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.

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

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

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-

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

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

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.

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

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

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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