperialism and colonialism endure (Checker 2008; Simbao 2015; Gómez-Barris 2017; Molho et al. 2020). Contemporary ecological art, in many cases deeply intertwined with mainstream Western environmentalism, has much to learn from intersectional movements for environmental and climate justice, both in the North American context and beyond (Nixon 2011; Demos 2016).

Considering these shortcomings, we aim to address how ecological art contributes to sustainable, equitable forms of urban renewal and examine how it can exacerbate conditions of gentrification and exclusion, among other issues (Paperson 2014; Gould & Lewis 2016).

SITUATING ECOLOGICAL ART

There are multiple terms—from “environmental art” to “eco-art” to “ecological art”—used to connote creative approaches and artistic activities that center the environment or nature in their scope, intent, or form (Matilsky 1992; Denes 1993; Watts & Lipton 2004; Weintraub 2012; Nisbet 2017). In this chapter, we focus on artworks and practices that many in the field refer to as “ecological art,” a term popularized in the 1990s to specify artworks set in the natural environment from the 1960s onward. Some of these artworks sought to repair damaged environments and utilize ecosystem-based approaches or address ecological, social, and political issues, often through participatory or community-based practices. The history of ecological art aligns in many ways with the inception of the modern environmental movement, early environmen-

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tal justice struggles (Hare 1970), and the growth of ecological art movements since the 1960s.[1] As modern environmentalism coalesced in the wake of Rachel Carson's *Silent spring* (1962), the unrest of the 1960s propelled artists away from object-based and pictorial representations of nature and toward conceptual, site-specific, process-oriented, and land-based approaches, a trajectory elucidated by critic and historian of environmental art Lucy Lippard (1973).

In her book *Overlay* (1983), which explores the merging of art, life, and land in prehistoric and contemporary artistic practice, Lippard describes how "ecological art—with its emphasis on social concern, low profile and more sensitive attitudes towards the ecosystem" (p. 229)—begins to distinguish itself from the broader shifts within the artworld (Azhari et al. 2014; Kepes 1972). Lippard has followed the evolution of ecological art, pointing to early examples of community-based, socially engaged art forms that continue to inform new models of transdisciplinary collaboration between scientists and artists (Lippard et al. 2007; Weintraub 2012; Ellison et al. 2018). As new thinking in systems science and ecology progressed, artists experimented with ambitious proposals to address environmental, social, and political concerns through technological and ecologically influenced strategies that presage current NBS approaches (Harrison & Harrison 1999; McKee 2007). Today, fields like ecology, climatology, social science, and emerging disciplines such as bioart, biotechnology, and multispecies studies play a critical role in how ecological art is conceptualized and practiced (Anker & Nelkin 2003; Costa & Philip 2008; Kirksey 2014).

In the following sections, we examine a range of selected ecological artworks. However, considering the limitations of both space and scope, we include Table 14.1 to provide additional examples of ecological artworks that engage urban environments or social-ecological issues within cities. This list is by no means comprehensive but rather a starting point to consider the multiplicity of approaches and contexts from ecological artists globally.

BRINGING URBAN ECOLOGICAL ISSUES INTO THE PUBLIC REALM

Researchers increasingly discuss the critical role artists play in raising public awareness and engagement about climate change and environmental issues (Nurmis 2016). A study by Sommer and Klöckner (2021) highlights how artworks that present novel solutions and offer a way for communities to participate are often more impactful than conventional methods (e.g., mainstream news media, scientific reports) because they can elicit a personal and emotional connection. These strategies are crucial, particularly as scholars and media critics continue to emphasize the insufficiency of conventional

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Table 14.1 Selected ecological artworks, 1965–2019

Name	Location	Artwork	Year
Alan Sonfist	New York City, USA	Time Landscape	1965/1978
Mierle Laderman Ukeles	New York City, USA	Maintenance Art Manifesto	1969
Bonnie Ora Sherk	San Francisco, USA	Portable Parks	1970–1971
Ant Farm	Berkeley, USA	Air Emergency	1971
The Harrisons	Los Angeles, Great Britain (+ multiple sites)	Shrimp Farm, Survival Piece #2	1971
Hans Haacke	Krefeld, Germany	Rhinewater Purification Plant	1972
W. Eugene Smith	Minamata, Japan	Minamata, Japan	1972
Liz Christy	New York City, USA	Green Guerillas	1973
Patricia Johanson	Dallas, USA	Fair Park Lagoon	1981–1985
Agnes Denes	New York City, USA	Wheatfield: A Confrontation	1982
Joseph Beuys	Kassel, Germany	7000 Oaks	1982
Gordon Matta-Clark	New York City, USA	Resource Center and Environmental Youth Program for Loisaida	1983
Oliver Kellhammer	Toronto, Canada	Lead Down the Garden Path	1988
Reclamation Artists	Boston, USA	Big Dig	1989
Mel Chin	St. Paul, USA	Revival Field	1991–present
Shai Zakai	Beit Shemesh, Israel	Concrete Creek	1999–2002
Mark Brest van Kempen	Seattle, USA	Ravenna Creek	2002–2009
Fritz Haeg	California, USA (+ multiple sites)	Edible Estates	2005–2014
Natalie Jeremijenko	San Diego, CA (+ multiple Sites)	Feral Robotic Dogs	2006
Eve Mosher	New York City, USA	HighWaterLine	2007
Lillian Ball	New York City, USA	WATERWASH	2007–2009
Francis Whitehead	Chicago, USA	SLOW Cleanup	2008–2012
Future Farmers	San Francisco, USA	Victory Gardens	2008
Yang Yongliang	Shanghai, China	Artificial Wonderland	2010
Lucia Monge	Lima, Peru (multiple sites)	Planton Movil	2010
Mali Wu	New Taipei City, Taiwan	A Cultural Action at the Plum Tree Creek	2011–2012
Mary Miss	New York City, USA	City As Living Laboratory	2011–present
Jan Mun	New York City, USA	The Fairy Rings	2013

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Name	**Location**	**Artwork**	**Year**
Zheng Bo	Shanghai, China	Plants Living in Shanghai	2013
SPURSE	Claremont, USA	Pitzer Multispecies Commons	2016
Mary Mattingly	New York City, USA	Swale	2016–2017
Lisa Myers and Sheila Colla	Vancouver, Canada	Finding Flowers	2017
Margaretha Haughwout and Marisa Prefer	Hamilton/Brooklyn, USA	Grafters XChange	2018
Jordan Weber	Omaha, Nebraska	Malcolm X Greenhouse	2018
T’uy’t’tanat-Cease Wyss	Vancouver, Canada	x̱aw̓s shew̓áy̓ New Growth (新生林)	2019

approaches to communicate about environmental issues in a significant way (Nisbet 2009; Corner & Groves 2014). Most communication has traditionally focused on providing facts, increasing literacy, or employing scare tactics concerning impacts or risks (O’Neill & Nicholson-Cole 2009). These methods are not always effective because environmental issues are complex and may require interdisciplinary perspectives, embodied experiences, or culture making for the public to resonate with key messages.

As artists expanded their practices in the 2000s, new knowledge of climate risks began to inform their public-facing projects. For example, artist Eve Mosher launched a public art project called *HighWaterLine* in 2006 to better understand the impacts of a 100-year flood event and sea-level rise in New York City (NYC) and the challenge of interpreting public scientific reports. Utilizing participatory and performance-based practices, Mosher turned a chalk dispenser commonly used for baseball diamonds into a drawing tool, marking a continuous line along the waterfronts in Brooklyn and Manhattan likely to be impacted by sea-level rise. The artist spent most weekends from May through October 2007 walking and pouring nearly 70 miles of blue chalk (Figure 14.1). As she navigated the streets of NYC, she catalyzed conversations about the impacts of climate change and urban flooding, answering questions from passersby and distributing small flyers with resources. Since launching the project, the *HighWaterLine* model has been replicated in Bristol, UK, and Miami, Boston, Philadelphia, and Honolulu, USA, bringing together community-based organizations, non-governmental organizations, and individuals.

As an artwork that blurs the lines between performance, public art, and activism, there are several key issues to consider in how *HighWaterLine* operates aesthetically and epistemologically to generate new knowledge, awareness, and action. A key element is aesthetic experience generated by the work, or the process of making sense of an environment and the objects

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Source: Left: photograph by Eve Mosher. Right: photograph by Jayme Gershen.

Figure 14.1 Left: Eve Mosher performing HighWaterLine in New York City, 2014; right: Mosher performing HighWaterLine in Miami

or situations within it (Brady 2002). Although commonly understood as the philosophical study of beauty and taste, new aesthetic theories (e.g., environmental aesthetics) emphasize the importance of multisensory immersion and how this can motivate "becomings" and self-transformations (Strewlow et al. 2004). Elizabeth Grosz (2008) describes this as a disruption resulting in new understandings and states of awareness, which may be uncertain or uncomfortable. In previous interviews, Mosher recounts the experience of walking in a south Brooklyn neighborhood where she met several homeowners who admitted they were denied flood insurance without an explanation of why from the City (Nadir 2015). One afternoon, as Mosher was drawing her line in front of their homes, the implications of sea-level rise became visible in a new way. Mosher's performance created a disruption in the everyday experience of a frontline community potentially impacted by rising seas. The work unfolds as a pedagogical process by producing a set of meanings through the viewer's participation, and highlights how communities may be excluded from conversations about climate and demonstrating that there is a need for additional tools to aid public understanding (Atkinson 2012). Mosher's work in this sense points to crucial environmental and climate justice issues, providing an example of how an artwork can offer opportunities for communities to better understand the social-ecological implications of sea-level rise.

While planning her solo performance for other cities, Mosher ultimately had to consider the ethical implications of entering into a community that was not her own. She worked with the nonprofit ecoartspace to write an "Action guide" so that communities globally could recreate her project (Watts 2014). In Florida, Mosher worked with Resilient Miami to organize interactive workshops and training on how individuals can conduct *HighWaterLine* research in their communities. The organization also created a forum to review

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interventions and NBS proposals while envisioning alternatives for vulnerable communities in the Miami metro area. Mosher also partnered with the non-profit Creative Catalyst in the United Kingdom to perform *HighWaterLine* on the River Avon in Bristol, England. Participants noted how the visceral act of walking made sea-level rise something tangible and immediate.

Peruvian-born artist Lucia Monge's *Plantón Móvil* (2010–), originally launched in Lima, Peru, also takes a performative, public-facing approach to address an issue central to NBS in cities: that of establishing and maintaining public green space. As the second-largest desert city globally, Lima has been challenged by the intertwined issues of water scarcity, poor air quality, and the inequitable distribution of green space (Loris 2012). These challenges, along with her interest in plant agency and urban green space, inspired Monge to develop an ongoing public artwork that plays with the double meaning of the Spanish word "plantón," which refers both to a sapling and a peaceful protest. For each iteration, Monge invites local community members to join her in a "walking forest" performance (Monge 2018). Participants take to the streets to walk, roll, or otherwise move through the city with plants to stress the importance of vegetal life, urban nature, and public green space (Figure 14.2). Each performance culminates in pre-arranged plantings where participants contribute directly to building public green spaces using the plants involved in the performance, ideally building ties that will contribute to their ongoing maintenance and care. Monge explains the artwork is also about reimagining the meaning of movement and migration, offering participants the opportunity to experience "moving-with as a form of solidarity" across species (Monge 2019, p. 28). Here, Monge positions urban habitats as an important place to cultivate interspecies awareness and multispecies kinship as she works to help plants claim their place in the city.

Aesthetically, Monge's project operates much like Mosher's. It creates a new point of reference or attunement to overlooked urban issues by engaging a diverse public both as participants and onlookers. As a participant in the performance, the collective act of walking with plants down a busy city street invites a form of sensory immersion similar to *HighWaterLine*. As a witness, passersby contend with an interruption to the everyday ritual of city life, and the work creates an opportunity for shared experience around the possibility of more abundant public green spaces. Although initially conceived as a singular event, *Plantón Móvil* has spread to other cities, and each iteration has grown more collaborative, interdisciplinary, and responsive to community needs (Monge 2018). For example, in a 2019 edition in NYC, Monge partnered with the Queens Museum, NYC Parks Department, John Bowne High School Agriculture Department, and local immigrant communities to develop a performance centered around plants as conduits of connection to cultural heritage and public green space. Like Mosher's *HighWaterLine*, Monge's *Plantón*

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Source: Photo by Jorge Ochoa.

Figure 14.2 Lucia Monge's Plantón Móvil *(2011)*

Móvil has been able to grow and adapt because it has a flexible formula that can be applied to site-specific contexts through careful work with local stakeholders, community members, and institutions, who contribute to the project's ability to address issues of equity and exclusion. Going beyond simply raising awareness, both of these efforts cultivate social cohesion and build community, which many researchers point to as crucial to the success of envisioning and implementing effective NBS (Frantzeskaki et al. 2019).

ART AND REGENERATION: "REMEDIATING" DAMAGED LANDSCAPES

Land degradation from industrialization, urbanization, agricultural practices, and climate change impacts nearly a quarter of the Earth's land area, affecting 3.2 billion people, and contributing to biodiversity declines worldwide (Intergovernmental Panel on Climate Change 2021). This is particularly critical in urban areas, which continue to impact health and well-being. In response to these challenges, fields like restoration ecology, the practice of restoring degraded ecosystems and habitats, have emerged (Hobbs & Cramer 2008). The popularization of these practices has inspired many ecological artists to explore concepts of remediation and regeneration (Matilsky 1992; Watts 2010;

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Ingram 2013). While many of these artworks are well intentioned, they also raise questions about the artwork's capacity to function as an effective NBS and the scientific claims some artists make about their work.

One of the earliest examples is Alan Sonfist's *Time Landscape*, commissioned by the NYC Department of Transportation in 1965 and 1978. Acknowledging the loss of forested land in Manhattan, Sonfist proposed to recreate a historic forest on a vacant lot in Greenwich Village. Over several years, the artist worked with an architect and botanist to design a planting regime that mimicked endemic forests. The artwork is not necessarily about the experience of a native landscape, but rather the conceptual exercise of considering the time it takes for a forest to grow. While the artist and team initially sought public involvement by recruiting volunteer stewards, the site today is aesthetically unassuming, and could easily be mistaken for an informal green space. Viewers are kept at a distance by a wrought-iron fence adorned with a plaque explaining the project. While well intentioned, this separation can inadvertently fracture city dwellers' relationship with the site and urban nature more generally. Additionally, it discounts the dynamism and complexity of historical ecosystems and the crucial role of Indigenous human populations in stewarding them and the need for ongoing care (Gould 1998; Ball et al. 2011; Higgs 2012; Orion 2015; Armstrong et al. 2020).

In another well-known work, *Revival Field* (1991–ongoing), artist Mel Chin collaborated with agronomist Rufus Chaney to study the effectiveness of hyperaccumulating plants to remediate contaminated soil at the Pig's Eye Landfill in St. Paul, Minnesota (Boswell 2017; Loring 2020). Chin worked with Chaney to create a land-based sculpture that doubled as an experiment in phytoremediation, a form of bioremediation that uses hyperaccumulating plants to absorb heavy metals like cadmium, zinc, and lead. Although recognized as a compelling example of an artist experimenting with a NBS, the work itself was not able to significantly reduce rates of soil contamination during the run of the experiment. Despite this, the documentation of the work alludes to the site being partially restored, with some art critics and writers mischaracterizing the project as a functional solution to contaminated sites classified as a "superfund."[2] Chin's work offers a cautionary tale, highlighting a need to recognize both the limits of what art can and should do while also creating space for further experimentation and interdisciplinary exchange that was able to generate new research and understanding of the capacity of *Thlaspi caerulescens* (alpine pennygrass) to absorb some contaminants. In so doing, the work offers a salient example of artistic and scientific collaboration and the ability of ecological art to amplify and circulate public understanding of nature-based approaches like phytoremediation.

In a related vein, from 2008 to 2012, Chicago-based artist Francis Whitehead launched the project *SLOW Cleanup*. Like Chin, Whitehead addressed soil

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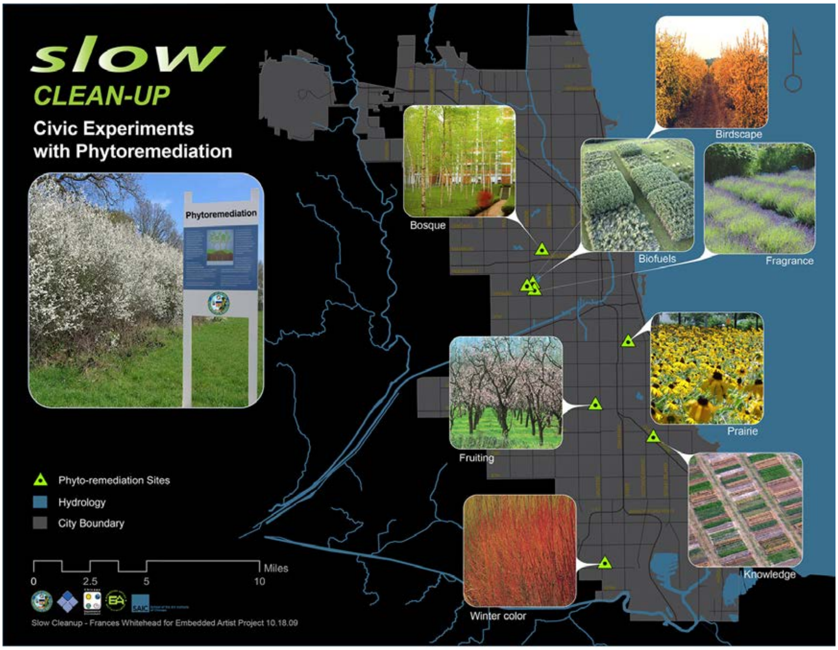
contamination utilizing phytoremediation, applying experimental processes to city-controlled abandoned gas station lots that had previously housed underground storage tanks. Whitehead worked with the Chicago Department of Environment to select 10 lots from 100 identified, revealing the spatial distribution of racial and economic inequity on Chicago's West and South Sides, where a large majority of African American communities reside (Figure 14.3). Working with a soil scientist at the Cottage Grove Heights Laboratory Garden for their first field trial, they identified ornamental plants with fibrous root systems that would activate soil microbes to break down the petroleum and its byproducts. Many of the plants chosen had not been tested previously, generating new knowledge about the plants' efficacy for phytoremediation. The project also removed leftover pavement, and soils compacted for over 50 years were tilled with compost and new plantings. The other nine sites were not addressed due to the incoming Mayor of Chicago in 2012, who eliminated the Department of the Environment.



Source: Courtesy of the artist.

Figure 14.3 *"Phyto-scape" map developed for* SLOW Cleanup *by Frances Whitehead showing the original 10* SLOW Cleanup *sites identified in Chicago, IL*

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As Whitehead's project concluded, artist Jan Mun launched the *Greenpoint Bioremediation Project* (2012) to work with local communities and develop DIY bioremediation solutions for the Newtown Creek in NYC, a waterway designated a superfund site in 2010 following decades of degradation and petroleum leakage. Mun worked with the organization Newtown Creek Alliance to develop a proposal for ExxonMobil, the entity responsible for a majority of the leak, utilizing a bioremediation practice known as mycoremediation. In this process fungi consume and break down environmental pollutants. Mun proposed a living sculpture called *The Fairy Rings* (Figure 14.4), which mimicked the pattern of certain fungi and consisted of circular mounds inoculated with varieties of oyster mushrooms (*Pleurotus djamor complex* and *Pleurotus osteatus*). After an initial test, Mun began to work with Brooklyn College's Soil and Microbiology Lab to research whether the fungi could break down long-chained toxins found in the creek's groundwater. However, like Chin's work, Mun's efforts could not extract a significant concentration of contaminants from the site (Egendorf et al. 2021). The project was successful in other ways, though, bringing together diverse communities across the city to participate in hands-on workshops and training, producing educational materials, and highlighting the potential for bioremediation strategies to remediate the creek.

In examining these works, Chin, Whitehead, and Mun's efforts point to an interesting tension that many ecological art projects present. On the one hand, there is often an ambition to emulate ecological processes and offer practical solutions, and on the other, a desire to experiment with aesthetic forms and concepts. The friction that arises is critical for artists and collaborators to consider in conceiving artworks that aim toward the remediation of damaged landscapes. In many cases, these works gesture toward complex processes that may require decades or centuries to be effective, yet also promote NBS strategies that look beyond carbon-intensive and human-centered stewardship practices. These artworks help bridge siloed disciplines, generating new knowledge, and showcase the capacity of an art–science nexus that may prove critical to realizing effective NBS in cities moving forward.

ENVISIONING POSITIVE FUTURES: NEW MODELS AND PROTOTYPES FOR NATURE-BASED SOLUTIONS

In his essay "Ecoaesthetics," artist and commentator Rasheed Araeen (2009) recalls the art manifestos of the early twentieth century that implore artists to abandon the creation of objects for museums and instead develop radical ideas to address emerging eco-social challenges. Araeen emphasizes the power of the artistic imagination to confront the impacts of rapid urbanization and climate change. As the projects in the previous section demonstrate, art can

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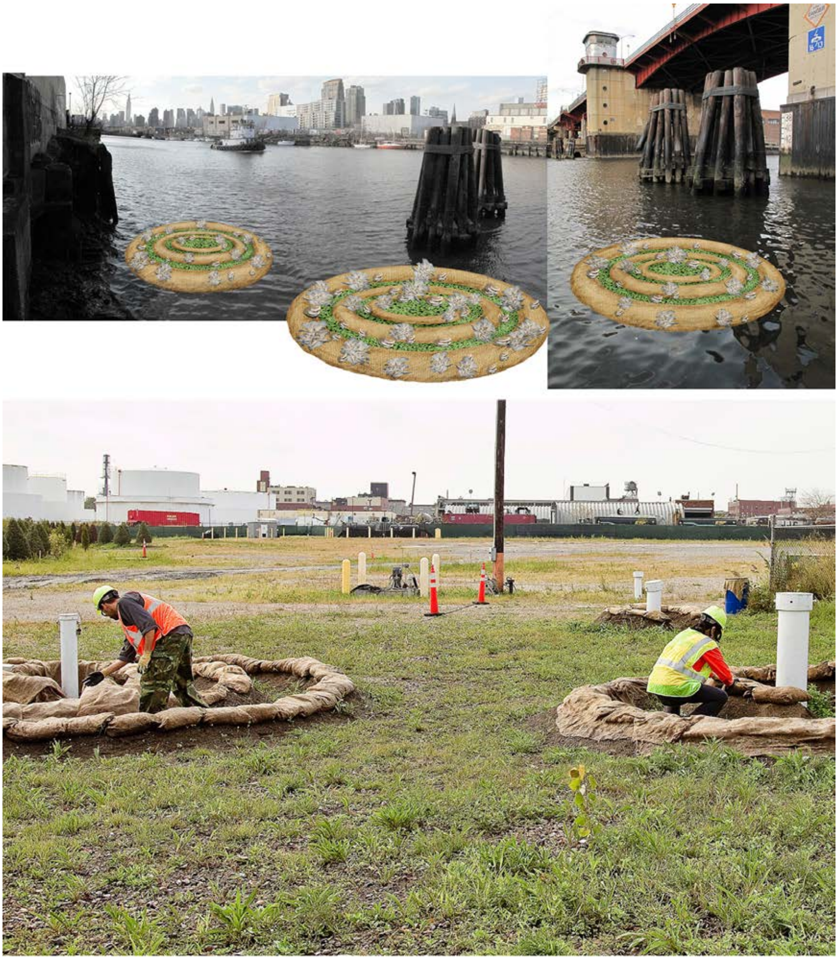

Source: Images provided and taken by the artist, Jan Mun.

Figure 14.4 Top: Illustration of an early prototype of artist Jan Mun's The Fairy Rings *(2013); bottom: Jan Mun working with technicians to install mycelial mounds at the Newtown Creek site in Brooklyn, New York*

accomplish more than raising awareness and help to realize new prototypes and models for sustainable living and NBS for cities.

Beyond the bioremediation approaches explored, early works from ecological artists like Liz Christy or Bonnie Ora Sherk showcase how artists

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began to experiment with new models for land stewardship, food production, and community-based mutual aid (Kirchberg 2016). In San Francisco, Sherk created a project called *Crossroads Community (The Farm)* (1974–1987), which was sited underneath a freeway interchange at the intersection of several low-income predominantly Black, brown, and immigrant neighborhoods with low access to quality green space and fresh produce. Sherk's project explored decentralized food systems and communal models of living by co-creating a space to grow food, keep farm animals, an art gallery, and school. Around the same time in NYC, Christy founded the Green Guerrillas (1973) and rallied actions to revitalize underutilized vacant land with "seed bombs." The efforts later inspired the creation of the Bowery Houston Community Farm and Garden, the first and oldest community garden in NYC. These early works recognized critical gaps in urban services that impacted marginalized communities in ways that continue to exacerbate environmental inequities. What's more, they attended to the lack of flexibility in municipal planning and decision making common in many urban areas. Aesthetically, the emphasis of the work is not necessarily on creating a particular art object, but rather the co-creation of dynamic models for new kinds of relations, practices, and collective experience.

Over the past decade, this propensity to experiment with new models or prototypes for NBS has continued. For example, Mary Mattingly's *Swale* project, a floating food forest built atop a barge that travels to public piers in NYC (2016–), is a response to local ordinances that prevent communities from growing or foraging for food on public lands. Staffed with youth from the New York State Summer Youth Employment Program and facilitators from Youth Ministries for Peace and Justice, the public is able to visit the barge, forage publicly for food, and interact with local gardeners. In placing a food forest on a floating vessel exempt from the ordinance, Mattingly offers a novel model for food resiliency and an opportunity for New Yorkers to exchange practical knowledge about soil and water quality, urban agriculture, and medicinal plants. In 2017 the artwork docked at Concrete Plant Park in the Bronx, where it helped inspire a new pilot project called the Bronx River Foodway, which provided the first public foraging garden in NYC in a neighborhood deeply impacted by environmental racism and food apartheid (Beurteaux 2019).

As both a conceptual artwork and a NBS, the project asks us to consider the impacts of industrial farming and the right to grow food in public space. Mattingly's work also surfaces the procedural barriers that many governance and planning models present for communities and highlights how artistic interventions can showcase alternative models of decision making and planning. Yet Mattingly's work in some respects is temporary. The barge, for instance, was at one point decommissioned because of funding issues, problems with finding a reliable docking location, and other challenges. Ecological artworks

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like this, while novel models that can inspire, promote, and even realize NBS, may inadvertently emerge as short-sighted or exclusionary. In the case of Swale, Mattingly's project was effective in bringing together disparate groups and created an opportunity to advocate for the Foodway initiative and the pressing need to address food access. Yet, in many places worldwide, long-term strategies co-produced by local communities are urgently needed to address social and ecological challenges seriously.

Ecological artists must tread carefully in this sense. Artworks such as Swale may not be enough to address systematic problems and realize NBS at sufficient scale long term. The pressure placed on artists to create a compelling rendering or beautiful object can prevent other impactful approaches, which potentially limits the creation of new models or prototypes for NBS. Christy and Sherk's work is successful because the efforts originate in response to the community's needs and continue to be embedded in a particular place. The projects also adapt, evolve, and sometimes end, emphasizing a need to continually be in relation to the work, its intent, and capacity to be flexible and responsive.

ARTISTS AS TRANSDISCIPLINARY BRIDGE BUILDERS

In recent years, artists have increasingly worked collaboratively in interdisciplinary teams, making social engagement and participation an integral part of their practice. Socially engaged art can be traced back to artistic movements that arose during the cultural and social unrest of the 1960s (Sholette & Stimson 2005; Finkelpearl 2013), but also has precedents in early twentieth-century avant-garde movements (Bourriaud 2002). In urban centers—from Paris to Berlin to Moscow to Milan— artists began to respond to industrialization and urbanization, imperial expansion and collapse, and the turmoil of the First World War (Bishop 2012). This shift provoked artists to confront a range of social and political issues and to reconceptualize the relationship between artist, artwork, and audience to "channel art's symbolic capital towards constructive social change" (Bishop 2012, p. 17).

In large part, these socially engaged works recognize the importance of approaches and knowledge from multiple domains to address the complexity of urban environmental issues. Over the past several decades, artists have begun to work more closely with entities like urban planning offices, economic development departments, community groups, and other stakeholders to inform the visions for green infrastructure or development (Landry 2006; Kovacs & Biggar 2018). In many respects these collaborations can help build bridges between disparate disciplines, stakeholders, and diverse communities. For example, artist Jordan Weber collaborated with the Malcolm X Memorial

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Foundation and members of the Shabazz Community Garden to create *4MX Greenhouse* (2018), a hub for environmental health inspired by the legacy and teachings of Malcom X. Through a partnership with local communities and the Memorial Foundation, the project addresses issues of environmental racism, while providing access to the greenhouse's harvest and educational programs for and by the Black community in Omaha, Nebraska (Colón & LeFlore 2019).

In another example, artist Mark Brest van Kempen worked with the Seattle Department of Parks and Recreation and the Metro/King Wastewater Treatment Division from 2002 to 2009 to design and implement a public art project that traced Ravenna Creek's historic and present-day flow (Watts 2009). The work builds on a decades-long struggle by watershed groups to redirect the naturally fed water source, which had been diverted to a sewer line and water treatment plant in the 1950s. This shortsighted decision unnecessarily treated the creek water, and by 2002, the county began to develop plans to return the creek to where it had initially flowed—primarily underground. Brest van Kempen developed several components for the project, including an outfall structure and viewing station where the creek enters the pipeline underground from Ravenna Park. Along the sidewalk bordering the Creek on 25th Avenue Northeast, he also marked a blue line to delineate the underground pipe, including three daylighting vaults to show pedestrians the stream, as well as embedded plaques with inset capsules of native seed (Figure 14.5). Overall, the project created 650 feet of new streambed with naturally occurring riparian and woodland habitat and resulted in a 20 percent increase in creek flow, which may have significant impacts on the aquatic ecology downstream.

Aesthetically and conceptually, Brest van Kempen's work does not aim to romanticize the waterway but instead urges the viewer to consider the complexity of urban infrastructure and our relation to sensitive waterways often overlooked or displaced in cities. The effort is a salient example of an effective NBS while also showcasing how artists can be a critical part of the planning, implementation, and promotion. Brest van Kempen, for instance, worked with the Ravenna Creek Alliance to help determine an appropriate compromise between community members who were concerned the project would remove a frequently used baseball field, attending City Council hearings and discussions. Eventually, an agreement was forged that allowed the project to move forward. Although it is difficult to discern whether Brest van Kempen's presence or input was the driving force behind the agreement, it offers an example of how artists can be integral to a project's public planning process and realization.

Ecological artists and artworks can also be instrumental in supporting community involvement in decision making and governance. A useful case to consider is the curatorial work of Wu Mali in East Asia, who, from 2011 to 2012, developed the project *A Cultural Action at the Plum Tree Creek*,

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Figure 14.5 Mark Brest van Kempen, Ravenna Creek Drop, 2002–2009

situated in the Plum Tree Valley/Zhuwei area of New Taipei City in Taiwan (Figure 14.6). Working with collaborators at Bamboo Curtain Studio, an artist residency and performance venue, they focused on raising awareness of water quality and pollution issues in the watershed through creek explorations and oral stories told by local elders. The studio also organized community events and exhibitions to engage local artists and professionals in addressing urban sprawl and improving municipal management of public infrastructure, as well as collaborations between elementary, middle school, and university students and their teachers to encourage the exploration of better land care practices. Following the project, the New Taipei City government began paying more attention to the waterway and working on a new landscape plan. Before Wu's project, the city government had failed to disclose and discuss policy plans with residents. As the project progressed, plans were sent to the artist through Bamboo Curtain Studio to distribute in the community, creating a platform for dialogue and exchange to strengthen community representation and cohesion in a low-income, semi-agricultural region heavily impacted by urbanization and population growth.

While both Brest Van Kempen and Wu's work have successful aspects, their efforts highlight the complexities of artists working across disciplines and collaborating with those from other fields. Several scholars emphasize a need for additional research and theoretical understanding of the impact

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Source: Courtesy of Wu Mali.

Figure 14.6 Aerial image of the Plum Tree Creek (2017)

and process of artists working with planners and other stakeholders (Metzger 2011). In many cases, artist collaborations can be patchy, underfunded, and hyperlocal, making it difficult to determine best practices. Additionally, the

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artist may be brought into a process only after key components have been decided upon and can easily be coaxed into consensus or confront immovable power dynamics. Yet, the artist also has the power to uncover hidden dimensions of a particular challenge and can provoke necessary disorientation or "making strange" that can motivate new perspectives and more earnest, open dialogue within planning processes (Metzger 2011). However, these ways of working can be easily co-opted and institutionalized, assuming that an artist or artwork can be inserted into a place to solve a presumed "problem" without careful consideration of the long-term needs of a community. In particular, creative place-making concepts are touted as effective revitalization efforts that attempt to infuse art and cultural infrastructure into city planning (Markusen & Gadwa 2010). Although these efforts can benefit some, practices such as place making can be appropriated as a "neoliberal cultural development agenda" or a "philanthropic route to gentrification" (Wilbur 2015, p. 97). Others like Roberto Bedoya (2012) argue that arts-based place-making initiatives have historically ignored issues of race, poverty, and the social dynamics of place, instead privileging forms of urban revitalization "generated by dominant white ideology" (as cited in Webb 2013, p. 37). These concerns reiterate what Grant Kester (1995, p. 9) refers to as "aesthetic evangelism," describing how artists are increasingly positioned as "transhistorical shamans" sent to restore social bonds with disenfranchised communities.

CONCLUSION: MOVING FORWARD

The examples described here provide a glimpse of the immense scope of work by artists engaging with issues of ecology and the environment around the globe. Artists are increasingly involved in co-visioning urban greening plans, working closely with scientists and other stakeholders, co-creating participatory works that foreground the importance of urban nature, and helping city dwellers shift their worldviews, among other efforts (Potter 2009; Perovich 2018). Yet, despite the enormous potential, artists are still rarely included meaningfully in the planning processes or decision making at the city or regional level (Brigham 1993; Metzger 2011). Assumptions about what artists can bring to the table and recurring resistance to realizing flexible and inclusive decision-making processes are fundamental factors. As practitioners with expertise, artists should be recognized as valuable contributors and integrated into all research and planning stages.

Still, there are many limitations and barriers to utilizing art to advance NBS. Artists, for example, are increasingly being asked to serve multiple roles, often with little support or guidance on how to integrate considerations of equity and inclusivity. Critic and scholar Grant Kester (2011) warns that the artist or the institutions that support them can easily use their authority to exploit this

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arrangement, assuming a community needs to address these issues without first consulting or collaborating directly with the communities. If left unexamined, these attempts to restore the "social bond" may do more harm than good. What's more, artists are rarely financially supported in meaningful ways for their contributions, thus influencing the potential impact of the artwork and set of relations forged through a community-led project (BFAMFAPhD 2014).

Yet, hope persists. Artists across the globe increasingly recognize the urgency of the climate crisis and integrate social-ecological concerns and solutions into their work and practice. We can see evidence of this daily, in demonstrations and protests, new public artworks and urban infrastructures, the planning and design of cities, and the emerging discourse of NBS. Ecological art offers a unique capacity to help individuals and communities envision positive futures, to see themselves as not only part of the problem but also the solution, and perhaps what Lucy Lippard (1983, p. 9) would argue is an embrace of the "sensuous dialectic between nature and culture."

NOTES

1. Many scholars point to the emergence of Earth art in the 1960s and also land art in the 1970s as a critical turning point in the history of ecological art and the environmental art movement more broadly (Moyer and Harper 2012; Cheetham 2018). Rejecting the art object as separate from its environment, artists began to develop large-scale interventions on outdoor sites. Rather than fill gallery cubes with paintings or sculptures, works like Walter De Maria's *Lightning Field* (1977) in New Mexico, Nancy Holt's *Sun Tunnels* (1973–1976), and Robert Smithson's *Spiral Jetty* (1970), both in Utah, proposed a new relationship between art and the land.
2. In the United States, "superfund" is the informal term used to describe sites determined to be contaminated enough to qualify for special federal funding for cleanup and remediation under the 1980 superfund act, also known formally as the Comprehensive Environmental Response, Compensation, and Liability Act.

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15. 1 + 1 = 3: stories of imagination and the art of nature-based solutions

Patrick M. Lydon, David Maddox, Robin Lasser, Baixo Ribeiro, and Carla Vitantonio

Ecological being
acts within the earth
the earth within acts

Cradling unique DNA
Sewers spawn community
Sublime dank pipe dreams

Troppo vicino
Rabbia scintille voci?
Viva io brucio[1]

O tempo e o vento
A poesia
Na rua, na cidade.[2] (P. Lydon, R. Lasser, C. Vitantonio, and B. Ribeiro)

Picture yourself sitting in a small forest on the edge of a big city. If you listen, there are faint sounds of city life, a train moving across metal tracks, the clanking from a small factory, shouts of a corner merchant over laughing children playing on their way home from school. These sounds are joined by the sounds of those who dwell in and around the trees; there are the shouts of two heron bickering as they take flight from their high perches, and below them the steps of a deer over leaves as it moves toward the edge of a small creek.

These are the sounds along a small river path in Osaka, one of Japan's largest urban areas. Although such places as this might seem uncommon, most cities have some of them, and every city has potential for them, at the borders where nature meets urban. These are the places where—at least for a moment—nature and humanity strike some kind of balance.

Can awareness and a celebration of this world and our place in it help us imagine more equitable, ecological ways of living for more people and non-human organisms in this world? Yes, they can, and the way of the

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artist—a way rooted in relationships between ourselves, our work, and the natural environment—offers routes and methods to help us get there.

This chapter seeks to explore how the artist mindset—one typically though not always explicitly employed by the painter, the sculptor, the dancer, the writer, or the musician—is one which can help individuals in all disciplines explore novel and innovative paths to achieve nature-based solutions (NBS)—paths that often involve collaboration and imagination.

We often think of art as a way to help illuminate human–nature interactions, ecologies, and what we broadly describe as "nature-based solutions," and it is. There are many urban ecological artists working to illuminate NBS (see, for example, Curating Cities, www.eco-publicart.org; Ecoart Network, www.ecoartnetwork.org; Forum for Radical Imagination on Environmental Cultures, www.thenatureofcities.com/friec/). At times their work takes place alongside scientists, politicians, and planners, and has direct ecological impact. Other times, the artistic practice may focus simply on the experience of our relationships with nature, which in turn may serve to expand appreciation of NBS among people who are not NBS professionals. A key value of these approaches to art and NBS is in their tendency to work at the edges of how we define the world, exploring the active frontiers between concepts and places. As in nature, these edges are abundant places for solutions.

HOW IS ART A NATURE-BASED SOLUTION?

> Science describes accurately from outside, poetry describes accurately from inside, you could say. Science explicates, poetry implicates. Both celebrate what they describe. We need the language of both science and poetry to save us from ignorant irresponsibility. (LeGuin, 2014)

Like science, art is also its *own way of knowing*. In Ancient Greece, the arts were said to be rooted in the act of *mimesis*, a term that relates to the imitation of nature and to the experience of coming to know *oneself as nature, and nature as oneself* (Taussig 1993; McGinnis 1999). A human being engaged in the creation or experience of art is entering into a way of seeing that challenges our contemporary society's common relationship with nature—one of domination and extraction. The view of art as a fundamental human capacity to connect with nature is one that has seen striking consistency across time and culture for thousands of years (Kelly 1998; Fuentes 2017), and mainstreaming human–nature connections must be central to an expanded use of NBS in societies.

Is such a concept of art completely unrelated to other disciplines? Hardly. Think of a world-renowned chef, or figure skater, or urban planner. These occupations may seem to be distinct from art—and from each other—yet,

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when they are done with excellence we commonly assign the word *art* to them. The *art* of cooking, the *art* of figure skating, the *art* of urban planning all sound like natural statements. Indeed, when we witness any of these jobs being performed as an *art*, we call the practitioner *a natural* at their job.

This is not mere wordplay: the words *artist* and *natural* are both rooted in the acknowledgment of human beings acting in accordance with nature (Haley 2011). At its most radically essential definition, therefore, *art* might be best distinguished as the pure act of giving form to our relationship with nature (Lydon 2020). Biomimicry and biophilia are logical expressions of this relationship.

The artists and practitioners in this chapter share the view that the core value of art to the NBS movement is that *art itself* is an ecologically connected way of doing: both a way of knowing and a mode of action. Although art may not always carry explicitly ecological messages, it is always a collaboration between human beings and the environment.

Throughout the chapter, we dance with the idea of art as a NBS in theory and in practice with statements from individuals who are working within various contemporary cultures and mediums in the urban landscape. These statements are woven together with contextual writings, tying individual artistic practices to potential actions, municipal musings, and social movements for NBS in our cities.

We explore these ways of knowing, being, and doing in three stages, each connected to a mode or philosophy of engagement that helps connect ideas to artistic and transdisciplinary expression:

1. *Awareness* with artist and professor Robin Lasser from the United States.
2. *Radical imagination* with curator Baixo Ribeiro from Brazil.
3. *Becoming storytellers* with actress and author Carla Vitantonio from Italy.

ART AS A WAY OF DOING, FOR EVERYONE

> Art takes nothing from the world, it is a gift and an exchange. It leaves the world nourished. (Snyder, 2013)

To discover *art* as an ecological way of thinking and doing, we must first rid ourselves of the notion that *artist* only applies to a painter or a musician or someone otherwise engaged in what contemporary Western society calls art. Creatives of all sorts, beyond the boundaries of traditional “art,” are “artists.” In acts of science, too, though the process and outcome may seem vastly different, there are deep threads of imagination and creativity. Such creative threads tie together innovative work in every field, allowing both the scientist and the artist to “celebrate” this place we inhabit (LeGuin 2014).

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You, the reader, are an artist, too. Or at least you hold the potential for this way of working with a creative and imaginative awareness and connection to the environment. Within each of us is an art that allows the opportunity for all humans to discover and use their own creativity in their work. This is the art that allows for new innovations in NBS to emerge, whatever the discipline.

Art has a tremendous role in illuminating and interpreting NBS (Adams 1992; Cheetham 2018). But we take a different approach here: to examine how an artistic *sensibility* can transform approaches to collaboration and innovation within the natural world. Words like "imagination," "creativity," and "intuition" are native to conversations in art. But they are often seen as problematic in science and policy. It should not be so. In this sense, we are proposing a collaborative approach to work in NBS and the environment, one that specifically explores the role of creativity, intuition, and imagination.

PART 1: AWARENESS IN TENT CITY SANCTUARIES: A THREE-ACT PLAY BY ROBIN LASSER

Act 1: Refuge in Refuse

The campfire is red hot. It burns the rubber soles of my shoes and boils the blood in my heart. It's midnight under the stars and the San Francisco city lights glisten across the bay. Boxer Bob is here with me, hammering away, building his mansion by the sea. He is using materials upcycled from the site of a former construction dump turned California State Park, where he lives. Locals refer to this place as the Albany Bulb (Figure 15.1). Boxer Bob taps compulsively; the nail that sticks out gets hammered in. He turns down the blast from his solar-powered radio, his eyes piercing mine.

> In boxing you are dealing with the fight for perfection, in boxing you deal with the fight of the fittest. Building, yes, that is a fight too. To feel the way that Noah felt when he built the ark, bringing all the wood up here from the dumpster, doing stuff I had never done before and then actually witnessing myself doing it. My biggest fear is becoming homeless and that great motivation turned into the mansion.

The Albany Bulb, where Boxer Bob's mansion rises from the refuse, is a man-made spit of land on the east side of San Francisco Bay. Mining sediment dating back to the California Gold Rush formed the base, and in 1963 the area became a construction dump for the rebar, concrete slabs, and marble from Richmond's demolished City Hall and Berkeley's former library. In 1983, the dump was closed and the area was covered over with "green waste," such as soil, tree trimmings, and yard waste. Plants were able to take root, and today the landfill looks lush.

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Source: Photo by Robin Lasser.

Figure 15.1 Refuge in Refuse *at the Albany Bulb Landfill, 2014*

In the Bulb's more recent history, renegade artists erected fantastical sculptures, dog walkers strolled with pets, and in the 1990s people with nowhere else to go settled in and called it home. They evolved their own small community and created both extraordinary personal dwellings and community structures for enjoying life on their terms—a gym, a library, a mansion, a castle for fairies. These diverse denizens of the Albany Bulb—residents, recreationalists, artists—co-existed side by side for some 20 years. On April 25, 2014, however, the 60 residents were evicted from the place where they had created and lived their dreams, to make way for a to-be-built California State Park.

For me, the Albany Bulb was a last stand, one of the few places in America where creative anarchy ruled. By that I mean the plants were wild, the art dotting every square inch of the peninsula was unsanctioned, and the residents embraced alternative lifestyles. They lived in much the same way as many urban dwellers might live in the not too distant future. There are no cars on the peninsula; water was brought in by bicycle; there were no power lines, only generators run by solar power. A kindred spirit, I have roamed the Bulb for almost two decades, observing the intersection of people, art, and ecology.

The interdisciplinary arts project related to this place, *Refuge in Refuse: Homesteading Art and Culture*, commemorates the creative spirit of the former Bulb residents, who called themselves the landfillians.[3] The memory of the landfillians, with their fiercely alternative lifestyles and their unique art, is preserved in surviving art works from the Bulb and lens-based documents I produced collaboratively with the community, including large-scale photographs, a feature-length film, and sculptural installations. Aerial photographs and 3D

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scans help preserve the landfillian moment in the Bulb's history in accurate detail, and an archaeological record of the former residents and their culture was created as *The Atlas of the Albany Bulb* by project director Susan Moffat. A group of landscape designers have now created visions of possible future uses of the Bulb, exemplifying diverse forms of, and the tensions between, sustainable creative placemaking and placekeeping.

Act 2: Dress Tents

I look through binoculars toward home, San Diego where I grew up, California which I still call home, and the country that has erected the border wall at my back. The sun beats down, but beneath me there is shelter, a place to rest in the shade and reflect on this place.

For the past 13 years, I have worked with collaborator Adrienne Pao to create a series of 17 pieces of wearable architecture called "dress tents." Each installation references topics pertaining to the place and culture where the dress tent is located, allowing us to explore body and land as two symbols of shelter and to construct a fashion of place in these community meeting grounds.

My students are with me on this exploration, as are fellow professors. Some of them have crossed this border; some have family on both sides of this divide. Tomorrow we will incur the anger of a border patrol agent, though we have a permit to be here. Tomorrow we will face intimidation. But today we install, create, document this place, turn our gaze inward and toward home. We meditate on those who are forced to leave their home, due to violence, extreme poverty, climate-caused evictions, the drive for a better life.

Installed in San Diego, California, at the border park beneath the United States–Mexico border fence, the monolithic *Ms. Homeland Security: Illegal Entry Dress Tent* (2005) is militant and quirky, dressed in military fatigues while baring her skin (Figure 15.2). This tent is a "gatekeeper," mimicking minutemen vigilantes and patrol guards. Visitors are invited to step inside the dress tent, write and draw about their own relationships to border issues on the cot in the tent interior, and thus cross the border between public and private space. *Ms. Homeland Security* is a shelter providing refuge from the desert extremes, a temporary encampment that encourages community story sharing and awareness with regard to one of the most pressing issues of our time—global immigration rights. We are currently in the greatest age of migration since the Second World War. Climate refugees magnify and focus a lens on the environmental causes of mass migration. The Border Field State Park, where the work is installed, sits on the Tijuana Estuary Watershed. This important wildlife habitat is home to critically threatened and endangered birds such as the Western Snowy Plover, the California Least Tern, and the Light-footed Ridgway's Rail. The Tijuana River and surrounding landscape

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are in constant threat from unregulated polluting toxins emanating from the urban environment. Sharing stories within the intimate space of the dress tent creates opportunities to rekindle our relationship with each other and with nature, beyond borders.

Source: Photo by Robin Lasser.

Figure 15.2 Ms. Homeland Security: Illegal Entry Dress Tent*, 2005*

Act 3: Floating World

It is twilight. I am walking the route from Diridon train station to the heart of the city, San José. A tent city installation, built on stilts to protect occupants from the possibility of floods, lights up the corridor beneath the SR 87 highway overpass, along the San Fernando Street corridor. Each tent contains a lantern and a speaker or microphone. I suddenly feel safer walking at night. I feel less alone. Someone is singing to me from one of the miniature disaster relief tents gracing the bridge that crosses over the recently flooded Guadalupe River (Figure 15.3). The voice sounds familiar, singing tunes about the history and

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health of the Guadalupe Watershed and the relationship of floods to climate change. I hear bird songs reverberating from the interior of another tent. When an airplane passes overhead, the bird sings at a higher pitch, calling to his mate, nesting in another cluster of tents. Someone told me that urban birds are beginning to modify their songs in order to be heard over the din of anthropogenic noise. I wonder how birds who cannot change their tune survive. I hear footsteps behind me, someone carrying their life possessions in a grocery cart, heading toward the underbelly of the bridge to sleep that night. He passes me and says: “these tents are mine.”[4]

Source: Photo by Robin Lasser.

Figure 15.3 Floating World: A Tent City Campground for Displaced Human and Bird Song*, 2010*

Awareness for NBS

The act of doing *art* is achieved by paying full attention to our innate connection with what is around us. This kind of awareness is characterized by a respect for other points of view, and by actively seeking out novel perspectives.

Most of us have difficulty engaging the world in this way, especially when we address the often uncomfortable interconnections among the wicked problems such as climate change, racism, nationalism, migration/displacement,

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and equitable urban planning, to name a few. Robin Lasser makes such issues approachable—often employing whimsy, fantasy, or spectacle merged with scientific inquiry—to produce installations that are driven by respect for various points of view, nature and human alike, yet which also engage our curiosity about difficult subjects.

As a tool for NBS, artistic and collaborative approaches can be productive doorways for considering our relationships with the world around us. For Lasser, art provides both a physical space and experience where audiences engage in the spaces between environmental and cultural issues, allowing for alternative modes of seeing, thinking, and communication.

The case of the Albany Bulb resonates strongly with conversations around the world, about how to reconcile informality with sustainability planning (Zárate 2016). The *Refuge in Refuse* arts project brings up questions asked often by sustainable urbanists: for whom are the new diverse, sustainable placemaking efforts, and who gets to enjoy the benefits? We ask these questions, but rarely come up with good answers. Lasser's work suggests that engaging both the unsanctioned residents and the land could help our society find more appropriate solutions.

What could we learn, for instance, if we listened to the story of Boxer Bob, or the countless other artists who built their homes *inside* a landfill, using only solar power and construction trash? Motivated by a fear of becoming homeless, the *landfillians* were nothing if not innovative, finding myriad ways to build a sustainably sourced neighborhood using refuse. Globally, such stories are common. Yet informal settlements, their markets, wares, structures, ecologies, innovations, and social networks tend to be invisible to the modernist systems of value and worth. Through the lens of art Lasser found value within this informal settlement.

There is no manual for how to interact with tenants of informal settlements and their landscapes. Listening to and engaging with such circumstances requires that an individual's attentiveness and willingness to listen take precedence over training and protocol. This is where we begin to listen and genuinely *hear* both the environment and other people.

Boxer Bob's case revealed innovations in materiality, community, and land use that are not common practice, and would not have been documented if it were not for Lasser and her artist-led, transdisciplinary coalition. Here, art can provide a key to recognizing the often unseen roots of issues and to find creative, sometimes radical, pathways to sustainable, citizen-powered NBS solutions.

In the case of the Mexico–United States border, Lasser and Pao question the problematic role of human borders, and their fraught relationship to the climate, environmental pollution, and mass migration. It is revealed through their *Ms. Homeland Security: Illegal Entry Dress Tent* that *environmental*

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issues caused by one nation can freely cross to threaten another nation, yet *people* are somehow not allowed to flow the other way when those environmental issues threaten their livelihoods. With climate change-induced migration contributing to the increase of such conflicts, this seems to be another area of need for awareness (Oxfam International, 2004).

Lasser suggests that in using art to build space and time for awareness into the urban fabric our cities might be elevated in unexpected ways—psychologically through our increased chances for biophilic relationships, or literally through the social, ecological, and economic effects of resilience-building biodiversity. If anything, such *awareness* in cities might feel a bit less like impermeable concrete and a bit more like the floating, always changing, and environmentally complete worlds that they are, or should be.

PART 2: RADICAL IMAGINATION: A NEVER-ENDING EXHIBITION, BY BAIXO RIBEIRO

Many of today's children will reach the next century having absorbed part of our culture and knowledge. What will their future look like? Imagine a future where you want to be—and please, have a radical imagination! Have you thought about it? Do you want a city of cars or trees? Do you want rivers flowing alive, or channeled and turned into sewers? Do you want food farmed by everyone on the streets, or more supermarkets and malls filled with food transported from far away?

With this provocation, imagine the *Radical Imagination* exhibition, promoted by *Choque Cultural* in Vila Madalena in São Paulo, Brazil. It takes place in January 2021 in public, with works in several languages. The works include contemporary graffiti by the Argentine artist Tec; collages and posters with phrases written by young African and Latin American refugees hosted by the architectural colleges of the universities of Lapland, São Paulo, and in partnership with Baurú; night projections by the Liquid Media Lab collective; disruptive sculpture-like car carcasses transformed into gardens by the collective Bijari; and a pair of large linocut prints mounted on cut-out wooden boards made 10 years ago by the artist Swoon and installed in the Coopamare waste-recycling cooperative, among other works and urban interventions.

All the works are installed in an area that crosses Vila Madalena, following the Green River, a watercourse that—even though channeled and buffered by streets—remains alive, meandering through the neighborhood, constituting a walk that includes squares, streets, and alleys. The Green River, which for part of the year remains "hidden" and quiet, overflows and appears raging in the rainy season, transforming the streets and alleys of Vila Madalena into an awkward Venice—one without the gondolas or glamor.

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Radical Imagination is an exhibition that has no end date. This is part of an exhibition program that started 10 years ago, and we hope it will never end. This annual exhibition event has accumulated artistic legacies that have helped transform the Vila Madalena neighborhood into a huge open-air art gallery, becoming one of the main tourist and cultural attractions of São Paulo. Since 2011, this program of exhibitions has stood by its mission, keeping activism vibrant by the occupation of public space through art, incorporating other diverse causes that, together, reinforce each other, such as recycling, bicycle activism, the restoration of urban rivers, and the transformation of local squares into urban farming areas.

The exhibition has held true to the following main features:

- Exhibition of works outdoors, in public space.
- Encouraging collaborative and multidisciplinary work that combines art with education, ecology, tourism, and creative economy.
- Encouraging active public participation through an intense program of practical workshops and conversation roundtables.
- Promoting integration between residents, people who work in the neighborhood, visitors, nature, and including everyone through spaces for dialogue and, in particular, spaces for speech for minority groups.

Looking back over 10 years of exhibitions, we can say that the legacy of urban transformation in the region is palpable. At the origin of the process is our experience with the exhibition De Dentro and De Fora, which we set up in 2011, in partnership with the São Paulo Museum of Art (MASP). For this collective exhibition, we invited eight artists, among them the French artists JR and Invader and the North American artist Swoon, to perform a large collective installation occupying the entire MASP and, simultaneously, artistic installations in the public space around the city.

Swoon designed an installation in the open space of the museum, an exhibition area that merges with the public walk and the museum's own bold architectural work by Lina Bo Bardi. Swoon produced a complex sculptural installation built of wood, which served as a temporary shelter for the homeless in the region. During the five months in which the work was exhibited, people were able to take shelter, sleep, eat meals, read, and even take a bath inside the artistic installation.

The reason for the success of this small, autonomous, and self-managed village—which was attended by thousands of people without any serious problems during the entire period of artistic occupation—was the daily and permanent care provided by volunteers who administered the many workshops and activities that animated life in *Ersilia*, the name of the facility.

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For this to happen, in partnership with the artist we gathered more than 100 non-governmental organizations distributed along the lines of urban housing, recycling, urban planting, and bicycle mobility to together organize the programming of activities around *Ersilia*. One of the organizations that participated in this collaborative creative process was Coopamare, a cooperative of recyclers formed by “scavengers,” typical São Paulo figures that circulate in the streets pulling heavy carts with mountains of discards and take them to the recycling plant near Vila Madalena. It was there that the artist installed her own temporary studio, where she produced her works for the exhibition at MASP. In return, the two pieces of linoleum were donated to Coopamare and are still there today. These works also took part in the exhibition in 2021.

In 2012, the exhibition called “Existe Amor em SP” (“There Is Love in São Paulo”) was associated with a large movement of occupation of public squares for political demands through music shows and various artistic activities. “Occupy the Streets” was the idea which inspired us to come together with an exhibition that was at the same time a street party.

In 2013, the exhibition “Existe Rio in SP” (“There Are Rivers in São Paulo”) asked the public to support the construction of the Green River Park, an urban project created by the architect Anna Dietzsch. Works spread along the river path, passing through graffiti alleys, between shows by street musicians, cycling, and street occupation by residents, merchants, restaurants, in a big celebration in honor of the river and the park in which the community gathered.

In 2015, the exhibition that occupied the streets was called *Poesia no Concreto* (Poetry on Concrete) and presented to the general public the artistic movement of poetry disseminated through posters (“lambe-lambes”) glued directly on walls, poles, and other areas of the city. The written word and the poetry of the artist Lau Guimarães and the collectives Transverso and Paulestinos began to share the exhibition space with the innumerable graffiti that made the neighborhood famous.

In 2018, the exhibition focused on the creation of *Praça Da Simpatia* (Sympathy Square), transformed into a multisensory experience space through several installations by the artist Alê Jordão. Solar-energy plates activate neon pieces and devices to charge our cell phones for free, and sculptures made with car-beaten guard rails serve as furniture for the square, being used as benches or toys for children. This square, which was abandoned and restored by the artist, has been home for over 30 years to an orchard with mango, avocado, guava, lemon, tangerine, as well as coffee trees and pomegranates planted by former residents of the neighborhood. With the maintenance facilitated by the restoration of the square’s space, today residents also take care of the vegetable garden that was planted in the square.

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In 2020, permaculture and agro-forest were the main focus of the exhibition *Praça Agro Eco* (Agro Eco Square), with the association of art and urban farming for the occupation of another square in Vila Madalena. The artists Thais Gil, Jotapê Pabst, Cicloartivo Collective, and Dablio Black produced works that spoke directly with the agro-ecological activities taking place in the square, as well as the painting of an imaginary river with its fauna and flora, done on the ground next to composters and hedges. Currently, there are many workshops for children, adults, tourists, and even street sweepers who have classes on composting.

In 2021, the exhibition resumed the struggle for the official installation of Parque do Rio Verde, which, in addition to cleaning up the lower and flooded areas of Vila Madalena, mitigating the effects of the great floods that happen every summer, established an identity for this set of equipment that has been spontaneously built by the community. The park has been imaginatively built and managed for years under the stewardship of various community members, but has not yet obtained recognition from the municipality for what it is: an innovative model of urban occupation in its most diverse motivations.

Art activates our ability to collectively see a better future, a better city. Art helps us to imagine radical changes in current customs and forge good collective ideas about our future. With that in mind, we have invited artists and audiences to actively participate in this permanent experience of collective creation for a new urbanity.

Radical Imagination for Nature-Based Solutions

When we happen upon situations that seem on their surface to be impossible, only to discover later that they are not, we are in the company of radical imagination. This kind of "radical imagination" exists under the soil, and indeed the very word radical comes from the Latin adjective meaning "rooted." Just as the roots of trees support not only the tree but an immense web of life both under and above ground, this rootedness flows from a concept—deeply embedded in theater—that through collaboration we can create something we could not have created by ourselves.

Baixo Ribeiro's provocation is both an example and a question. A "radical imagination," he poses, is not to imagine *our* future, but to imagine the *future of today's children*. What kind of world would we like them to live in? Many of us know how we *want* to answer this question. Few of us, though, know how to *act* on the imagination inside of us. We don't think it is real, or possible. As the instigator of *Choque Cultural*,[5] Ribeiro shows us how art can help envision the possibilities, to bring them into reality, and even to alter our reality as we know it through the act of radical imagination. *Choque Cultural*'s projects help

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us realize, with our eyes, hands, hearts, and all of our senses, what it is to be part of a culture that sees and responds to the living network around us.

By working collectively with groups who often would never talk to each other—connected also to the idea of *awareness*—let alone collaborate creatively, Ribeiro is doing more than community building; he is showing us how radical imagination, at its most productive, is an inherently collective, and often collaborative act. The ongoing *Radical Imagination* exhibition reinforces common goals to create new and deeper meaning for participants, combining the power of art, activism, and community building, and applying them directly to the service of solving our most difficult urban social and environmental problems.

Works such as Swoon's homeless shelter artwork *Ersilia* highlights collective stewardship, seen in the mass volunteer efforts to feed, house, and care for fellow citizens and the environment. Likewise, exhibitions centered on ill-kept public spaces—such as the forgotten orchards in *Praça Da Simpatia*—have inspired nearby residents to see the beauty in their common ecological spaces, and to care for these spaces once again. Here, Ribeiro uses the engagements to shift perception, inspiring communities to a shared vision of transforming their public spaces together.

Although art can and does serve the purpose to suggest beauty or deeper meaning in things, the *Radical Imagination* exhibition sees art primarily as a vehicle for generating new knowledge and suggesting new ways of seeing that are rooted in local social and ecological circumstances. When art in this sense is paired together with meaningful community interactions, Ribeiro shows that something beautiful and practically functional is produced: *Art as a means for bringing forth NBS in a physical and cultural form*.

Ribeiro makes a key point in his work: to show that truly sustainable solutions cannot be achieved by government regulation, nor by financial reward alone. Sustainable solutions will only come when we, individuals across *all sectors of society*, begin to believe that our actions and the outcomes of those actions have inherent value in themselves. This is an observation seen around the world, including in social science research (Welchman, 2012).

PART 3: AOIDOS, THE STORYTELLERS: BUILDING THE EPIC OF THE MOVEMENT BY CARLA VITANTONIO

Seoul, Fall 2011. Demonstrators are sitting with discipline, carefully avoiding any damage to the public green, exactly as it has been ordered by the police through the media. Everyone has their banners and their candles. I believe I'm the only non-Korean in the whole demonstration, which feels extremely strange to me. Everyone stands still, every now and then chanting a slogan, or singing

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a short song (Figure 15.4). Used to the mayhem of Italian demonstrations—not necessarily violent but yes, always dynamic with music, theatrics, and movement—I am almost bored here. Therefore, I start thinking about the *aoidos*. Aoidos were sorts of storytellers who, in ancient Greece, repeated tales of the deeds of the ancestors for the use and benefit of the people.

Source: Photo by Suhee Kang.

Figure 15.4 *Environmental protesters in Seoul, South Korea, sing about the beauty of organic farms*

Every civilization has its aoidos, whose main task is to reveal some semblance of order in the chaos of human lives and happenings. In ancient times, those happenings usually implied wars, rapes, murders, plunders, and lootings. Aoidos transformed this huge mess into the beautiful stories of damsels and knights, often mixed with the wills and whims of superior influences of the gods. They repeated these stories wherever they could, so everyone had the possibility of knowing their own story, the story of their people, and their own place inside the cosmogony that the story represented. Aoidos reflected, with grace and cunning, the social order of their times. We used to call this *epic*.

While indulging in such lyrical thoughts, I am participating in what I think, at the time, will be the last demonstration of my life. I am living in Seoul, while awaiting a move to Pyongyang—where without any doubt I will not

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be joining any such demonstrations. In the past few months, I have illegally infiltrated a group of activists, on watch against a state project which will have devastating environmental impact. It's called *The Four Rivers Project*. I say illegally because according to the democratic South Korean law, foreigners living in Korea are not allowed to participate in any political event, on pain of deportation. Right. Used to disobedience as a form of political agency, I stand here in the middle of this watch—a little bit too static for my habits of demonstration—and think of the aoidos.

***

For years I have been the storyteller of the movement. Or at least one of the storytellers.

Every time, after a demonstration, an occupation, a disturbing action—I will never forget that time when under the snow we occupied the highway ring in the outskirts of Bologna—I returned home and, still fully soaked in adrenaline and dirt, I put that story online. Our story. Our epic. While official news spoke about *disorders*, about *groups of extremists*.

It has never been important to me to stay in the first row during actions, but to narrate them. This. Yes. Because we learned by our own skin, that history, as they say, it's the story of the winners, and that we are lucky in Italy, at the end of the dirty and messy story of the war and the Resistance, the anti-fascists won. It was only thanks to this one detail that today we have the story of those who defended us: the partisans, men and women. Yet it would have only taken so much as a wrong throw of the dice and all this would have been canceled; history would have told us a different story because our grandfathers and grandmothers, aoidos under cover, could not have told us the story of our daily Resistance, until liberation.

Following the tradition, even today, being 12,000 kilometers from home and having matured a strong distance from the movement, I decide I have the responsibility to tell a story that is not the official one. Tomorrow I'll write a tale on this demonstration: on the young South Korean environmental activists, on their dreams, desires, on their composed, polite strength. I will reaffirm the narrative that the movement has organized for itself: we, the good ones, the Davids of this unequal struggle, against the bad ones, the Goliaths, the rich ones, those who want to destroy, abuse, seize.

While modest, my role is not useless. Not at all. Often this role is focused on internal usage, on creating a coherent *internal* narrative for our actions, which very often does not reach external audiences. This is important because it allows us to recognize ourselves, to create a shared ground. It allows us to elaborate, using a common denominator, through experiences which are inevi-

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tably individual and unique, as each demonstration is. It allows us to meet and say: “Do you remember that time?”

But still, I miss the aspect that I have always considered essential when, as a young student at acting school, I dreamt of becoming a storyteller: the possibility of reaching, and ideally *influencing*, those who have a different opinion. Briefly, of igniting a spike in social change. I have been missing this so much lately that I convinced myself that the only solution was to leave my country in order to gain a different point of view on things and events.

The lack of access, through our *internal* narrative, to the outside world—the world of *normal people*, those who do not go to demonstrations—is one of the strongest limits that I have identified in my most recent years of activism. When I perform a show where I tell the story of our fights—say, for the right to public and free water—it is only those who already agree on the concept that come to the show. There is a transparent and seemingly insurmountable wall between one side and the *other*.

***

What will I do, then? Will I surrender? Surrender, no, I won’t. Tonight, I’ll return to my small room in Itaewon, Seoul, I’ll write my report on today’s demonstration, if I am lucky enough it will even be translated into English and some comrade from San Francisco will read it.

Within one year and a half, in one of the many serendipities of my life, I’ll find myself in the middle of the electoral struggles organized by the political opposition in Malaysia. I’ll ask questions, I’ll observe, I’ll write my report. Diligently. Later, after having lived for four years in North Korea, I will write a book and record a podcast, trying to tell a different story, seeking an alternative view on that complex country. No matter how far I grew from the movement, I never stopped feeling that the most useful thing I could do was tell otherwise untold stories.

Is it useful? I cannot say if it is, but in my own cosmogony, in the one that I’ve received from my parents and grandparents, in that whirlwind of affections and rhizome-shaped relations, ordered exclusively through the stories of the elders, I learned that there is always a need for someone to tell the story. And this is what I can do, this is what I *have* to do. Change the world, I do not know, but tell the story of those who try, yes, this, I believe, is still worthy.

Storytelling for Nature-Based Solutions

One of the key challenges of communicating across disciplinary divides is that, within disciplines, we tend to construct our messages as gatherings of facts and methods that make sense to our colleagues within our discipline, but make

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little sense to others. That is, they are ineffective stories. Building momentum for NBS requires that we communicate effectively well beyond the boundaries of disciplines. For this, we need to tell better stories.

Carla Vitantonio is determined to tell the stories of activists; they are examples of storytelling methods that would help us all to study. She knows her stories will not often be heard or celebrated by those outside of her group, yet she makes the record. She knows that those who hold sway over public opinion will often discount her story, yet she tells the story.

This unyielding determination to tell the story is required if we hope for new ideas about NBS—ideas acquired through awareness and radical imagination—to move beyond the realm of the academics and specialists and into the realm of communities and implementation.

Vitantonio takes on the role of the *aoidos*—in Greek a classical singer, or skilled oral epic poet—because she knows that for any movement to succeed there must be a record, a story. Certainly there is the importance of the *internal* narrative—intradisciplinary narrative. Yet Vitantonio's work also explores an additional layer: narratives that *connect* one movement to another and *bridge* one way of thinking with what might seem the unrelated, or even opposed.

One of the keys to successfully enacting NBS is *our ability to creatively tell stories that act as bridges, between people, between movements, between ourselves and the rest of nature*. Storytelling is an act that—through visual art, through dance, through music, theater, writing, and similar media—helps us co-evolve. We have the ability to tell stories that show how our cultures, our ways of thinking and acting and doing, can be woven together in ways that make us more resilient. We use this gift far too little. Vitantonio's story demonstrates how all kinds of storytellers are important for any movement to succeed.

We live in a time where it is imperative that NBS must be developed, where imaginative NBS solutions must be shared, and where the importance of NBS must be heard widely. Like Vitantonio, our work will not be easy. Yet it is just this kind of determination that we all need to embrace in order to succeed.

For those engaged with NBS, what we can learn from Vitantonio's stories is to follow our own nature, and to accept that there is a time and place for every story. The most important part, it seems, is to tell it in the first place, and to aspire to tell stories that can penetrate beyond the people who already believe.

Who and where are the aoidos of our generation? We need them now, more than ever.

CLOSING AND CONTEXT

> It is difficult to take in all the glory of the Dandelion, as it is to take in a mountain, or a thunderstorm. (Burchfield, 1945)

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Charles Burchfield (1893–1967) is legendary for his watercolor landscapes, painted near his Buffalo, New York home. His paintings are typically about nature: swamps and forests and backyards that include plants and birds and insects and rays of light. They are full of shapes and living things. His late-period works, especially, are intense and even hallucinatory. There was a remarkable exhibit of his work at the Whitney Museum in New York City in 2010 (https://whitney.org/exhibitions/charles-burchfield).

He was also a great journalist and over his lifetime wrote over 10,000 pages in various handmade volumes. It was there, May 5, 1963, that he wrote the passage quoted at the beginning of this section.

And so they are difficult to take in, both for their beauty and their complexity. How can you describe and assess them? Convey them to one who hasn't seen them? You finally stumble, awestruck, into saying that they are "beautiful," or "majestic," or just "amazing." But as scientists and decision makers we often have to describe and quantify such entities and then communicate the results in ways that aren't hopelessly obscure. That are somehow specific. That is, we need to communicate a very complicated thing in a simple, essential, and, above all, useful way.

It is a role of science to tease apart the details and understand how they function together to make a whole. But science is less adept at conveying the mystery and wonder—the 1 + 1 = 3—of nature and human–nature relationships. If we are going to reduce complex landscapes down to elements that facilitate description and conversation, and that reduction is fundamentally embedded with values, then the next question logically is: Whose values? What values? What elements will we value in our description?

Disconnects often reside when the language turns out to be imprecise or inconsistent across ways of knowing. The rewards don't exactly match. The information that is needed is at a different scale—time, space, detail—than the information that is on offer. The value systems don't quite align. Or sometimes what we're trying to communicate about is amazing, like a Dandelion. Irreducible. We try to reduce it to something we can measure, comprehend, and communicate. But we don't quite capture it. The discussion becomes a frustration of ill-matched assumptions and disconnects of language.

What is that famous saying? It is below, generally attributed to William Bruce Cameron in his 1963 *Informal Sociology: A Casual Introduction to Sociological Thinking*: "It would be nice if all of the data which sociologists require could be enumerated because then we could run them through IBM machines and draw charts as the economists do. However, *not everything that can be counted counts, and not everything that counts can be counted*" (p. 13). And yet, people who have to make real decisions about the design of cities and parks and plazas and buildings and forests crave—even require—clear bases for their decisions; they crave data and information that would suggest

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the right course of action. Elected officials, too, have to spend a lot of money to obtain data in support of projects that, in the end, often must proceed on a hunch, on intelligent intuition. Intelligent intuition is a powerful thing. It is that, plus values, which lead us to say: “That Dandelion is beautiful.” And so it is.

Words like improvisation and imagination and intuition can sound awkward in the context of science and policy (Maddox 2015, 2020). Yet these are the very abilities that we need in order to see past and beyond the details—this species is here, that process is there—to create and understand how a vast and majestic thing works and how it might change (Fuentes 2017). Without these abilities, our image of the world, and what is possible in it, stands incomplete.

Even “storytelling” can have awkward connotations when contrasted with the “truth” of science. The essence of storytelling, however, is to convey a meaningful idea in an engaging way. The dry and often jargon-filled narratives of science often make for less-than-compelling stories. Could we not do better by collaborating on our modes of voice and story? For example, Goldstein et al. (2015) offer a planning approach that uses personal narratives to promote social-ecological resilience in urban environments. Through storytelling, individuals are emboldened to subjectively share how environmental degradation has affected their urban systems and livelihoods and such storytelling may serve as the catalyst for initiating complex policy and community planning efforts to envision future alternatives. Scientists and artists could take similar productive approaches.

Perspective is another important word—a sense of what you value in the picture you are creating (Maddox 2018; Campbell 2020). The Dandelion seeds are close up in Burchfield’s picture. He values them. The sky is there, too. You need to *see* and *feel* the patterns and perspectives, and not only the details; the beating of the heart and not just the heart’s location in the chest.

How do you “take in” a complicated, multidimensional thing like a mountain? Or a park? Or a community garden? Or a city? With acts of art, science, and a bit of social imagination.

As summer changed to fall, Burchfield felt the same urge to imagine. “All day on the gateway to September putting in the huge insect tree in the August part. For the first time in weeks I let myself go in improvisation and fantasy” (Burchfield 1950).

Throughout this chapter, we have explored how art can make vital contributions to NBS at a fundamental level through acts of awareness, of radical imagination, and of storytelling. Yet the examples here, diverse as they are, offer only a small sample of possibilities. To further this in our respective fields, we need also to imagine how this work might be facilitated collaboratively with others—including the environment and other species—in more creative, imaginative, or improvisational ways.

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These approaches are rooted in questioning our relationships, and so on many levels, the answers are inherently personal. When we do find specific answers that work for our own disciplines, we will usually find radical, rooted changes in how we engage that work. This is when we know that we are indeed working as an artist does! Hopefully, the words and works here inspire us to know that the *art of NBS* is indeed a movement for all individuals in all fields, and a chance for our own practices, actions, musings, and movements to know, celebrate, and work together with the environments in which we dwell.

NOTES

1. Italian verse by Carla Vitantonio: "Too close/Rage sparks voices?/Living I burn."
2. Portuguese verse by Baixo Ribeiro: "The time and the wind/Poetry/On the streets in the city."
3. The exhibition was created in conjunction with SOMARTS Commons Curatorial Residency Program. Lasser is the principal curator and artist lead, with co-curators Danielle Siembieda and Barbara Boissevain.
4. *The Floating World: A Tent City Campground for Displaced Human and Bird Song* project was commissioned by the San José Public Art Program with the ZERO1 International Biennial. It was created by lead artists Robin Lasser and Marguerite Perret, along with partners Bruce Scherting, James Stone, Anthony Teixeira, Keay Edwards, and Sasha Vermel.
5. *Choque Cultural* is a hybrid project by Ribeiro that unites exhibition and educational space on art, the city, and education.

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16. Towards mainstreaming nature-based solutions for achieving biodiverse, resilient, and inclusive cities

Timon McPhearson, Nadja Kabisch, and Niki Frantzeskaki

Nature-based solutions (NBS) are systemic solutions for urban development, climate adaptation and mitigation, and human health and wellbeing. NBS have the potential to be dramatically expanded in urban development if coupled with biodiversity conservation, restoration, and protection programs as a key part of building more livable cities. How can we design, manage, and plan cities through a nature-based urbanism paradigm that systematically and holistically considers equity, resilience, and sustainability together? The chapters in *Nature-Based Solutions for Cities* written by over 60 authors provide a critical starting point for developing and implementing a livable urban planet vision that regards cities as the locus for global-scale solutions and that puts nature and people at the center of how we reimagine, retrofit, and build cities where most of humanity lives. Our vision for cities in the future is ambitious – a just, equitable, resilient, and sustainable landscape of virtuous relations among people, nature, and infrastructure – and not one where nature and its benefits in cities are sporadically located or only available to the wealthy. This vision requires rethinking, retrofitting, and redefining cities (and their connected regions) as social-ecological-technological systems that have at their infrastructural core a network of NBS. These networked NBS must be implemented and maintained, operate at city scale, connect, restore, and reinforce social-ecological flows and provide multiple ecosystem services and co-benefits for health and wellbeing. This must also be accomplished while establishing productive urban–land teleconnections that are deeply inclusive in ways that improve and foster equity and justice. We hope the chapters in this book provide pathways towards this positive, resilient, and equitable future for all.

Our book investigates NBS as opportunities and challenges from multiple perspectives, knowledges, and disciplines. Key findings from chapters reviewing the state of the art in NBS literature are set in the context of urban challenges, critical lenses for advancing the science of NBS in cities, and fron-

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tiers for next-generation NBS in cities. In this final chapter, we synthesize key insights, opportunities, and next steps for NBS for cities drawn from findings across the book chapters. Insights leverage the work of a diverse set of scholars from around the world spanning urban ecology and geography, planning, design, engineering, art, environmental economics, and health, among others, which themselves review diverse literature and practices of NBS around the world. Below we describe *seven key insights* for policy, planning, implementation, and research critical to advancing knowledge and practice on NBS to support cities in their efforts to achieve more equitable, resilient, and sustainable urban futures. When reading and reflecting on these critical insights consider them as takeaway messages and tenets for working collaboratively and cross-disciplinarily for nature-based urbanism.

INSIGHT 1: PUT NATURE-BASED SOLUTIONS FIRST IN ADAPTATION TO CLIMATE CHANGE IN CITIES

Most, if not all, of the world's cities are located in areas of relatively high climate hazards such as along coastlines and rivers, in water-stressed regions, or are especially vulnerable to extreme weather risks like floods, droughts, and heat waves due to modes of urban development which exacerbate climate and weather impacts in cities. *Grimm and colleagues* highlight that urbanization and climate change are on a collision course, making NBS key to providing solutions that are affordable and effective in delivering protection from extreme weather events. They discuss how NBS provide opportunities for addressing urban resilience to extreme weather events that can be compatible with existing infrastructure systems and provide flexibility in design and management of solutions. The authors note that NBS are more flexible in accepting changes to system design and management than traditional gray infrastructure and in responding to shifting risk profiles or environmental changes. Thus, NBS can be invested in as "safe-to-fail" infrastructure in design and management. However, they also highlight challenges. Although NBS are multifunctional and an important component of urban resilience, they cannot solve every problem. Trade-offs often exist with different types of NBS in terms of the ecosystem services and nuisances or disservices that they can produce.

Building from this argument *McPhillips and colleagues* discuss the wide range of NBS that can be employed for addressing issues of surface water management including for urban and coastal flooding and water quality across a spectrum of blue/green/turquoise/brown-to-gray infrastructure. They provide evidence of how blue NBS, aquatic features, can provide safe water storage and conveyance. Green NBS are terrestrial including soil and vegetation that can provide critical infiltration, evapotranspiration, and water quality improvement, and may provide temporary storage of water during storm events. Brown

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NBS including soil-based and minimally vegetated features such as fallow gardens or vacant lots are an important source also for infiltration, temporary storage of water, and water quality improvement. Turquoise NBS, such as wetlands, are a mix of green and blue and include soil, vegetation, and water elements that are important sources of coastal flood protection and provide stormwater infiltration, as well as storage, conveyance, and improve water quality. The many options for investing in NBS for water resilience shows also that hybrid strategies including some mix of ecological and technological elements can be particularly effective such as through bioswales, eco or green roofs, and retention ponds or basins.

Coseo and Hamstead focus on the role of NBS for alleviating unequal impacts of heat and air pollution in cities. They note that these twin atmospheric threats kill more people than all other weather hazards. Effectively reducing vulnerability to heat and air pollution requires simultaneously examining the exposure of places but also the social dimensions of vulnerability determined by place-based lived experiences. The authors review a vast literature demonstrating the effectiveness of NBS for providing cooling through shading and evapotranspiration by vegetation, as well as the importance of reflectivity of built and ecological infrastructure for heat reduction. They also discuss the role of urban vegetation in absorbing harmful air pollution. However, the authors make clear that rising heat and air pollution in cities disproportionately impact communities of color and those unable to afford technologically controlled indoor environments. Thus, solutions to challenges of heat and air pollution cannot be isolated from their environmental justice dimensions.

INSIGHT 2: MAKE EQUITY AND JUSTICE CENTRAL IN THE DESIGN, PLANNING, MANAGEMENT, AND GOVERNANCE OF NATURE-BASED SOLUTIONS IN CITIES

From ideation and design, to planning, implementation, management, and maintenance of NBS, all phases must put equity and justice at the center of, and as necessary conditions for, efficacy. This goal can be safeguarded through careful consideration and design of how participation is organized, who is represented, and how representation overall is facilitated, as well as ensuring accessibility and openness in processes and attention to distributional aspects of co-benefits or disservices of NBS.

Considering distributional aspects of justice, *Guerry and colleagues* analyzed the distribution of ecosystem services by NBS or urban green spaces by different groups of beneficiaries in Minneapolis. They found that neighborhoods with high poverty rates are hotter than average and benefited less from the cooling function of NBS. Their chapter puts forward a strong message:

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actions to deal with inequality and injustice in cities should not only be informed by mapping benefits or the lack thereof of NBS. Policy programs for urban injustice must always consider deeply entrenched, embedded socio-economic and socio-cultural injustices and how they relate to (or even juxtapose) the distribution of benefits from urban NBS.

Tozer and colleagues point to the importance of investigating and considering how people with different cultural backgrounds (especially in cities with a large proportion of migrant populations) perceive "environmental quality" and the benefits and disservices of NBS. Bringing a critical perspective on how NBS planning needs to take socio-cultural context conditions seriously, they explicate this perspective with case studies from the Global South. In their chapter, they propose ways forward to employ a restorative justice perspective, according to which any NBS intervention or design needs to ensure equal distribution of benefits, or "positive rights to benefits." Transformative co-production is proposed as a way forward that brings together actors from different demographic backgrounds and can improve procedural and representational aspects of justice.

Similarly, *Coseo and Hamstead* argue that often, those threatened most by heat and air pollution are also those who are the least likely to benefit from NBS implementations installed to mitigate such health threats. The authors highlight that such environmental burdens for poorer, low-income communities may be further exacerbated through social-ecological-technological segregation practices together with the ongoing privatization of adaptive capacities. Identifying distributional inequalities and visualizing them through easy-to-understand local urban maps may encourage urban planning and city officials to push NBS investments to such vulnerable neighborhoods to improve equity and environmental justice. Such actions, however, need to be regarded in the context of potential deeper, structural inequities that need to be simultaneously addressed. Otherwise, as reinforced by *Guerry and colleagues*, local upgrading activities with NBS may impact the private housing sector and create risks of gentrification and displacement for the very communities intended to benefit from NBS.

With regards to procedural and recognitional justice aspects, *Frantzeskaki and colleagues* point to the importance of understanding and addressing different aspects of inclusivity in planning and managing NBS in cities. Specifically, they point to the importance of including five dimensions to inclusivity as starting points: (1) cross-sectoral inclusivity to incorporate representation across sectors such as science, policy, and polity, including market/business actors; (2) multi-species inclusivity to include the voice of species and their representation in NBS planning; (3) intergenerational inclusivity to ensure there is no age divide or discrimination in their design, planning, and use; (4) epistemological inclusivity taking into consideration a pluriform basis

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of knowledge that includes local and Indigenous knowledge; and (5) spatial inclusivity that looks at the geography and geospatial aspects of accessibility, inclusivity, and equity in benefiting and connecting with NBS in cities.

Achieving equity through NBS will not be easy and requires a critical evaluation of the process of urban design, architecture, and planning. *McGrath et al.* argue that equitable and sustainable urban design is only achieved through the "material resolution of the dynamics between socially produced spaces and natural processes." They call for urban design to explicitly take up the right to the city and the right to nature as foundational principles for critically incorporating NBS into urban design. The adoption of cooperative and inclusive processes bringing local and Indigenous knowledge into the center of NBS approaches is key to recognizing that inclusive and more just processes must be nested in consensual management and governance practices.

INSIGHT 3: ENSURE BIODIVERSITY IS A PRIORITY IN URBAN PLANNING FOR NATURE-BASED SOLUTIONS

Considering biodiversity for conservation purposes and species selection should be key in any NBS implementation and maintenance action. *Knapp and MacIvor* argue that there is, however, no one-size-fits-all solution of NBS to support biodiversity. Context in terms of climate, biogeographic region, and local knowledge as well as socio-economic conditions impact not only the benefits provided by NBS, but also how NBS should be constructed in terms of biodiversity. Biodiversity aspects such as species richness or traits which are well studied and manageable should be part of a selection process by practitioners. Often, local knowledge already provides important expertise to support species selection and maintenance decisions for resilient and sustainable long-term NBS.

Further, ecosystems must themselves be resilient to a wide variety of urban stressors if we are going to rely on them to provide the ecological functioning that underpins NBS for urban resilience and sustainability. As *McPhearson and colleagues* argue, this requires a deeper ecological understanding of the traits of species that can respond to human or environmental impacts to better plan and manage urban ecological communities in ways that ensure species can thrive and deliver the NBS benefits human societies need. The authors provide an urban ecological resilience conceptual framework for urban social-ecological-technological systems that relies on species diversity, abundance, and trait data to (1) support emerging urban ecology research, (2) provide a methodological approach for assessment, and (3) guide planning and management for urban ecological resilience. They discuss the need for urban ecological resilience assessment, why measuring and developing indicators for species traits are important, and demonstrate through a case study

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of urban street trees in New York City how the conceptual framework can be operationalized using available local species and trait data. *McPhearson et al.* argue that bringing biodiversity conservation, management, and planning into NBS investments is critical to ensure that species, populations, and ecological communities are designed and managed to support ecological resilience as a critical pillar to social and infrastructural resilience. In this way, we can begin to move towards generalized social-ecological-technological system resilience that ensures resilience in all three domains is considered together, as *Grimm et al.* describe.

Further, when planning NBS, their full life cycle and the related resources needed for maintenance should be kept in mind. Maintenance in terms of watering or energy use may act as trade-offs. For example, young trees may not provide the ecosystem services in the same quality and quantity as older trees do. The issue of a full life cycle and context consideration also relates to the important question of whether any urban green space can be regarded as a NBS. *Hansen et al.* conclude that this question is linked to the overall local climatic and environmental context conditions. They consider the International Union for Conservation of Nature's definition of NBS, which argues that every NBS should provide a number of different ecosystem services but simultaneously contribute to biodiversity and suggest that under this definition not every urban green space may qualify as a NBS. Still, these urban green spaces such as public parks in some spatial context may provide other values such as being a spatial resource to be further developed through thoughtful and sustainable urban planning and thus sites of future NBS. Overall, when NBS are planned and implemented to provide ecosystem services and biodiversity benefits, they need to be planned with the necessary financing for maintenance for the long term which also requires commitment and investment in knowledge, skills, and resources.

Urban planning can be further innovated and transformed by integrating holistic urban design of NBS. *McGrath et al.* position urban design as a "socio-natural resolution" at the landscape level that considers social dynamics as well as ecological ones. Stemming from their work, they argue that urban design needs to be one piece of the puzzle when designing NBS to fit the context conditions of a place as well as a negotiation platform for understanding the changing dynamics over time in relation to space and specifically, space implications. As the authors point out in their case study, the multiple iterations, discussions, and redesigns together with students, experts, and villagers show how adaptive design processes can encounter social ties, connections to places from local communities, as well as the need to preserve, protect, and restore ecological features of the landscape. Bringing forward lessons for urban designers, *McGrath et al.* offer a way to understand not only the contribution of urban designers in interdisciplinary teams for designing

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and assessing the fitness and suitability of NBS, but also what disciplinary strengths and departure points urban designers have for interdisciplinary teams to recognize and consider when weaving knowledges for planning NBS in urban and peri-urban environments.

INSIGHT 4: EMPLOY AND DESIGN NATURE-BASED SOLUTIONS TO IMPROVE HUMAN HEALTH IN CITIES

With more than 5 percent of the global adult population estimated to suffer from depression, poor mental health can be regarded as a global pandemic. Given these high numbers, mental health illnesses should be regarded as a societal challenge to which NBS can act as a therapeutic solution. As *Kabisch and colleagues* show, NBS are an important contribution to keeping urban residents mentally healthy, and to help them adapt to and mitigate a potentially stressful life in the urban landscape. Given these important NBS to mental health, wide urban planning and decision-making efforts are needed to bring nature into the city, and to increase nature quantitatively but qualitatively by considering the needs of a diversity of user groups. As *Besser and Lovasi* show, planning for sustainable, healthy cities may also integrate a careful Health Impact Assessment that can help assess the potential (mental) health and environmental impacts of a NBS implementation. In qualitative terms, NBS may be designed that are group specific and use lessons learned from nature-based interventions already used to treat people with psychiatric illnesses. Results from studies on mentally supportive environments, e.g., in terms of planning for a specific size of green space with secluded areas and escape routes, can help to improve city planning in designing mentally supportive, healthy, and sustainable cities.

Research on the mental health benefits of NBS has shown the positive effect of nature exposure on human wellbeing. As *Kabisch et al*. explore, mental health benefits work through different pathways which are also related to the local cultural context of beneficiaries. In Western societies for example, relaxing in urban nature or being physically active in nature may be the main benefit and ecosystem service while in other contexts, a NBS may rather act through its religious and cultural value, as the example of Hyderabad in India has shown with the religious value of trees. Future research and future planning for a NBS implementation should always consider the local context with local knowledge and the local meaning of nature also including the associated cultural and religious values.

Studies on the potential positive health effects of nature exposure are increasing. In their chapter, *Besser and Lovasi* provide an overview of recent literature studies and meta-analyses about the overall nature–health pathway.

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They conclude that evidence of the NBS–health effect is often not conclusive and does not always confirm potential expectations. The authors showed that moderate evidence was found for decreases in all-cause mortality and even less for maintained or improved cognitive functioning, decreased risk for birth outcomes, or poor pregnancy or cardiovascular disease. Many others addressing health outcomes, such as cancer, showed no or inconclusive relations with nature exposure. To improve the evidence base, more rigorously conducted, high-quality studies, including observational studies, natural experiments, and NBS implementation evaluation studies, are needed to strengthen the argument for a positive NBS–health association.

INSIGHT 5: REALIZE NATURE-BASED SOLUTIONS IN CITIES WITH INCLUSIVE URBAN PLANNING AND INNOVATIVE GOVERNANCE APPROACHES THAT RESPOND TO LOCAL CONTEXT DYNAMICS

To realize NBS in cities, urban policy, planning, and governance need to understand, incorporate, and respond to local context dynamics. Many chapters point to the importance of local context, to map and assess it as well as to critically unpack local dynamics to respond to the quest for justice and inclusivity for planning with NBS. Specifically, the context specificity in urban planning was also noted by *Hansen and colleagues*. In their overview chapter on the planning and maintenance of NBS, they conclude that any strategy for mainstreaming NBS and their maintenance are context specific. Very local conditions with the different planning schemes, climatic conditions, etc. always require carefully adapted measures in terms of NBS implementation and maintenance. Particularly in the context of a changing climate, NBS implementations should be planned with foresight. The authors suggest that NBS should be selected and developed to be adapted to current but also future climate conditions, having in mind also the local biodiversity.

Bringing arts and humanities to speak to and to collaboratively design and plan NBS is another suggestion for innovating the governance of and with NBS. As *Lydon and colleagues* present in their chapter, an active engagement with artists will allow for new perspectives, voices, and understandings of how the planning and governance of and with NBS can be more inclusive to marginalized citizens as well as animals. Innovative governance approaches to ensure more inclusive planning of NBS in cities can start with some radical (re)imagination of cities and continue with a deeper understanding of the context and how it can guide planning and governance, as *Hansen et al.* posit. Still, these approaches must remain open to adapt and transform.

Frantzeskaki et al. unpack and conceptually propose a way to understand inclusive governance of and with NBS in cities and point to the need for careful

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consideration for inclusive governance with NBS, especially in the context of the combined crises of climate change and biodiversity loss. Co-designing NBS with stakeholders from different demographic groups and age groups and finding innovative ways to include children and youth in urban planning and governance are well-understood ways to open up cross-generational dialogues about the future in the city, especially with NBS. *Tozer and colleagues* point to transformative co-production of NBS to progress procedural and representative justice in urban planning and governance. They further highlight epistemological justice considerations – something *Tozer et al.* and *Frantzeskaki et al.* have as a common point when unpacking urban justice. Here, inclusivity in relation to NBS planning and governance suggests it is critical to know and reflect about whose knowledge system is represented and included when designing and planning NBS in urban environments.

What still needs improvement, however, is the science and practice of NBS to advance intergenerational justice through a richer evidence base of methods and approaches that come together with systematically documented results about the new perspectives and innovations resulting from such approaches. In their chapter, *Frantzeskaki et al.* point to the need to advance and extend interdisciplinarity and transdisciplinarity as a base for future research of NBS to transform towards inclusive urban planning and of governance with them.

INSIGHT 6: ASSESS THE HOLISTIC VALUE OF URBAN NATURE TO MAKE A CASE FOR NATURE-BASED SOLUTIONS IN CITIES

Assessing the holistic value of urban nature can support the research and practice of NBS in two ways. First, assessing the value of urban nature will support building a case (or a business case where needed) for investing in urban nature and restoring it or enhancing it with NBS. *Guerry et al.* present approaches and tools for mapping the multiple benefits of NBS and extend it to how these benefits flow to different types of actors and beneficiaries. Their analysis demonstrates the opportunity costs of investing in nature in cities and extends the evidence base on the value of NBS across multiple ecosystem services. Their analysis suggests the need to expand our effective definition of value to include not only the services rendered, but the relative needs of the recipients as well. This supply and demand approach responds also to what other chapters in the book highlight, namely the important politics of NBS in cities and considerations of NBS. As we advance the science and practice of NBS, a holistic assessment of their value that is contextually informed or nuanced is the way forward. We must ask: Nature for whom? Who benefits? Who and how is the value of urban nature recognized and appreciated?

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Evaluation is important, too. Assessing the holistic value of urban nature before and after the introduction of NBS can reveal the short-, medium- and long-term impact of such interventions in cities. Mapping, measuring, and valuing the benefits provided by NBS through monetary or non-monetary approaches can inform land use change decisions in cities. Looking at different scales, such as a neighborhood or a total city, such valuation approaches may also be used in alternative scenario creations, which can help assess the potential delivery of ecosystem services once a NBS is introduced via a land use change. With this kind of valuation approach potential inequalities in the provision of services may be identified which in turn helps city officials to prioritize specific areas for NBS introduction.

INSIGHT 7: BRING ART INTO NATURE-BASED SOLUTIONS AND POSITION ART AS A NATURE-BASED SOLUTION IN CITIES

Nature in urban areas can be a source of inspiration and creativity for and with artists. Artists can express through creative processes the emotions and relations or loss of relations with urban nature but also showcase new relations with it. Artists, such as in the chapter by *Lydon et al.*, have presented a rethinking of art as an ecologically connected way of doing and knowing, and so itself this is a nature-based process. Although art may not always carry explicitly ecological messages, it is always a collaboration between human beings and the environment. As *Lydon et al.* point out, we need to open the conceptualization of who an artist is and consider a broader understanding of the creatives in our cities. And yet, as *Kennedy et al.* highlight, ecological art that is explicitly creating art to address environmental issues or situated in urban green spaces can also play a crucial role in advocating for and implementing NBS. Innovating the practice of NBS with collaboration and/or interdisciplinary bridging with arts means bringing artists more centrally into NBS design, planning, and implementation. Yet, there is much work still needed to effectively integrate and support artists' visions in urban planning and governance for and of NBS, and more broadly for nature-based urbanism.

Artists are rarely meaningfully included in urban planning processes or decision-making. *Lydon et al.* propose the need for the inclusion of marginalized, unheard of, or unrepresented views of citizens through art – making art the platform and the medium for inclusivity in designing and planning NBS. In the same vein, *Lydon et al.* call for recognizing that flexible and inclusive decision-making processes are fundamental factors to leverage the enormous potential of the arts and humanities in achieving visions of inclusive, ecologically centered urban landscapes that reconnect humans to the biosphere.

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Kennedy et al. also describe how artists in urban areas have been the expressors and even conduits to the tensions, contestations, as well as signals of positive change with and of urban nature, presenting through ecological art. With the quest for a better way to integrate arts with urban planning and urban science as a global phenomenon, understanding the role of artists in raising awareness, in voicing concern and loss (also grief) for degenerated urban nature, as well as "remediating" damaged landscapes is a vital first step to steer away from a co-optation mode of interaction and engagement, to a co-creation mode of collaboration between scientists, planners, and artists.

CONCLUSIONS: HOW DO WE MAKE NATURE-BASED SOLUTIONS WORK FOR PEOPLE AND THE PLANET?

As we look beyond the present to the remainder of this urban century, it is abundantly clear that our cities need to become the places where we actively build a society that is inclusive, equitable, and resilient, and that harnesses the collective political, economic, social, technological, and nature-based tools to solve our twin crisis of climate change and biodiversity loss. Investing in urban development, design, and governance that brings nature into the center can be the source for reconnecting humanity to the biosphere and be part of delivering the cities we want.

In this book we started with two realizations: first, that NBS are multi-disciplinary projects, requiring interdisciplinary research and transdisciplinary collaborations, and second, that NBS are really a suite of solutions varying from wild landscapes to highly managed and constructed urban green and blue infrastructures. For NBS to be effective they require the weaving and coordination of expertise across ecology, urban design and architecture, urban policy and planning, environmental engineering, governance, and art at multiple scales. We have intended to accomplish this weaving through the five parts of the book including Part I: Nature-based solutions for what and for whom?, Part II: The nature of nature-based solutions, Part III: The multiple benefits of nature-based solutions, Part IV: Nature-based solutions governance, planning, and value, and Part V: Engaging art and design for and with nature-based solutions.

In this concluding chapter we summarize seven key insights for working with NBS whether as a practitioner, researcher, or engaged citizen: (1) put NBS first in adaptation to climate change in cities; (2) make equity and justice central in the design, planning, management, and governance of NBS in cities; (3) ensure biodiversity is a priority in urban planning for NBS; (4) employ and design NBS to improve human health in cities; (5) realize NBS in cities with inclusive urban planning and innovative governance approaches that respond to local context dynamics; (6) assess the holistic value of urban nature to make

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a case for NBS in cities; and (7) bring art into NBS and position art as a NBS in cities. These insights are drawn from the rich content of the chapters to provide an outlook on how to improve the efficacy and inclusivity of NBS in all stages, from ideation to implementation and beyond.

As researchers working in the interface of science-policy-community we've recognized an increasing and imminent need to design, plan, and implement NBS with the integrated knowledge of different disciplines and a diversity of types of knowledge. We hope this book, *Nature-Based Solutions for Cities*, and the insights we provide here offer a set of diverse pathways forward for realizing the future cities that we want, that put people and nature at the center of our collective work.

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In this urban century, the period of the fastest urban growth in human history, humans still need nature to survive and thrive. In this crucial book, some of the best urban scientists in the world give us a guide for how nature can be a solution to the pressing needs of our time, including climate resilience and equity. For anyone planning, implementing, or monitoring nature-based solutions in cities, this is an essential book.
Robert McDonald, Lead Scientist for Nature-based Solutions at The Nature Conservancy

A lot has been written about nature-based solutions for cities, but this book by some of the leading experts in this field is a must read. It provides a systematic and highly accessible overview of what nature-based solutions are and (can) do for cities, while also offering great examples of making these solutions work, from governance approaches to mobilizing art.
Cecil Konijnendijk, University of British Columbia, Canada

This comprehensive book describes in accessible fashion nature-based solutions for cities. It brings together the latest knowledge and experiences and is essential reading for researchers, policy makers, and practitioners.
Mark J. Nieuwenhuijsen, ISGlobal – Barcelona Institute for Global Health, Spain

This book captures a wonderful diversity of knowledge on the multitude of solutions that nature presents to the growing challenges of our urban world. It offers inspiring ideas and practical insights for making the transition to more livable, peaceful, and resilient cities for all living creatures, in every part of the world. The book presents great examples of nature-friendly and inclusive design and cost-effective nature-based solutions that improve quality of life, climate resilience, and equitable and regenerative business opportunities.
Chantal van Ham, Arcadis, Belgium

For too long, cities were thought of as the opposite of nature. Now scientists and planners understand that nature is in fact present in cities. This excellent new book shows how cities can enhance the work of nature within their boundaries to improve people's lives and the biodiversity of our urban world.
Steward T.A. Pickett, Cary Institute of Ecosystem Studies, USA

Cities are facing unprecedented challenges with an urgent need to adapt to a rapidly changing climate and to address accelerating levels of social and economic inequality. This thought-provoking and stimulating book gives us exciting pathways forward for regions and residents to transform toward cities that are livable, just, and equitable, but in an inclusive way and inspired by nature. It's an inspiration for us all.
Thomas Elmqvist, Stockholm University, Sweden

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Cities around the world are employing ecological, nature-based designs to provide a variety of urban services for urban residents. How can we ensure that they are effective, equitable, and will last? This book is essential reading for graduate students and practitioners alike on the state of the art in how to harness the power of nature for transformational change.
Gretchen Daily, Stanford University, USA

As the international community is urgently called to put the lofty goals of the United Nations Kunming-Montreal Global Biodiversity Framework into practice in an increasingly urban planet, this book offers valuable insights based on tested approaches to make urban sustainable consumption and production a transformative force for human well-being and ecosystem health in challenging times. Recognized by the United Nations Environmental Assembly, nature-based solutions has become an essential tool for resilience to climate change, and for mainstreaming nature and human rights into urban planning, development, and governance.
Oliver Hillel, urban development specialist and officer in the United Nations Secretariat of the Convention on Biological Diversity, 1996–2023

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