Nature-based solutions for urban climate change adaptation: linking the science, policy, and practice community for evidence-based decision-making

Abstract

Nature-based solutions offer an exciting prospect for resilience building and advancing urban planning to address complex urban challenges simultaneously. In this paper, we formulated through a co-production 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 co-production*, *indicators and big data* and *novel financing models*. With this paper, 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 co-producing nature-based solutions.

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

1. Introduction

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 (Frantzeskaki et al. 2017a; Bulkeley et al. 2016) where collaborative and co-designed 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 (Kabisch et al. 2017a, McPhearson et al. 2015). 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, Cortinovis and Geneletti 2018, Willis et al 2017) 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 wellbeing (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, as hybrid approaches (Cherrier et al. 2016, Depietri and McPhearson 2017)

integrated with technology-based and/or engineered solutions to foster urban resilience and sustainability (Halbac-Cotoara-Zamfir et al. 2017, Urge-Vorsatz et al 2018, Keesstra et al 2018).

Nature-based solutions (NBS) 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 (Gabriel and Endlicher 2011, Gill et al. 2007, Harlan et al. 2006, Depietri et al. 2013) while enhancing well-being (Martens et al. 2011, Gulsrud et al. 2018). However, 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 (Haase et al 2017, Wolch et al 2014). 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 co-production process, a series of synthesis statements from a global set of NBS experts on the role of NBS for climate change adaptation and mitigation through dialogue and workshops held during the IPCC Cities and Climate Science Conference in Edmonton, Canada in March 2018. With this paper, 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, heatwaves, and storms. The paper will address several interlocking questions including: *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?*

2. 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. As thus, we aim to contribute to the future advancement of knowledge on novel ways to co-design, co-produce, co-evaluate and co-finance nature-based solutions in cities. Firstly, we recognize the importance of *collaborative research* and point at learning the lessons from examples of co-produced knowledge, where researchers and practitioners are involved in the iterative, collaborative generation of data, evaluation and actionable knowledge Secondly, 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 utilized 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 (Creutzig et al. in press; Ilieva and McPhearson 2018), where they are working, to what extent, and where they fail, to what consequences. Thirdly, we examine how *investment models and novel financing* for implementation of nature-based solutions can help to make NBS more widely available and implemented, considering the demands on public finances and taxpayer expectations.

2.1 Collaborative research and knowledge co-production

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-practice approaches cannot satisfy. A valuable outcome of these partnerships and collaborative approaches is the applicability and legitimacy of research because of the co-creation 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 co-production and the factors that deliver successful co-production outcomes. In this way, beneficiaries of NBS will be elucidated but, in addition, there is the aspiration for the co-design, co-production and contribution to post-

implementation sustainability driven by a continuous co-production process with stakeholders at multiple scales and across sectors (Biggs et al. 2017).

While 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 (Fernandes and Guiomar 2018; Fink 2016). Academic research can also be beneficial where it provides a critical perspective to complex, ill-defined urban-climate challenges, and can make visible e.g. political processes that can confound, or, lead to perverse solutions (Steiner 2014). In collaborative research, partnerships interface with policymaking, design/management and community, and researchers often fulfill multiple roles including a brokerage role between community and policy that needs to be reflected upon 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 efforted is called for in order to identify how these partnerships play a role in the governance of different types of NBS at different scales, to understand the interactions between the processes of designing, implementing and maintaining NBS and the outcomes they generate. Research has also to chart trade-offs between NBS 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, high demand for services and 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 co-designed and therefore relevant to fit city needs and context (Nel et al. 2015, Cowling et al. 2008). Knowledge required for NBS is dependent on the time, efforts and skills of those generating and weaving together diverse knowledges (Tengo et al. 2017). This demands the ability to interpret knowledges across different disciplines, and a shout-out to the oft-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 co-design of NBS need to incorporate solid evaluation and evidence-generating mechanisms that can then inform targeted and cost-effective interventions. If co-developed carefully, plans for NBS can and should incorporate real-world experimentation that can clarify causality and allow for comparison between different types of NBS. 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 knowledges 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 co-produced 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 co-production 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, while 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 non-material benefits of NBS in a persuasive manner (through for example revenue generation, costs-savings, or, other ways of portraying the importance of defined values and meanings) such that these non-material benefits may be counted and traded-off in the same frame as other types of benefits (Díaz et al. 2018, van Wyk et al. 2014).

Fourth, co-created 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/policy makers (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, while 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 EU alone (Bourguignon 2017). An example on a NBS co-creation research is given in Photo 1. Nature-based solution researchers could in fact be leading the creation and implementation of impact agendas e.g. Australia's National Science and Innovation Agenda. While scientific development of theories and evidence is of utmost importance for NBS, we should also strive for academic output that is understandable by larger audiences.

INSERT PHOTO 1

Finally, nature-based solutions can provide a democratic entry point to addressing many urban challenges (Andersson et al. 2015). For instance, initially they may 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 co-developing NBS, 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/data aggregation may not be the same scale of available data nor analyzed data from academic work (Acuto et al. 2018) (Photo 2).

INSERT PHOTO 2

2.2 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 and continent-wide 'franchises' such as *Vital Signs* in Canada or *Cómo Vamos* across Latin America are growing in number and sophistication. While 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 multi-disciplinary 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, NBS designs need to consider evidence presented in CIS and CIS need to make sure the perspectives of NBS are considered in indicator selection and design. This will generate the very much-needed data on socio-economic alongside with socio-ecological performance (Brink et al. 2016).

Although trade-offs and co-benefits of NBS are often mentioned in the literature (Demuzere et al. 2014, Raymond et al. 2017), *only few such trade-offs are empirically documented*. Additionally, 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 NBS itself 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 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; Kabisch et al 2017a; Gulsrud et al 2018; Langemeyer et al 2018; Lafortezza et al 2018; Simic et al 2017; Xiang et al 2017). 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.

INSERT BOX 1

Furthermore, environmental impacts of nature-based solutions have been more extensively analyzed and documented, whilst the evidence on social and health effects remains rather scarce, or, fragmented, in great part due to 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 in Schiefer & der Noll 2017). Clarifying the health and social cohesion impacts of NBS 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 (Ilieva and McPhearson 2018; Roman et al. 2013). 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 where nature-based solutions are most needed and should be implemented. City tax assessor data, 3D 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 (Hamstead et al. 2018, Donahugh et al. 2018; Creutzig et al. in press). 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 SMD 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 wellbeing data, social perceptions, identities, values and behaviors can be used to identify how different socio-demographic 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 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 impact different socio-demographic groups.

2.3 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 which focuses on the kinds of services that nature-based solutions provide, if only they were implemented in the right way. While 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 amongst 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 (for example, used in the delivery of grey infrastructure solutions) would be able to adequately capture the non-monetary benefits and value of nature-based solutions. There was a call to identify ways to assess non-material 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 NBS post-scaling (Bai et al 2018). A case study to this direction is shown in Box 2.

INSERT BOX 2 HERE

The contribution of nature-based solutions to climate related risk reduction must be based on solid statistical and geospatial data and it also must 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 which should be better understood in the context of nature-based solutions and which may affect the way one would want to influence/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 co-benefits. 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.

3. Bridging the divide

It is tempting to think that way forward relating to collaborative research and co-production 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, UNASYLVA 2018), and novel models for financing (such as social enterprises, investment in 'green' bonds, crowd-funding) 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 outwards is to focus on innovation. Innovation is already occurring in developing and testing new nature-based solutions themselves, though 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 co-creation processes occur and are elaborated upon; there is potential innovation in the way nature-based solutions can be financed and thus validated; there is potential innovation in the way institutions co-create nature-based solutions and thus break siloed thinking and practices; and there is potential innovation in the way nature-based solution knowledge is communicated *with* (not 'towards') communities of interest and communities of influence.

3.1 Ways forward relating to collaborative research and knowledge co-production

While 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 between policy makers, urban planners, the community, and research scientists. While knowledge brokerage can involve academic knowledge translation for practitioners, post-production, 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 co-design, and co-learning. 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 in sound science, to higher levels in their government. Participatory analyses involving a wide range of stakeholders can provide critical information on where to put adaptive efforts (Berkhout et al. 2002, van Aalst et al. 2008). Examples from the US (Brandt et al. 2017) and Canada (Ordóñez and Duinker 2015) have helped identify the socio-ecological 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 trans-disciplinary, and span different expert knowledges, disciplines, and ontological and epistemological approaches. Processes that foster trans- and inter-disciplinary 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, NBS projects offer researchers the opportunity to increase the quantity of research being undertaken. While a high proportion of NBS 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 co-production 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, co-creating research with impact supporting a shift towards national/university impact agendas for example, Australia's National Innovation and Science Agenda. Here, 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, NBS 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, experience working in multidisciplinary research teams, and to develop interdisciplinary thinking and knowledge. Knowledge generated through collaborative approaches and transdisciplinary methods, is time-demanding. Transdisciplinary approaches have the additional benefits of adaptability, 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 e.g. 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. While 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 co-produced 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 e.g. project steering and oversight committees.

3.2 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 based on 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 while data must be more equitably and globally available, especially to the global South where many forms of data do not exist or are incomplete, or even if they do, expertise for working with them are 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 and IoT as opportunities that come with their own funding, bias, and ethics challenges. Further, 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 multi-culturalism, racialized communities, and hidden cultures (Buriayidi 2015). These aspects of diversity define different ways to relate to and prioritize nature in cities (Dai 2011) and is associated with the unequal distribution of urban natural resources (Pham et al. 2013, 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.

3.3 Ways forward relating to new finance and new business models

As we document above, 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 (for example, 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. 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 non-profit) are established through which returns on investment can be realized. While some initial work has been conducted to survey the different kinds of business models being deployed in relation to nature-based solutions (Toxopeus and Friedmann 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 towards sustainable development goals and yet 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 NBS.

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 multi-functional 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 'grey' 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.

4. 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.

Acknowledgements

The research leading to this paper has received funding from the European Community's Framework Program Horizon 2020 for the Connecting Nature Project (Grant Agreement number: 730222; www.connectingnature.eu), and the NATURVATION project (Grant Agreement 730423; www.naturvation.eu). Funding was also received from the National Science Foundation of United States: URExSRN project (https://sustainability.asu.edu/urbanresilience/) (award number SES-1444755), the European Joint Program Initiative Biodiversa ENABLE project (http://projectenable.eu) and the Australian Research Council (Linkage Grant LP-160100780). The United States Agency for International Development (USAID) is thanked for supporting the participation of ICLEI staff in the IPCC 2018 in Edmonton, Canada.

References

Andersson, E., M. Tengö, T. McPhearson and P. Kremer. 2015. Cultural Ecosystem Services as a Platform for Working Towards Urban Sustainability. Ecosystem Services DOI http://dx.doi.org/10.1016/j.ecoser.2014.08.002

Bai, X., Dawson, R.J., Urge-Vorsatz, D., Delgado, G.C., Barau, A.S., Dhakal, S., Dodman, D., Leonardsen, L., Masson-Delmotte, V., Roberts, D., and Schultz, S. 2018. Six priorities for cities and climate change. Nature 555:23-25.

Biggs, H.C., Cifford-Holmes, J.K., Freitag, S., Venter, F.J., and Venter, J. 2017. Cross-scale governance and ecosystem service delivery: a case narrative from the Olifants River in north-eastern South Africa. Ecosystem Services 28(B):173-184.

Bourguignon, D. 2017. Nature-based Solutions: Concept, opportunities and challenges. European Parliamentary Research Service, EPRS.

Bulkeley, H., Coenen, L., Frantzeskaki, N., Hartmann, C., Kronsell, A., Mai, L., Marvin, S., McCormick, K., van Steenbergen, F., and Palgan Voytenko, Y., (2016), Urban Living Labs: Governing urban sustainability transitions, Current Opinion in Environmental Sustainability, 22:13-17.

Chawla, L. 2015. Benefits of nature contact for children. Journal of Planning Literature 30:433-452.

Cherrier, J., Klein, Y., Link, H., Pillich, J., and Yonzan, N. (2016), Hybrid green infrastructure for reducing demands on urban water and energy systems: a New York City hypothetical case study. Journal of Environmental Studies and Sciences 6(1): 77-89.

City of Melbourne. 2017 Nature in the City Strategy, Melbourne, Australia.

Cohen-Shacham, E., G. Walters, C. Janzen, and S. Maginnis. 2016. Nature-based Solutions to address global societal challenges. IUCN, Gland, Switzerland.

Collier, M. J., S. Connop, K. Foley, Z. Nedović-Budić, D. Newport, A. Corcoran, P. Crowe, L. Dunne, H. de Moel, S. Kampelmann, S. McQuaid, H.-G. Schwarz von Raumer, A. Slaev, E.-M. Stumpp, P. Van den Abeele, and P. Vandergert. 2017. Urban

transformation with TURAS open innovations; opportunities for transitioning through transdisciplinarity. Current Opinion in Environmental Sustainability 22:57-62.

Connop, S., P. Vandergert, B. Eisenberg, M. J. Collier, C. Nash, J. Clough, and D. Newport. 2016. Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. Environmental Science & Policy 62:99-111.

Cortinovis, C., and D. Geneletti. 2018. Ecosystem services in urban plans: what is there, and what is still needed for better decisions. Land Use Policy 70:298-312.

Cowling, R.M., Egoh, B., Knight, A.T., O'Farrell, P.J., Reyers, B., Rouget, M., Roux, D.J., Welz, A., and Wilhelm-Rechman, A. 2008. An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences of the United States of America 105(28):9483–9488.

Davies, H., K. Doick, P. Handley, L. O'Brien, and J. Wilson. 2017. Delivery of ecosystem services by urban forests. Forestry Commission, Edinburgh.

Depietri, Y., Welle, T., Renaud, F.G., 2013. Social vulnerability assessment of the Cologne urban area (Germany) to heat waves: links to ecosystem services. International Journal of Disaster Risk Reduction 6: 98–117. https://doi.org/10.1016/j.ijdrr.2013.10.001

Depietri, Y. and T. McPhearson. 2017. Integrating the grey, green, and blue in cities: Nature-based solutions for climate change adaptation and risk reduction. (pp91-109) in Kabisch, N., Korn, H., Stadler, J., Bonn, A. (Eds), *Nature-based Solutions to Climate Change in Urban Areas: Linkages Between Science, Policy, and Practice,* Springer.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S. and Shirayama, Y. 2018. Assessing nature's contributions to people: Recognizing culture, and diverse sources of knowledge, can improve assessments. Science 359(6373): 270-272.

Creutzig, F., S. Lohrey, X. Bai, A. Baklanov, R. Dawson, S. Dhakal, William F. Lamb, T. McPhearson, J. Minx, E. Munoz, B. Walsh. Upscaling urban data science for global climate solutions, Global Sustainability, in press.

Donahue, M., B.L. Keeler, S.A. Wood, D. Fisher, Z.A. Hamstead, and T. McPhearson. 2018. "Using social media to understand drivers of urban park visitation in the Twin Cities, MN." *Landscape and Urban Planning* 175:1-10, https://doi.org/10.1016/j.landurbplan.2018.02.006

DG Environment. 2017. Green Infrastructure and Public Health.

EC (European Commission). 2015. Towards an EU Research and Innovation policy agenda for Nature-Based Solutions and Re-Naturing Cities. DG Research and innovation, Brussels.

Faivre, N., M. Fritz, T. Freitas, B. de Boissezon, and S. Vandewoestijne. 2017. Nature-Based Solutions in the EU: innovating with nature to address social, economic and environmental challenges. Environmental Research 159:509-518.

Fernandes, J. P., and N. Guiomar. 2018. Nature-based solutions: the need to increase the knowledge on their potentialities and limits. Land Degradation & Development.

Fink, H.S. 2016. Human-Nature for climate action: Nature-based solutions for urban sustainability. Sustainability 8, 254; doi:10.3390/su8030254

Frantzeskaki, N., A. Dumitru, I. Anguelovski, F. Avelino, M. Bach, B. Best, C. Binder, J. Barnes, G. Carrus, M. Egermann, A. Haxeltine, M.-L. Moore, R. G. Mira, D. Loorbach, D. Uzzell, I. Omman, P. Olsson, G. Silvestri, R. Stedman, J. Wittmayer, R. Durrant, and F. Rauschmayer. 2016. Elucidating the changing roles of civil society in urban sustainability transitions. Current Opinion in Environmental Sustainability 22:41-50.

Frantzeskaki, N., and Kabisch, N. 2016. Designing a knowledge co-production operating space for urban environmental governance – Lessons from Rotterdam, the Netherlands and Berlin, Germany. Environmental Science and Policy 62:90-98.

Frantzeskaki, N., Castan-Broto, V., Coenen, L., and Loorbach, D., (Eds) 2017a. Urban sustainability transitions. Routledge: New York, ISBN 978-0-415-78418-4.

Frantzeskaki, N., Borgstrom, S., Gorissen, L., Egermann, M., and Ehnert, F. 2017b. Nature-based solutions accelerating urban sustainability transitions in cities, in Kabisch, N., Korn, H., Stadler. J., and Bonn, A., (Eds), Nature-based Solutions to Climate Change Adaptation in Urban Areas - Linkages between Science, Policy and Practice, SPRINGER, ISBN: 978-3-319-53750-4, DOI 10.1007/978-3-319-56091-5. https://link.springer.com/book/10.1007%2F978-3-319-56091-5

Gabriel, K.M.A., Endlicher, W.R. 2011. Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. Environmental Pollution 159:2044–2050. https://doi.org/10.1016/j.envpol.2011.01.016

Gill, S.., Handley, J.., Ennos, A.., Pauleit, S. 2007. Adapting Cities for Climate Change: The Role of the Green Infrastructure. Built Environment 33:115–133. https://doi.org/10.2148/benv.33.1.115

Gómez-Baggethun, E. and Barton, D.N. (2013). Classifying and valuing ecosystem services for urban planning. *Ecological Economics* 86:235-245.

Gómez-Baggethun, E., Å. Gren, D.N. Barton, J. Langemeyer, T. McPhearson, P. O'Farrell, E. Andersson, Z. Hamstead, and P. Kremer. 2013. "Urban Ecosystem Services," In, *Cities and Biodiversity Outlook*: *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, (Eds: T. Elmqvist, et al.), Springer Netherlands, pp.175-251, DOI:10.1007/978-94-007-7088-1_11

Gulsrud, N.M., Hertzog, K., and Shears, I. 2018. Innovative urban forestry governance in Melbourne?: Investigating "green placemaking" as a nature-based solution. Environmental Research 161:158-167, https://doi.org/10.1016/j.envres.2017.11.005

Haase, D. 2015. Reflections about blue ecosystem services in cities. Sustainability of Water Quality and Ecology 5:77-83.

Haase, D., Kabisch, S., Haase, A., Andersson, E., Banzhaf, E., Baro, F., Brenck, M., Fischer, L.K., Frantzeskaki, N., Kabisch, N., Krellenberg, K., Kremer, P., Kronenberg, J., Larondelle, N., Mathey, J., Pauleit, S., Ring, I., Rink, D., Schwarz, N., and Wolf, M. 2017. Greening cities - To be socially inclusive? About the alleged paradox of society

and ecology in cities. Habitat International 64:41-48, http://dx.doi.org/10.1016/j.habitatint.2017.04.005

Halbac-Cotoara-Zamfir, R., S. Herban, J. Stolte, and C. Bozan. 2017. Integrated Water Hazards Engineering Based on Mapping, Nature-Based and Technical Solutions. IOP Conference Series: Materials Science and Engineering 245.

Harlan, S.L., Brazel, A.J., Prashad, L., Stefanov, W.L., Larsen, L., 2006. Neighborhood microclimates and vulnerability to heat stress. Social Science & Medicine 63, 2847–2863. https://doi.org/10.1016/j.socscimed.2006.07.030

Hartig, T., R. Mitchell, S. de Vries, and H. Frumkin. 2014. Nature and health. Annu Rev Public Health 35:207-228.

Ilieva, R.T. and T. McPhearson. 2018. Social media data for urban sustainability. Nature Sustainability 1:553–565 DOI : 10.1038/s41893-018-0153-6

Kabisch, N., N. Frantzeskaki, S. Pauleit, S. Naumann, M. Davis, M. Artmann, D. Haase, S. Knapp, H. Korn, J. Stadler, K. Zaunberger, and A. Bonn. 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecology and Society 21.

Kabisch, N., Korn, H., Stadler, J., Bonn, A. (Eds) 2017a. Nature-based Solutions to Climate Change in Urban Areas: Linkages Between Science, Policy, and Practice, Springer.

Kabisch, N., van den Bosch, M., and Lafortezza, R. 2017b. The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A

systematic review. Environmental Research 159:362-373, http://dx.doi.org/10.1016/j.envres.2017.08.004

Keesstra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., and Cerda, A. 2018. The superior effect of nature based solutions in land management for enhancing ecosystem services. Science of the Total Environment 610-611:997-1009, http://dx.doi.org/10.1016/j.scitotenv.2017.08.077

Langemeyer, J., Camps-Calvet, M., Calvet-Mir, M., Barthel, S., and Gomez-Baggethun, E., 2018. Stewardship of urban ecosystem services: understanding the value(s) of urban gardens in Barcelona. Landscape and Urban Planning 170, 79-87, http://dx.doi.org/10.1016/j.landurbplan.2017.09.013

Lafortezza, R., Chen, J., Konijnendijk van den Bosch, C., and Randrup, T.B. 2018. Nature-based solutions for resilient landscapes and cities, Environmental Research 165, 431-441, https://doi.org/10.1016/j.envres.2017.11.038

Littke, H. 2015. Planning the green walkable city: conceptualizing values and conflicts for urban green space strategies in Stockholm. Sustainability 7:11306-11320.

Loorbach, D., Frantzeskaki, N., and Avelino, F. 2017. Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annual Review of Environment and Resources 42:599-626, doi.org/10.1146/annurev-environ-102014-021340.

Maes, J., and S. Jacobs. 2015. Nature-based solutions for Europe's sustainable development. Conservation Letters:n/a-n/a.

Martens, D.; Gutscher, H.; Bauer, N. 2011. Walking in “wild” and “tended” urban forests: The impact on psychological well-being. J.Environ.Psychol. 31 (1):36-44.

Masi, F., A. Rizzo, and M. Regelsberger. 2017. The role of constructed wetlands in a new circular economy, resource oriented, and ecosystem services paradigm. J Environ Manage.

McPhearson, T., E. Andersson, T. Elmqvist, and N. Frantzeskaki. 2015. Resilience Of and Through Urban Ecosystem Services. *Ecosystem Services* 12:152-156, DOI: 10.1016/j.ecoser.2014.07.012

McPhearson, T., D. Haase, N. Kabisch, and Å. Gren. 2016. Advancing understanding of the complex nature of urban systems. Ecological Indicators 70:566-573.

McPhearson, T. 2017. Hurricanes: enlist nature's protection. *Nature* 550:43, doi:10.1038/550043c

McPhearson, T, D Iwaniec, and X Bai. 2017. Positives visions for guiding transformations toward desirable urban futures. Current Opinion in Environmental Sustainability. 22:33–40 DOI: 10.1016/j.cosust.2017.04.004

McPhearson, T., M. Karki, C. Herzog, H. Santiago Fink, L. Abbadie, P. Kremer, C.M. Clark, M.I. Palmer, K. Perini, and M. Dubbeling. 2018. “Urban Ecosystems and Biodiversity”, pages 259-320, In, Rosenzweig C, Solecki W, Romero-Lankao P, Mehrotra S, Dhakal S, Ali Ibrahim S, eds. 2018. Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. ISBN: 9781316603338

Nel., J.L., Roux, D.J., Driver, A., Hill, L., Maherry, A.C., Snaddon, K., Petersen, C.R., Smith-Adao, L.B., Van Deventer, H. and Reyers, B. 2015. Knowledge co-production and boundary work to promote implementation of conservation plans. Conservation Biology 30(1): 176-188.

Nesshöver, C., T. Assmuth, K. N. Irvine, G. M. Rusch, K. A. Waylen, B. Delbaere, D. Haase, L. Jones-Walters, H. Keune, E. Kovacs, K. Krauze, M. Külvik, F. Rey, J. van Dijk, O. I. Vistad, M. E. Wilkinson, and H. Wittmer. 2017. The science, policy and practice of nature-based solutions: an interdisciplinary perspective. Science of the Total Environment 579:1215-1227.

Panno, A., G. Carrus, R. Lafortezza, L. Mariani, and G. Sanesi. 2017. Nature-based solutions to promote human resilience and wellbeing in cities during increasingly hot summers. Environmental Research 159:249-256.

Richards, D. R., and P. J. Edwards. 2017. Quantifying street tree regulating ecosystem services using Google Street View. Ecological Indicators 77:31-40.

Roman, L.A.; McPherson, E.G.; Scharenbroch, B.C.; Bartens, J. 2013. Identifying common practices and challenges for local urban tree monitoring programs across the united states. Arboriculture & Urban Forestry 39 (6): 292-299.

Scott, A., O. Hölzinger, and J. Sadler. 2017. Making Plans for Green Infrastructure in England: Review of National Planning and Environmental Policies and Project Partners' Plans. Northumbria University & University of Birmingham.

Simic, I., Stupar, A., Djokic, V. 2017. Building the green infrastructure of Belgrade: The importance of community greening. Sustainability 9:1183; doi:10.3390/su9071183

Steiner, F. 2014. Frontiers in urban ecological design and planning research, Landscape and Urban Planning. 125: 304-311, dx.doi.org/10.1016/j.landurbplan.2014.01.023

Stuart, J. 2013. Planning for Urban Biodiversity. Queen's University Kingston, Ontario, Canada.

TEEB (The Economics of Ecosystems and Biodiversity). 2010. Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB. UNEP.

Tengo, M., Hill, R., Malmer, P., Raymond, C.M., Spierenburg, M., Danielsen, F., Elmqvist, T., and Folke, C. 2017. Weaving knowledge systems in IPBES, CBD and beyond – lessons learned for sustainability, Current Opinion in Environmental Sustainability. 26-27:17-25.

Thompson, M.A., Owen, S., Lindsay, J.M., Leonard, G.S., and Cronin, S.J. 2017. Scientist and stakeholder perspectives of transdisciplinary research: Early attitudes, expectations and tensions. Environmental Science and Policy, 74: 30-39. http://dx.doi.org/10.1016/j.envsci.2017.04.006

Toxopeus, H., Polzin, F. 2017. Characterizing nature-based solutions from a business model and financing perspective, Deliverable 1.3 Part V, Naturvation Project (www.naturvation.eu). Available from the authors.

UNASYLVA. 2018. Forests and Sustainable Cities.

Urge-Vorsatz, D., Rosenzweig, C., Dawson, R.J., Rodriguez, R.S., Bai, X., Barau, A.S., Seto, K.C., and Dhakal, S. 2018. Locking in positive climate responses in cities, Nature Climate Change, https://doi.org/10.1038/s41558-018-0100-6

van den Berg, A. E., J. Maas, R. A. Verheij, and P. P. Groenewegen. 2010. Green space as a buffer between stressful life events and health. Social Science and Medicine 70:1203.

van der Jagt, A. P. N., L. R. Szaraz, T. Delshammar, R. Cvejifá, A. Santos, J. Goodness, and A. Buijs. 2017. Cultivating nature-based solutions: the governance of communal urban gardens in the European Union. Environmental Research 159:264-275.

Voytenko, Y., McCormick, K., Evans, J., and Schliwa, G. 2016. Urban Living labs for sustainability and low carbon cities in Europe: towards a research agenda. Journal of Cleaner Production 123: 45-54.

Willis, K.J., Petrokofsky, G., 2017. The natural capital of city trees. Science 356, 6336: 374-376.

Wolch, J.R.; Byrne, J.; Newell, J.P. 2014. Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. Landscape and Urban Planning 125:234-244. 10.1016/j.landurbplan.2014.01.017:

World Bank. 2008. Biodiversity, Climate Change and Adaptation: Nature-Based Solutions from the World Bank Portfolio. The International Bank for Reconstruction and Development / The World Bank, Washington.

World Bank. 2017. Implementing Nature-based Flood Protection: Principles and implementation guidance. The World Bank, Washington.

van Wyk, E., Breen, C. and Freimund, W. 2014. Meanings and robustness: Propositions for enhancing benefit sharing in social-ecological systems. *International Journal of the Commons* 8(2):576–594.

Xiang, P., Wang, Y., and Deng, Q. 2017. Inclusive nature-based solutions for urban regeneration in a natural disaster vulnerability context: A case study of Chingqing, China. Sustainability 9:1205; doi:10.3390/su9071205

Zolch, T., L. Henze, P. Keilholz, and S. Pauleit. 2017. Regulating urban surface runoff through nature-based solutions - an assessment at the micro-scale. Environmental Research 157:135-144.

CAPTIONS OF PHOTOS AND BOXES

PHOTO 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 co-benefits 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. (Photo credit: Timon McPhearson).

PHOTO 2: PICTURED is 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 co-creation 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 co-created 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

UK and are an ideal model for co-management of nature-based solutions (Photo credit: Marcus Collier).

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 prioritise 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 NGOs and local experts and a small facilitating team, consisting of ICLEI and UFZ. Partners contributed data and deliberative insights to co-produce 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 co-learning 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)

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 which is 75 per cent 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 run-off. This justifies using public funds to incentivise greening privately owned space. The private benefits of improved amenity are recognised by requiring projects to be matched dollar for dollar with private funds. In this way, it leverages private finance to double the greening outcome.

SHORT BIOGRAPHICAL NOTES OF AUTHORS

Dr. Niki Frantzeskaki is Associate Professor on Sustainability Transitions and Transition Governance at the Dutch Research Institute For Transitions, Faculty of Social Sciences at Erasmus University Rotterdam. Niki has published close to 100 peer-reviewed articles and in 2017 and 2018 released three books on urban sustainability transitions. She has also edited 12 special issues in top-ranked journals about sustainability and sustainability transitions. She is coordinating research on environmental governance, and urban sustainability transitions by leading and being involved in a portfolio of research projects with research institutes across Europe. She is actively contributing as an author in CBO, GEO-5, GEO-6 and IPBES assessments.

Dr. Timon McPhearson is Associate Professor of Urban Ecology and Director of the Urban Systems Lab at The New School in New York City. He is Lead Author for the Intergovernmental Panel on Climate Change (IPCC), a Senior Research Fellow at The Cary Institute of Ecosystem Studies and Associate Research Fellow at Stockholm Resilience Centre, Stockholm University. He studies the ecology *in, of,* and *for* cities to advance resilience, sustainability, and justice. He co-leads the U.S. National Science Foundation "Urban Resilience to Extreme Weather Related Events" Sustainability Research Network (UREx SRN) in the US and Latin America, and teaches courses on urban resilience, urban social-ecological-technological systems, and nature-based solutions. His most recent co-edited book *Urban Planet* was published in 2018 by Cambridge University Press.

Dr. Marcus Collier specializes in social-ecological systems thinking and the environmental governance issues at the nature-culture interface. To this end he has carried out research in: land use and land-use change, resilience thinking and societal transitioning, collaborative management and planning, urban and rural governance, biodiversity impact, as well as novel landscapes and landscape elements. As an environmental consultant, prior to entering academia, he worked with communities and governmental agencies to co-devise and implement environmental projects through adaptive collaborative processes.

Dr Dave Kendal is a senior lecturer in environmental management, in the discipline of geography and spatial sciences within the school of technology, environments and design at the University of Tasmania. He is interested in researching and teaching human-plant (and wildlife) relationships in cities and beyond, particularly the drivers and effects of environmental management.

Dr. Harriet Bulkeley's research is concerned with environmental governance and focused on three key themes. First, theorizing and explaining the processes and practices of governing the environment. Her work in this area has focused on the politics of managing municipal waste in the UK and, through the EPSRC funded *Carbon, Control and Comfort* project and the ESRC-EPSRC InCluESEV research cluster is currently developing in the field of energy systems. Second, the urban politics of climate change and sustainability. Harriet has a long standing interest in research in this field and currently holds an ESRC Climate Change Leadership Fellowship, Urban Transitions: climate change, global cities and the transformation of socio-technical systems,

through which she is developing this work. The third area of Harriet's research interests lies in the political geographies of environmental governance, in particular emerging (transnational) political spaces on the boundaries of public/private authority through which climate change is being governed. Harriet leads the Leverhulme international network *Transnational Climate Governance* and through her Philip Leverhulme Prize is examining the politics of climate change emerging beyond the nation-state in the UK.

Dr. Adina Dumitru is a Senior Researcher at the University of A Coruna (Spain) and Director of a recently established Specialization Campus in Sustainability Research. Her current research focuses on the psychological determinants of sustainable lifestyles, their relationship to wellbeing and the development of indicators for the impact of nature-based solutions on social cohesion, empowerment and health. She has received a Doctorate in Psychology from the University of A Coruna, and MA in Political Science from Washington State University, as a junior Fulbright Scholar.

Dr Claire Walsh is a Lecturer in the Water Group in the School of Engineering. She joined the school in 1999 as a PhD student; her thesis, 'Simulation and analysis of river flow regimes: implications for sustainable management of Atlantic salmon (Salmo salar) under climate change' was funded by NERC and investigated how climate change may affect river flows in the River Eden, Cumbria, and in turn assessed how these projected changes would impact on Atlantic salmon habitat. Prior to this, Claire studied Geography, also at Newcastle University.

Ernita van Wyk assists ICLEI Africa's projects as an urban development expert. After a career start in Ecology and Conservation, Ernita developed an interest in issues of values, behaviours, ecosystem services (benefits), dialogue and legitimacy and in particular how these aspects interact to shape the trajectory of social-ecological systems. These ideas have been applied (research and practice) to restoration and the implementation of policy on invasive species. Ernita recently joined ICLEI as professional officer: urban development.

Dr. Camilo Ordonez is a researcher at Melbourne University in Australia. His research strives to understand the social and ecological dynamics of urban natural resources to create resilient cities, with a focus on urban forests. He studies how people relate to urban nature, understanding the role that urban nature plays in climate change adaptation, improving management and planning processes of urban nature, advancing green infrastructure technology (e.g. structural soil cells), and modelling socio-ecological systems in cities, with a focus on urban forests.

Dr Cathy Oke has over 20 years' experience in the sustainability sector. She has a PhD in molecular science. Cathy is the Knowledge Broker for the Clean Air and Urban Landscapes Hub (www.nespurban.edu.au), part of the National Environmental Science Programme, based in Earth Sciences University of Melbourne. Cathy is also an Associate at the Melbourne Sustainable Society Institute (MSSI). Prior to this Cathy was a research fellow at the Interdisciplinary Conservation Science Research Group within the Centre for Urban Research at

RMIT. For 8 years Cathy worked in environmental education and events with the Kids Teaching Kids program. Cathy has been a Councilor at the City of Melbourne since 2008. At ICLEI, Cathy is the chair of the Regional Executive Committee of ICLEI Oceania, a member of the Global Executive Committee and Biodiverse Cities portfolio holder. Cathy is also a founding board member of Tipping Point Australia.

Dr Laszlo Pinter has over two decades of experience working on sustainable development at the global scene. His main research interests include sustainable development governance and strategies, measuring and integrated reporting on progress, and integrated outlooks, scenarios and transition pathways, often focused on the natural resources sectors. He currently carries out research focused on the post-2015 development agenda and the sustainable development goals (SDGs), with emphasis on the mechanisms of goal selection, monitoring and review, and means of implementation. Dr Pinter co-established and co-chaired various sustainability-related initiatives, including the International Forum for Assessing Sustainability in Agriculture (INFASA), the Community Indicator System for Winnipeg (PEG), he helped initiate the Canadian Sustainability Indicators Network (CSIN), and lead the development of UNEP's Integrated Environmental Assessment training program for sub-global audiences. He played a key role in the establishment of the Bellagio Sustainability Assessment and Measurement Principles (BellagioSTAMP) by IISD and the OECD. He works worldwide and over his career collaborated with a wide range of major organizations such as the World Bank, the OECD, UNEP, UNDP, UNIDO, the Asia-Europe Foundation, various Directorates of the European Commission, the GEF, and the China Council, and also with many Canadian organizations including Agriculture

and Agri-Food Canada (AAFC), Environment Canada, the National Roundtable for the Environment and the Economy (NRTEE), the Canadian Index of Well-Being, CIDA, IDRC, provincial governments, various consulting firms and others.