Nature-Based Solutions for Urban Climate Change Adaptation: Linking Science, Policy, and Practice Communities for Evidence-Based Decision-Making

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Nature-based solutions offer an exciting prospect for resilience building and advancing urban planning to address complex urban challenges simultaneously. In this article, we formulated through a coproduction process in workshops held during the first IPCC Cities and Climate Science Conference in Edmonton, Canada, in March 2018, a series of synthesis statements on the role, potential, and research gaps of nature-based solutions for climate adaptation and mitigation. We address interlocking questions about the evidence and knowledge needed for integrating nature-based solutions into urban agendas. We elaborate on the ways to advance the planning and knowledge agenda for nature-based solutions by focusing on knowledge coproduction, indicators and big data, and novel financing models. With this article, we intend to open a wider discussion on how cities can effectively mainstream nature-based solutions to mitigate and adapt to the negative effects of climate change and the future role of urban science in coproducing nature-based solutions.

Keywords: nature-based solutions, cities, climate change, resilience, urban

Cities are at the frontline of global responses to climate change. As key sources of greenhouse gas emissions and with large populations vulnerable to the impacts and risks of a changing climate, cities are increasingly required to act to mitigate and adapt to climate change. Cities capitalize on the fact that urban decision-makers have both the opportunity and the capacity to implement local and global climate solutions to climate change impacts and risks. Cities are fertile grounds for smart design, innovation and experimentation (Bulkeley et al. 2016, Frantzeskaki et al. 2017a) where collaborative and codesigned solutions are being developed to wicked problems such as flooding, heat stress, drought (McPhearson et al. 2016). Recently, nature-based solutions have shown potential for mitigating climate driven extreme events and contributing to adaptation and resilience in the context of human settlements (McPhearson et al. 2015, Kabisch et al. 2017a). Nature-based solutions, such as constructed wetlands, contribute to water purification and flood attenuation (Masi et al. 2017, Zolch et al. 2017), or others such as urban forests and street trees (Davies et al. 2017, Richards and Edwards 2017, Willis et al. 2017, Cortinovis and Geneletti 2018) and mangrove forests (World Bank 2017), provide systemic solutions that can deliver refuge from heat (Connop et al. 2016), ameliorate the worst impacts of coastal and surface flooding (Haase 2015), foster human health and well-being (van den Berg et al. 2010, Panno et al. 2017, Kabisch et al. 2017b), and connect people with nature (Hartig et al. 2014, Chawla 2015, Frantzeskaki et al. 2017b, Gulsrud et al. 2018). Nature-based solutions beneficially exploit natural processes providing stand-alone solutions or hybrid approaches (Cherrier et al. 2016, Depietri and McPhearson 2017) integrated with technology-based or engineered solutions to foster urban resilience and sustainability (Halbac-Cotoara-Zamfir et al. 2017, Keesstra et al. 2018, Ürge-Vorsatz et al. 2018).

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Nature-based solutions offer exciting prospects and are being taken up around the world in urban planning to deliver multiple benefits and to reduce climate risks—for example, to mitigate urban heat islands (Harlan et al. 2006, Gill et al. 2007, Gabriel and Endlicher 2011, Depietri et al. 2013) while enhancing well-being (Martens et al. 2011, Gulsrud et al. 2018). However, while interest in nature-based solutions is on the rise, there are key challenges ahead in mainstreaming them in cities. These include building a balanced evidence base capable of assessing their efficacy, in particular within the context of trade-offs and complementarities with more technological-based alternatives (e.g., nature-based solutions replacing or complimenting air conditioning for heat risk reduction), their long-term impacts and ways to design and manage them (Connop et al. 2016, Kabisch et al. 2016, Nesshöver et al. 2017, Panno et al. 2017) to avoid potential unintended consequences—for example, gentrification, methane production, or providing habitat for disease vectors (Wolch et al. 2014, Haase et al. 2017). At the same time, there is a need to identify best practices and the processes through which these can be embedded and scaled up while balancing disservices (Cohen-Shacham et al. 2016).

We formulated, through a coproduction process, a series of synthesis statements from a global set of nature-based solutions experts on the role of nature-based solutions for climate change adaptation and mitigation through dialogue and workshops held during the Intergovernmental Panel on Climate Change's (IPCC) Cities and Climate Science Conference in Edmonton, Canada, in March 2018. With this article, we intend to open a wider discussion on how cities can effectively scale nature-based solutions to both mitigate and adapt to the negative effects of global climate change ranging from coastal and inland flooding, to drought, heat waves, and storms. The article will address several interlocking questions including this one: What evidence and in what format is knowledge needed to better integrate nature-based solutions in urban climate change adaptation and mitigation agendas? What challenges need to be addressed for advancing knowledge and evidence to more fully realize the potential of nature-based solutions in cities and urban regions around the world?

Evidence for nature-based solutions: Three suggested ways forward

We suggest three critical areas for the development of the evidence base for key implementation challenges as they relate to the efficacy, robustness, and performance of nature-based solutions in delivering multiple benefits to cope with climate adaptation in cities. Therefore, we aim to contribute to the future advancement of knowledge on novel ways to codesign, coproduce, coevaluate, and cofinance nature-based solutions in cities. First, we recognize the importance of collaborative research and point at learning the lessons from examples of coproduced knowledge, where researchers and practitioners are involved in the iterative, collaborative generation of data, evaluation and actionable knowledge Second, the types of indicators and indicator schemes and frameworks to be put in place requires not only a holistic and integrative approach but also a way of systematizing how multiple types of data and knowledge collected can be smartly used by planning for climate change adaptation and mitigation. Indeed, it is highly desirable to harness the capacities of big data to help generate the volume and scale of knowledge required to mainstream nature-based solutions and to illustrate and even measure the efficacy of nature-based solutions (Ilieva and McPhearson 2018, Creutzig et al. 2019), where they are working, to what extent, and where they fail, to what consequences. Third, we examine how investment models and novel financing for implementation of nature-based solutions can help to make nature-based solutions more widely available and implemented, considering the demands on public finances and taxpayer expectations.

Collaborative research and knowledge coproduction. The recent push to incorporate nature-based solutions into city making has resulted in a plethora of research and demonstration projects in cities globally (World Bank 2008, Frantzeskaki et al. 2016, Collier et al. 2017, DG Environment 2017). The responses are proving to be a useful catalyst of research–practice partnerships as knowledge and expertise is rapidly evolving. There is demand for innovation and experimentation that off-the-shelf or best-practices approaches cannot satisfy. A valuable outcome of these partnerships and collaborative approaches is the applicability and legitimacy of research because of the cocreation of research questions and knowledge outputs that are tailored to be applicable and acceptable. The 2018 IPCC Cities and Climate Science Conference, the first of its kind, identified the need to develop greater insights into the process of coproduction and the factors that deliver successful coproduction outcomes. In this way, beneficiaries of nature-based solutions will be elucidated but, in addition, there is the aspiration for the codesign, coproduction and contribution to postimplementation sustainability driven by a continuous coproduction process with stakeholders at multiple scales and across sectors (Biggs et al. 2017).

Although much research procured by cities is conducted by consultants, academic research in such interfaces can be valuable where new knowledge needs to be generated (over synthesis of existing knowledge) or where it provides a systematization of information (Fink 2016, Fernandes and Guiomar 2018). Academic research can also be beneficial when it provides a critical perspective to complex, ill-defined urban–climate challenges, and can make the invisible visible (e.g., political processes that can confound) or can lead to perverse solutions (Steiner 2014). In collaborative research, partnerships interface with policymaking, design or management, and community, and researchers often fulfill multiple roles including a brokerage role between community and policy that needs to be reflected

on for safeguarding objectivity and legitimacy of the value of research (Frantzeskaki and Kabisch 2016, Loorbach et al. 2017). Stemming from this, there are many challenges of these partnerships. A targeted and concerted effort is called for in order to identify how these partnerships play a role in the governance of different types of nature-based solutions at different scales, to understand the interactions between the processes of designing, implementing and maintaining nature-based solutions and the outcomes they generate. Research has also to chart trade-offs between nature-based solutions and social sustainability interventions (Maes and Jacobs 2015, Faivre et al. 2017, van der Jagt et al. 2017).

First, nature-based solutions have to be designed and implemented in a context of rapid urban development and challenges such as informality, a high demand for services and a good quality of urban life, and the scarcity of human capacity, skills, and financial resources to address these challenges. The complexity and uncertainty inherent in this situation, require knowledge from scientists, from practitioners and from the communities of influence within the cities, to be codesigned and therefore relevant to fit city needs and context (Cowling et al. 2008, Nel et al. 2015). Knowledge required for nature-based solutions is dependent on the time, effort, and skills of those generating and weaving together diverse knowledge (Tengo et al. 2017). This demands the ability to interpret knowledge across different disciplines and a shout-out to the often ignored social sciences. In generating knowledge for nature-based solutions, a key challenge is that research timelines are often longer than planning, design, and implementation. However, models for true codesign of nature-based solutions need to incorporate solid evaluation and evidence-generating mechanisms that can then inform targeted and cost-effective interventions. If they are codeveloped carefully, plans for nature-based solutions can and should incorporate real-world experimentation that can clarify causality and allow for comparison among different types of nature-based solutions. Sharing of data and lessons learned from interventions can further help the development of designs that target incremental evidence generation of impact.

Second, it is important to bridge different knowledge between academics and planners (Thompson et al. 2017). This role is often assigned to those policy entrepreneurs or other intermediaries that are skilled to translate academic knowledge to planning-ready knowledge. However, in coproduced knowledge, planning-relevant outputs may be produced before academic ones (Frantzeskaki and Kabisch 2016).

Third, it is important for leading or facilitating actors of the coproduction process to be in a partnership to ensure a common language and common understanding of the objectives and solutions being addressed between scientists and planners (McPhearson et al. 2017). Nature-based solutions are inherently devised and enacted using transdisciplinarity, with social, political, ecological, and technical dimensions, whereas both research and municipal enactment are heavily siloed. An important issue raised by the IPCC Cities and Climate Science Platform was the need to articulate nonmaterial benefits of nature-based solutions in a persuasive manner (e.g., through revenue generation, costs savings, or other ways of portraying the importance of defined values and meanings) such that these nonmaterial benefits may be counted and traded off in the same frame as other types of benefits (van Wyk et al. 2014, Díaz et al. 2018).

Fourth, cocreated outcomes such as the design of a nature-based solution or a new approach to planning and knowledge generation are the "new commons." This implies that it belongs to all engaged parties including researchers, practitioners and the community. When considered this way, it cannot be owned by a single actor. This poses challenges for both scientists and planners or policymakers (or perhaps more accurately, the universities and local governments they work for) who are focused on creating segregated intellectual property and land uses. Similarly, the reward systems for researchers can be poorly aligned with the kinds of outputs and outcomes that are useful for practice. Researchers are rewarded for producing academic publications, whereas reports guiding city practice may be about the impact agendas for nature-based solution projects and may offer a fantastic opportunity for researchers to adapt to this new world. At the time of publication, there are 12 nature-based solution research and innovation projects under way in the European Union alone (Bourguignon 2017). An example on a nature-based solutions cocreation research is given in figure 1. Nature-based solution researchers could, in fact, be leading the creation and implementation of impact agendas—for example, Australia's National Science and Innovation Agenda. Although scientific development of theories and evidence is of utmost importance for nature-based solutions, we should also strive for academic output that is understandable by larger audiences.

Finally, nature-based solutions can provide a democratic entry point to addressing many urban challenges (Andersson et al. 2015). For instance, they may initially seek to address a climate change related problem, such as the urban heat island, episodic rainfall and flooding, noise and dust, and so on. In the process to codeveloping nature-based solutions, communities of interest, and communities of influence open dialogues into wider areas where the main climate-related issue, behavioral inflexibility, can be addressed in a more normalized manner. Scientists can provide knowledge and expertise for complex urban problems and solutions. An ongoing challenge remains: The city-relevant scale of analysis and data aggregation may not be the same scale of available data nor analyzed data from academic work (Acuto et al. 2018; figure 2).

Indicators and the role of big data. Indicators in urban systems have a long tradition. Their modern track record is often counted from Sustainable Seattle's pioneering initiative in the late 1980s, leading to a flourishing and growing practice of community indicator systems (CIS). Country

Figure 1. Green roofs are being taken up as nature-based solutions in cities around the world to provide local cooling to mitigate current urban heat islands and projected increases in urban heat driven by climate change (McPhearson et al. 2018). These hybrid green infrastructure systems are also sources for many cobenefits from small- and large-scale food production, to new spaces for recreation and cultural benefits, to opportunities for stormwater capture, habitat for biodiversity and novel spaces for urban environmental education. The green roof pictured here atop the Vice Media Headquarters in Brooklyn, New York, is a biodiverse habitat providing multiple benefits and the site for an undergraduate Green Roof Ecology course at The New School focused on nature-based solutions in urban environments. Photograph: Timon McPhearson.

and continent-wide "franchises," such as Vital Signs in Canada or Cómo Vamos across Latin America, are growing in number and sophistication. Although not focused exclusively on nature-based solutions and climate change adaptation, CIS provide baselines of urban trends and patterns, they can help diagnose problems in a multi-issue and multidisciplinary sustainability context that nature-based solutions can contribute to. Indicators in CIS can also help track changes in vulnerability and impacts and provide the quantitative basis for assessing the contribution of nature-based solutions to resolving climate change vulnerability and adaptation challenges. To do this, nature-based solutions designs need to consider evidence presented in CIS, and CIS need to make sure the perspectives of nature-based solutions are considered in indicator selection and design. This will generate the very much needed data on socioeconomic alongside with socioecological performance (Brink et al. 2016).

Although trade-offs and cobenefits of nature-based solutions are often mentioned in the literature (Raymond et al. 2017), only few such trade-offs are empirically documented. In addition, beyond assumed trade-offs, evidence of the unintended effects of nature-based solutions is relatively scarce. Trade-offs and unintended effects depend on the diverse characteristics of the nature-based solutions themselves, as well as on the features of the process for their design and implementation, which include additional social and economic dynamics and policies targeting their

Figure 2. An example of a collection of nature-based solutions to tackle episodic rain but also build cohesion in London. Once a busy road, through the cocreation process it was closed to cars and repaved with permeable paving. Rain is also intercepted from the rooftops of this social housing building in storage boxes and the overflow is then further captured in rain gardens or wild flowers, herbs and insect-friendly plants. More bee-friendly plans can be seen on the roof of the bicycle shelter. The initiative was cocreated to the extent that it is now part of a community interest company (CIC). The CIC manages the nature-based solutions for the local authority and employs several people. There are over 10,000 CICs in the United Kingdom and are an ideal model for comanagement of nature-based solutions. Photograph: Marcus Collier.

enhanced performance. Indicators capturing such trade-offs will be particularly valuable to decision-making in urban policy (see an example of a good practice in box 1). Significant research on nature-based solutions has been conducted on single case studies in which a diversity of process and outcome features coexists (Faivre et al. 2017, Simic et al. 2017, Xiang et al. 2017, Kabisch et al. 2017a, Gulsrud et al. 2018, Lafortezza et al. 2018, Langemeyer et al. 2018). Such coexistence has made it impossible to systematically explore the effects of process features on the outcomes of nature-based solutions and to isolate causality of the specific processes affecting the impact of these interventions.

Furthermore, environmental impacts of nature-based solutions have been more extensively analyzed and documented, whereas the evidence on social and health effects remains rather scarce or fragmented, in great part because of the complexity of conceptualizing impacts such as social cohesion. Fuzzy conceptualizations of social cohesion are paramount in the literature and an urgent need to clarify whether social cohesion is either a real-life phenomenon (reflective construct) or a theoretical one has been signaled (Janmaat 2011, Schiefer and der Noll 2017). Clarifying the health and social cohesion impacts of nature-based solutions as well as their interaction with environmental effects will support more thorough impact assessment and generate the evidence base to support innovative governance and financing models (Bourguignon 2017).

New data streams are becoming available publicly at incredibly fast pace and provide new and unique opportunities for linking quantitative data with other forms of knowledge required for adapting nature-based solutions to local contexts and needs (Roman et al. 2013, Ilieva and McPhearson 2018). For example, linking spatial data on population density and social demographic indicators of risk and vulnerability to climate change driven extreme events (e.g., coastal flooding or heat waves) can help to identify

Box 1. Linking nature-based solutions and urban greening in Dar es Salaam, Tanzania.

During 2017, Dar es Salaam City Council identified an urgent need for decision support to prioritize investment in greening. A collective was formed, consisting of representatives from Dar es Salaam City Council, the five Municipal Councils, Regional Government, local universities, relevant nongovernmental organizations, and local experts and a small facilitating team, consisting of ICLEI and UFZ. Partners contributed data and deliberative insights to coproduce a Thematic Atlas. The Atlas indicates the spatial location of existing natural assets in the city and the locations of pressing urban issues such as urban heat islands and areas of poor air quality. A range of policy responses were identified for each issue, supported by ecosystem services concepts. The Atlas also provides a basis for designing local-scale demonstration projects to encourage continued colearning about the costs and effectiveness of such initiatives. The first greening demonstration project is proposed for the Sinza area of Dar es Salaam. (Read more in Gomez and Barton 2013)

where nature-based solutions are most needed and should be implemented. City tax assessor data, 3-D building data layers, or other information on the built infrastructure can help identify where nature-based solutions can be implemented—for example, assessing which buildings and with what characteristics have potential for green roof installations to combat the urban heat island. New data streams from remote sensing products to local environmental sensors and social media are being increasingly harnessed as indicators of social, ecological, and infrastructural change (Donahugh et al. 2018, Hamstead et al. 2018, Creutzig et al. 2019). Keeping up-to-date data on the state of urban natural resources, such as the risk level of street trees, can help identify where resilience making measures need to be implemented.

Social media derived data are fast becoming a vast and instantaneous source of information on people's attitudes, values, and activity, which is critical for understanding why, when, and how people make use of green infrastructure and nature in the city (Ilieva and McPhearson 2018). For example, a recent study in New York City used social media derived data for the first time to understand why people use some parks more than others to examine the social equity of urban park benefits that are not accessible equally to all (Hamstead et al. 2018). Data sources from Open Street Map for building and roads data, remote sensing from Landsat for land cover, census data sets for social demographics and population density, tax assessor database for detailed built infrastructure characteristics, social media data, downscaled climate projections, fine grained weather data, and more are becoming more widely available for cities around the world every year.

Furthermore, available health and well-being data, social perceptions, identities, values, and behaviors can be used to identify how different sociodemographic groups make use of and benefit from nature-based solutions. Comparative time-use data such as the HETUS (Harmonized European Time Use Survey) or MTUS (the Multinational Time Use Study) can shed light on patterns of activities as well as changes in lifestyles and social habits over time, with high utility for nature-based solution decision implementation. Innovative methodologies that use on-the-go data gathering that take advantage of highly extended technologies such as cellphone usage and citizen science approaches can be harnessed to gather more detailed and high-quality evidence on how nature-based solutions may affect different sociodemographic groups.

Investment models and novel financing for implementation of nature-based solutions. Inspired by traditions of ecosystem service assessments, much of the evidence base so far developed on nature-based solutions in cities has focused on the functions that they provide and how these can be evaluated (EC 2015, Kabisch et al. 2016). The result is a growing momentum behind an approach to evidence building that is focused on the kinds of services that nature-based solutions provide, if only they were implemented in the right way. Although such an evidence base is necessary, our dialogue reveals that it is far from sufficient. It is critical to develop more evidence about the nature of the implementation challenges involved, how this affects or distorts the delivery of intended ecosystem services and how these issues might be overcome.

Participants in the Cities IPCC dialogue were particularly concerned with the challenge of securing investment in nature-based solutions. Unlike their mainstream, hard engineered counterparts there is limited experience to date among the policy and investment communities in calculating the benefits of nature-based solutions over time and how these might be evaluated. Questions were raised as to whether existing approaches to evaluation (e.g., used in the delivery of gray infrastructure solutions) would be able to adequately capture the nonmonetary benefits and value of nature-based solutions. There was a call to identify ways to assess nonmaterial values of urban nature but also to find ways to communicate these findings in ways that are persuasive, relevant, and impactful in the context of city planning and design.

Mainstreaming and upscaling nature-based solutions in urban systems will require major investments, both in terms of retrofitting existing structures or establishing entirely new cityscapes. New policy and governance frameworks need to come hand in hand with investment models for ensuring continuity and maintenance of nature-based solutions postscaling (Bai et al. 2018). A case study to this direction is shown in box 2.

Box 2. City of Melbourne Urban Forest Fund, Australia.

In 2017, the City of Melbourne launched an Urban Forest Fund with $1.2 million seed funding. This financing model targets the cost barriers of green infrastructure on private land that is 75% of the city area. It provides financial support to new greening projects that otherwise would not be funded, such as green spaces, tree planting, vertical greening or green roofs. It also accepts private contributions who want to contribute to greening the city. The premise of the model is that green infrastructure on private land creates public benefit by reducing the urban heat island effect, enhancing biodiversity and reducing air pollution and stormwater runoff. This justifies using public funds to incentivize greening privately owned space. The private benefits of improved amenity are recognized by requiring projects to be matched dollar for dollar with private funds. In this way, it leverages private finance to double the greening outcome.

The contribution of nature-based solutions to climate related risk reduction must be based on solid statistical and geospatial data, and it must also be projected into the future, considering changes in climate and other framework conditions and the long lifespan of urban infrastructure. In addition, there are behavioral aspects around risk and the drivers of risk perception that should be better understood in the context of nature-based solutions and that may affect the way one would want to influence or direct investment from a nature-based perspective. For example, insurance companies may seek to encourage perceptions of risk (and associated investment) that assumes risk realization, whereas a nature-based solutions approach may instead direct investment in green infrastructure that promotes risk mitigation and the notion of cobenefits. Another issue that was raised was around situations where private investment leads to the enjoyment of public benefits at the community level. These scenarios need to be better understood from cost and benefit sharing and behavioral perspectives.

Bridging the divide

It is tempting to think that way forward relating to collaborative research and coproduction is not possible within current planning and fiscal timelines. This does not have to be the case. New mechanisms for long-term planning (Stuart 2013, Littke 2015, Bourguignon 2017, Scott et al. 2017, FAO 2018), and novel models for financing (such as social enterprises, investment in "green" bonds, crowdfunding) are increasingly being explored and scaled out. One of the more promising ways to bridge the gaps and scale nature-based solution science and practice outward is to focus on innovation. Innovation is already occurring in developing and testing new nature-based solutions themselves, although this new technology has a long way to go to be fully mainstreamed and retrofitted into city making. However, there is potential innovation in the way the cocreation processes occur and are elaborated on. There is potential innovation in the way nature-based solutions can be financed and, therefore, validated. There is potential innovation in the way institutions cocreate nature-based solutions and, therefore, break siloed thinking and practices. And there is potential innovation in the way nature-based solution knowledge is communicated with—not toward—communities of interest and communities of influence.

Ways forward relating to collaborative research and knowledge coproduction. Although many challenges have been identified for collaborative research, nature-based solutions offer a fantastic opportunity for addressing these challenges. Knowledge brokerage is required to bridge communication and practice divisions among policymakers, urban planners, the community, and research scientists. Although knowledge brokerage can involve academic knowledge translation for practitioners, postproduction, another pathway is the production of planning-relevant and academic knowledge in parallel. In this context, a trusted knowledge broker can foster two-way communication between different groups by understanding the different cultures and languages of each group.

Careful experimentation through demonstration projects can bring about powerful tools for codesign, and colearning. Demonstration projects provide opportunities for tracking the costs and benefits of actual "real" examples when they are of appropriate scale (Fink 2016). Such projects in turn, produce data and an evidence base for improved decision-making and a stronger case for the incorporation of nature-based solutions into urban planning and design through being urban living labs (Bulkeley et al. 2016, Voytenko et al. 2016).

Research-based tools may provide a bridge between research and implementation. For example, several Tanzanian cities have a long history of greening but perhaps without clear links to climate change mitigation and adaptation. But with exposure to the TEEB (The Economics of Ecosystems and Biodiversity) tool (TEEB 2010) and related ecosystem services concepts (Gomez-Baggethun et al. 2013), city planners now have a basis for thinking about the benefits of defined ecosystems, trade-offs among benefits, new partnerships to support certain suites of ecosystem services and a new way of articulating arguments, based on sound science, to higher levels in their government. Participatory analyses involving a wide range of stakeholders can provide critical information about where to put adaptive efforts. Examples from the United States (Samuelsson et al. 2018) and Canada (Ordóñez 2015) have helped identify the socioecological aspects of urban nature that will be affected by climate change, and demonstrated the need for a climate-adaptive approach with nature-based solutions.

Similarly, nature-based solution projects are inherently multi-, inter-, and transdisciplinary and span different types of expert knowledge, disciplines, and ontological and epistemological approaches. Processes that foster trans- and interdisciplinary research approaches are needed to produce useful collaborative solutions. Academic researchers can help scale up evidence on nature-based solutions, and generalization to the social–ecological contexts in ways that are scientifically robust (Frantzeskaki and Kabisch 2016, Frantzeskaki et al. 2017b). In the same vein, nature-based solutions projects offer researchers the opportunity to increase the quantity of research being undertaken. Although a high proportion of nature-based solutions research is conducted through practitioner–consultant partnerships, academic researchers could offer greater scalar and temporal perspectives if practitioner and researcher interests can be better aligned. At the same time, nature-based solution projects also offer an opportunity to increase the quality of research. Shifts to transdisciplinary research can improve the quality of research impact ensuring city–researcher partnerships that effectively lead to coproduction of research questions that better address pressing needs.

A key benefit for researchers working with cities is the opportunity to develop skills in and a track record of cocreating research with impact supporting a shift toward national or university impact agendas—for example, Australia's National Innovation and Science Agenda. In the present article, new reward systems are being developed within academia and within city administration that appreciate and celebrate partnerships and collaborative knowledge production and urban planning. For example, nature-based solutions projects can form the basis of impact case studies and create a network of data observatories for longitudinal urban research. There is also a great deal of interest in measuring the impact of academic research in terms of how this informs policy and planning decisions; perhaps this can be explored in conjunction with measurement of the efficacy of nature-based solutions and in this way integrate two pressing imperatives. Nature-based solution projects offer further opportunities for researchers and practitioners to develop valuable skills in science communication and experience working on multidisciplinary research teams and to develop interdisciplinary thinking and knowledge. Knowledge generated through collaborative approaches and transdisciplinary methods is time intensive. Transdisciplinary approaches have the additional benefits of adaptability and cultural and social inclusivity, democratizing both science and urban planning.

A key challenge for collaborative partnerships is aligning timeframes. Innovative approaches can be used to address perceived mismatches in timeframes—for example, staging projects through pilot studies leading on to larger, more comprehensive studies or perhaps adopting shorter timeframes with more restricted project scope. Timing of research outputs and evidence produced by research projects can be staged to deliver city-facing outputs first, to inform and strengthen planning decisions, and academic outputs later. Although nature-based solutions may be driven by short-term needs and must operate within relatively short-term political cycles, the slower temporal scale of research may be well suited to understanding the longer-term effects and successes (and failures) of nature-based solution projects.

By partnering with cities through multiple and targeted research- and innovation-focused projects, greater efficiencies in the understanding of specific problems will be generated and the communication and fostering of coproduced research questions will be enabled. There are also opportunities for researchers to be embedded in city practice to improve understanding of city perspectives. Similarly, there are roles for city practitioners to be more actively involved in guiding academic decision-making, through, for example, project steering and oversight committees.

Ways forward relating to evaluating schemes and big data. Arguably the first environmental impact bond (EIB), based in the wider principles of social impact bonds, was implemented by DC Water as part of its green infrastructure investment strategy to replace a combined sewer overflow. Whereas DC Water paid for installing the green infrastructure, in the "pay for success" model, investors receive payments on the basis of the performance of the infrastructure, which, in this case, was runoff reduction. The EIB enabled redistribution of the performance risk between public and private actors.

Despite incredible opportunity to harness big data for prioritizing nature-based solutions investments and the use of sensors to measure their efficacy, there are challenges as well. Making data useful requires new assessment and modeling approaches, whereas data must be more equitably and globally available, especially to the global South, where many forms of data do not exist or are incomplete; even if they do exist, expertise for working with them is in short supply (Bai et al. 2018). Filling data gaps is not a minor hurdle and will require new technologies to be deployed, with a vast array of sensors as opportunities that come with their own funding, bias, and ethics challenges. Furthermore, we need to link quantitative data with other forms of knowledge that is more qualitative but nonetheless critical, if not even more important for making nature-based solutions relevant, desirable, locally tailored, and effective.

Monitoring and modeling the impacts of nature-based solutions in different urban conditions is another way forward for advancing nature-based solutions knowledge. Another challenge concerns the resolution and the ways in which environmental functions are shaped by particular conditions that also influences the ways to work with indicators that can operate over diverse settings and provide sufficient approximations for decision-making. This requires shifts in institutional cultures used to working with indicators that can be readily transposed from one place to another (e.g., the cost per cubic meter of concrete) and where there is an assumption that "perfect" knowledge is available for decision-making.

Urban diversity is an issue of multiculturalism, racialized communities, and hidden cultures (Burayidi 2015). These aspects of diversity define different ways to relate to and prioritize nature in cities and are associated with the unequal distribution of urban natural resources (Roe et al. 2016). Nature-based solutions are assumed to be technical, value-free solutions, but they engulf meanings and social values. Given that one of the goals of nature-based solutions is to create successful human–nature interactions in multicultural cities (Ordóñez-Barona 2017), integrating multiculturalism into nature-based solutions can be a way to recognize diverse social and cultural values associated with nature and to scale up projects that are relevant to a wider cultural base.

Ways forward relating to new finance and new business models. As we documented above, the participants in our dialogues identified a lack of finance and investment as a key barrier to the uptake and mainstreaming of nature-based solutions. To date, much of the investment in nature-based solutions has been either wholly or partially supported by public investment (e.g., the demonstrator projects taking place under the auspices of the EU Horizon 2020 Sustainable Cities and Communities program). Such projects can serve as useful test beds and demonstrators for assessing the potential contribution of nature-based solutions to sustainable development goals, and they can provide evidence and knowledge concerning the opportunities and challenges involved in securing private investment in nature-based solutions if this is directly put in the cities' agendas for action. The literature suggests that securing investment often faces two key challenges: first, that private investment will also yield public benefits (e.g., flood protection) and, second, that return on investment is typically higher risk and longer term than for other investment opportunities. At the same time, it is important to realize that private investment is only ever forthcoming where business models (either for profit or nonprofit) are established through which returns on investment can be realized. Although some initial work has been conducted to survey the different kinds of business models being deployed in relation to nature-based solutions (Toxopeus and Polzin 2017), further research is required to identify and categorize these business models and evaluate their strengths and weaknesses.

A key knowledge need is therefore to develop an understanding of the forms of business model that can sustain nature-based solutions over the long term and attract investment. It is likely, however, that there will be many instances where nature-based solutions have the potential to make significant contributions toward sustainable development goals, but a workable business model cannot be selected off the shelf. In these contexts, overcoming the challenges requires that we identify viable public–private partnerships in which both risks and benefits of investment can be shared over time. Developing an evidence base of different kinds of governance arrangements through which such forms of investment can be realized will be an important part of generating the knowledge required to further the development of nature-based solutions.

Some cities are deploying new finance and business models to pay for green infrastructure, urban forests, and flood mitigation measures (e.g., City of Melbourne 2017). The case for investment is based on the monetized cost of environmental, social, and economic externalities where cost shifting can be demonstrated between locations (e.g., upstream and downstream impacts); across time (bringing forward investment in mitigation to reduce long-term cost of adaptation); or to correct cost shifting between actors, including government authorities such as water agencies and local governments and businesses such as insurance and property owners. The calculation of the return on investment for these nature-based solutions requires research on the estimated impacts and costs of climate risks and the mitigation and adaptation options to address them. There are many gaps in this research that urgently need to be addressed for cities to deploy nature-based solutions.

At the same time, it is important to recognize the need to develop evaluations of existing and potential projects that can open up the potential for investment. To date, there are relatively few studies that identify the economic value of nature-based solutions at the city level, both in terms of the potential for return on investment and the costs of risk avoided. Increasing our quantitative analysis of the costs and benefits of nature-based solutions will be key. At the same time, as the discussion above shows, the true benefits of nature-based solutions are to be found in their multifunctional nature. Being able to identify and evaluate these benefits, such that they speak to growing interest in "green" investment or social impact investment will also be essential. Finally, developing robust tools through which proposed nature-based solutions and, critically, their "gray" alternatives can be subject to rigorous assessment processes will enable the benefits from different forms of investment to be compared in a way that reveals the full impacts of different forms of investment.

Conclusions

Natural systems have the potential for providing climate mitigation solutions *and* simultaneously providing climate resilient and adaptation planning, especially in urban areas. It is not the intent to claim that nature-based solutions are a panacea for all climate-related urban problems. Technology-based solutions, cultural-based solutions, and behavior-based solutions (to name a few) should complement the work of nature-based solutions. An area of increased research urgency is how to combine multiple solutions to maximize the impact of climate adaptation and mitigation in cities, as well as to generate innovation.

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