PROJECT SUMMARY

Overview:

We propose an international network of networks that links researchers and practitioners working on the theory and application of nature-based solutions to urban problems characteristic of the Anthropocene. Urban resilience to extreme weather events, adapting to sea-level rise and heat waves in cities, the confluence of rapid urbanization with inadequate, aging, or non-existent infrastructure, and loss of ecosystem services as cities expand--all are challenges requiring transdisciplinary convergence that integrates nature-based solutions. Nature-based solutions are already a strong focus in European and US networks, but urgently needed in cities around the world, including in developing Global South cities. The urgent need in global cities provides a core rationale for a global network comprising existing worldwide networks focused on NATure-based solutions for Urban Resilience in the Anthropocene (NATURA). NATURA will synthesize knowledge, share best practices, understand where nature-based solutions are unique or can be more generally applied, and identify research gaps to further advance the field. Participating networks for NATURA include 26 funded networks of researchers and practitioners focused on Europe, South Africa, China, North and South America, and globally. Activities to be undertaken in NATURA include: 1) all-hands meetings of representatives of scholarly and practitioner networks to exchange knowledge and set thematic agendas for subsequent activities; 2) thematic working groups that will be initiated at all hands meetings and will meet virtually via regional nodes over a one- to two-year period; and 3) synthesis writing workshops hosted by network members and summarizing the outcomes of the workshop groups. Learning exchanges to advance peer learning and best-practice exchanges for implementation of research advances will feature: 1) short-term residencies (six or 15 weeks) at participating institutions for graduate students, postdocs, and junior scholars; 2) externships for scholars to be embedded in practitioner networks (six weeks); and 3) practitioner visits (six weeks) to research labs across the global network. NATURA is submitted as a full-implementation project.

Intellectual Merit:

NATURA will advance theory and research on nature-based solutions by exchanging knowledge and best practices across diverse global socio-cultural, ecological-biophysical, and technological-infrastructural contexts, and promote scientific synthesis on the potential for nature-based solutions to meet urban resilience challenges. NATURA will connect over 25 international networks converging on a global urban research agenda integrating intersectoral and interdisciplinary expertise, a number that is planned to grow. NATURA will create databases, foster collaborations, and produce syntheses of nature-based solutions. The United States, represented by existing Sustainability Research Networks (SRNs), the Long-Term Ecological Research (LTER) network, the Natural Capital Project, the Nature Conservancy North American Cities Network, and the Urban Sustainability Directors Network, will benefit from connections to international networks adopting similar approaches.

Broader Impacts:

Many of the networks in NATURA have practitioner members who are implementing nature-based solutions in their cities. Our collaborative activities include opportunities for students and other early-career scientists to work with practitioners in learning exchanges to be trained in inter- and trans-disciplinary research on resilience concepts and nature-based solutions. NATURA activities also prioritize opportunities for practitioners to embed within networks for short visits, which will integrate practitioners as research partners, enhance their access to and expertise from diverse contexts, and improve overall knowledge bases for planning and implementation on nature-based solutions in their home cities. NATURA will train postdoctoral scholars and graduate students through learning exchanges to networks around the globe. Through collaboration with our partners, international students will be invited to participate in these exchanges, hosted by US networks. In all, the activities proposed for NATURA will enhance connectivity among the world's urban scholars and practitioners and improve the prospects for global urban sustainability. The strong relationships with practitioners and researchers from global networks will be the basis for ensuring the successful long-term continuity of NATURA with our global partner, Future Earth Urban Knowledge Action Network, who have agreed--as part of their core mandate and ongoing funding--to become the institutional home for NATURA after AccelNet funding ends.

PROJECT DESCRIPTION

Network of Networks Theme

   The Anthropocene represents an age of compounded challenges of global urban growth and climate change that threaten the earth system's sustainability. Cities are the places where over half of humanity lives today; two out of every three people will live in urban areas by 2050 and perhaps more than 80% of the world population will be urban by the end of this century (UN 2018)—thus, the problem of sustainability, at least for the human population, will be solved (or not) in cities. Yet cities are especially vulnerable to extreme events like floods, drought, and heat because of their location and concentration of people and infrastructure. And this grand challenge only gets worse: extreme events are increasing in frequency and magnitude, cities in the Global North have failing, aging infrastructure and those in the Global South are growing at a pace that often outstrips social and financial capacity to build infra-structure. Urbanization and climate change are thus on a collision course, and cities need solutions that are affordable and effective in delivering services, including protection from extreme events, while at the same time providing additional synergistic benefits to well-being. Urban nature is a potential source of such solutions. **Nature-based solutions are increasingly being implemented in cities to improve urban resilience to complex challenges, yet there has been little synthesis across diverse contexts.**

   Here we propose to leverage the NSF-funded Urban Resilience to Extremes Sustainability Research Network (UREx SRN) and United States (US) partner networks, specifically in the area of nature-based solutions to resilience challenges in cities, joining 26 existing networks worldwide to accelerate discovery through increased speed of communication, knowledge generation, and synthesis. **We will create an international network of networks that links faculty, postdoctoral, and student researchers as well as practitioners who are working on the theory and application of <u>nature-based solutions for urban resilience in the Anthropocene (NATURA).</u>** The NATURA network of networks will explicitly address the call for integration among individual cities, regions, and global urban agglomerations to advance a *CONVERGENCE* <u>urban research agenda</u> (ACERE 2018); NATURA will feature <u>intersectoral and interdisciplinary integration</u> (*NSF CONVERGENCE*); and NATURA will contribute to <u>broadening participation by integrating practitioners as full research partners and exploring alternative career pathways with practitioners</u> (*NSF INCLUDES*).

   Our NATURA distributed network of networks is large at the outset, but we will seek to strategically increase access and opportunities for additional related networks to join NATURA. We will also create a <u>longer-term sustainable model of NATURA</u> for continuation beyond the funding period, in particular working with our global institutional partner Future Earth, which has a mandate and funding to support global networks of networks. While the nascent NATURA may be minimally connected, through network-wide <u>communication</u>, <u>data sharing</u>, <u>regional organization</u>, <u>thematic working groups</u>, and <u>network</u>
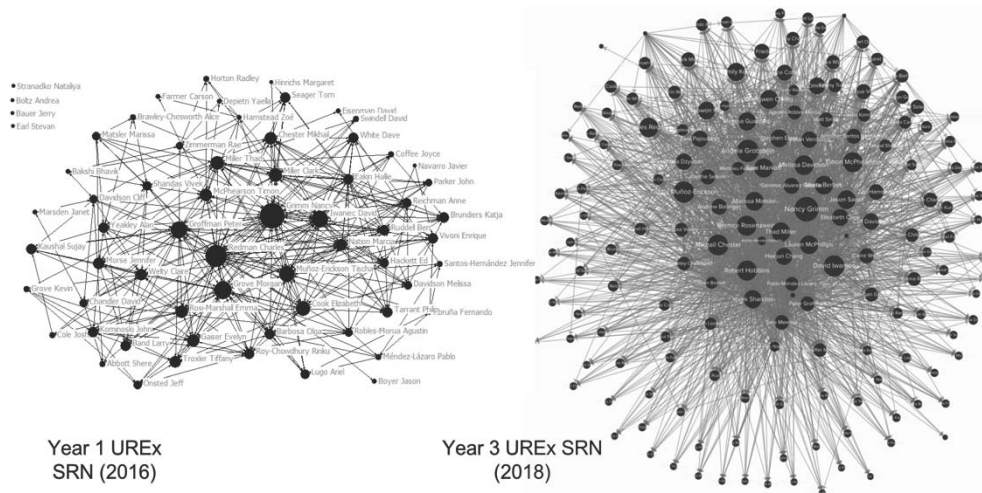
Figure 1. Changes in network structure of the UREx SRN as it has developed over three years.

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learning exchanges, we will increase connectedness and decrease centrality, contributing to a multiplier effect for professional capacity of our US-based networks, practitioners, and researchers. Over its three-and-a-half-year existence, the UREx SRN has become proficient at fostering productive, collaborative interactions between researchers at ~20 institutions in ten cities and three countries (US, México, and Chile). The evolution of the network (**Fig. 1**) shows increases between Year 1 and 3 in number of nodes, decreases in the centrality of individuals, and a dramatic increase in connections. This illustrates the power of our methods to establish and nurture a collaborative research network with strong communication and interaction among social, ecological, and engineering researchers working on urban resilience to extreme events. We will apply the UREx SRN approach to the challenge of integrating worldwide networks toward a common goal of advancing understanding and application of nature-based solutions. We assert that our approach will dramatically increase communication, idea and data sharing, and synthesis toward a transformation in how we use urban nature to build resilience.

Vision and Goals

NATURA will link knowledge globally across existing local, regional, and international networks focusing in whole or in part on nature-based solutions and resilience in urban systems. NATURA will develop shared understanding of nature-based solutions, train new researchers, share best practices, and fill research gaps for leveraging the role of urban nature in meeting urban challenges of the Anthropocene. **Our underlined vision for NATURA is a network of regional, national, and international networks that features transdisciplinary exchange of ideas and data among scholars and practitioners to explore and implement nature-based solutions, in order to build resilience of complex urban social-ecological-technological systems to increasingly severe challenges of the Anthropocene.** The integration of knowledge on nature-based solutions for improving resilience through the NATURA network is essential to improve the chances for thrivability and sustainability of the world's urban communities. NATURA has five goals:

1) Create a network of networks that **shares knowledge and best practices** about nature-based solutions in diverse socio-cultural, ecological-biophysical, and technological-infrastructural contexts across the research–practice divide;
2) Share ideas and data on research and implementation in multiple contexts to **generate and disseminate synthesis of state-of-the-science knowledge** about the role of nature-based solutions in social, ecological, and technological strategies for urban resilience challenges;
3) Establish and maintain lines of **communication among research and practitioners** in global networks to propel improvements in professional capacity and cross-sectoral collaboration;
4) Increase the **capacity of the next generation of urban scholars to conduct and communicate interdisciplinary research** on resilience concepts and nature-based solutions, and **to integrate this work into transdisciplinary planning and implementation** of nature-based solutions;
5) Provide a mechanism for **practitioners to learn about interdisciplinary research** on nature-based solutions that is more locally relevant to the decisions they make in their cities.

Why the NATURA Network of Networks?

Many of our greatest environmental and social challenges, including climate change, public health, and resource availability, will be determined by the past and future form, pattern, and function of urban environments (Seto et al. 2017)—requiring massive financial investments. An estimated US$50-60 trillion will be invested globally in new urban infrastructure by the year 2030, with an additional US$2.4 trillion per year needed to implement the UN Sustainable Development Goals (CCFLA 2015; Schmidt-Traub 2015). With rapid urbanization and growing needs for infrastructure, urban development in the next decade will have cascading implications for future social-ecological systems, further compounded by changing climate and extreme events. This is reflected in the inclusion of "Sustainable Cities and Communities" as one of the 17 global United Nations Sustainable Development Goals for 2030. Moreover, given the concentration of people and infrastructure in cities, progress on the remaining sixteen goals depends in large part on achieving the urban goal. And the urban goal is linked to building

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resilience, so that cities can persist, grow, and transform while maintaining their character and function in the face of stresses and shocks (Carpenter et al. 2001, Schlüter & Pahl-Wostl 2007, Folke et al. 2010).

With the complex sustainability challenges facing urban areas, city leaders need creative solutions that are cost-effective and deliver multiple benefits. A growing number of cities are exploring nature-based solutions, sometimes referred to as green infrastructure or ecosystem-based adaptations, that aim to promote public health and safety, enhance livability, and restore natural hydrologic and ecological processes (Nesshöver et al. 2017; Depietri and McPhearson 2017; Kabisch et al. 2017). At the same time, resilience has been widely adopted by both academic and practice communities as a means for envisioning urban transformation and dealing with the uncertainty of future climate conditions (Moser et al. 2019). However, the efficacy of specific nature-based solutions to address urban sustainable development and resilience across and within diverse world cities is relatively unknown (Cortinovis and Geneletti 2018). Although cities are already investing heavily in nature-based solutions, the relationship between these solutions and resilience is also largely unknown. Given limited resources and the heterogeneity of urban contexts and challenges, more work is needed to understand (a) how different cities should invest in nature-based solutions, (b) what benefits to expect, and (c) how nature-based solutions can effectively be scaled up in diverse contexts to improve local and global climate resilience.

Urban nature has the potential to improve air and water quality, mitigate flooding, enhance physical and mental health, and promote social and cultural well-being. These benefits are often described as urban ecosystem services; the benefits humans derive from urban nature (Gomez-Baggethun et al. 2013; Elmqvist et al. 2013). Nature-based solutions are a subset of urban ecosystem services (Kabisch et al. 2017, Grimm and Schindler 2018), and primarily encompass "regulating" services, such as urban cooling, stormwater absorption, coastal flood protection, water purification, air pollution absorption. The concept of nature-based solutions has expanded in both research and practice for investing in urban nature as a source of solutions for climate change adaptation and resilience, water and food security, and energy use reduction (Kabisch et al. 2017). Individual cities are investing heavily in nature-based solutions; for example, New York City has a US$1 billion fund for green infrastructure as a stormwater solution (NYC 2010). However, despite significant investments in green infrastructure, evidence for where nature-based solutions are most effective, for what challenges, in what contexts, and under what conditions is difficult to find. The results are typically buried in specialty literature or as part of industry best practices, which presents a challenge to both researchers and practitioners seeking to expand knowledge and investments in nature-based solutions for urban resilience. Research and investments in nature-based solutions are expanding rapidly in Europe. Yet, in the US, the pace of adoption and research on nature-based solutions is slower, emphasizing the need to connect EU and US networks more closely, as well as to learn from and share with other urban research and practice networks in Latin America, Asia and the Pacific, and Africa (all regions included in the NATURA network of networks).

NATURA will fill identified research gaps on nature-based solutions highlighted in a recent *Nature Sustainability* review of over 600 papers (Keeler et al. 2019; **NATURA Goal 2**). Keeler and colleagues (2019) concluded that the value and efficacy of urban ecosystem services remain highly uncertain, especially across the diverse social, ecological, and technological contexts represented among cities around the world. Current research on nature-based solutions and their impacts in cities is largely informed by urban ecology, urban forestry, and environmental engineering (Keeler et al. 2019) with more recent attention to the potential economic value of urban nature through urban ecosystem services (Bolund & Hunhammar 1999, Gómez-Baggethun & Barton 2013). By emphasizing linkages between urban nature and human well-being, the ecosystem services approach offers considerable promise for understanding where and when nature-based solutions will deliver a suite of services. However, there are limitations to the existing body of research. **We have identified five key limitations that provide a basis for why a NATURA network of networks is needed. NATURA will expand and bring together knowledge embedded in diverse and disconnected local, regional, and global networks to address key knowledge gaps and inspire research-practice on nature-based services for urban resilience (NATURA Goals 1–3).**

Background: Five key knowledge gaps on nature-based solutions for urban resilience

1. Key knowledge gaps remain in our understanding of nature-based solutions and their capacity to promote climate resilience. *First, it is not well understood how synergistic benefits provided by nature-based solutions interact to affect the efficacy and value of nature-based solutions.* It is assumed that urban nature and nature-based solutions provide multiple benefits through ecosystem service "bundles," especially in comparison to engineered infrastructure (Raudsepp-Hearne et al. 2010, Andersson et al. 2015). Yet, understanding the interaction of ecosystem service bundles—their synergistic benefits or potential unintended consequences—is essential in determining the value and rationale for investing in nature-based solutions over gray, engineered infrastructure in distinct contexts. Most scientific studies focus on a limited set of nature-based solutions and one or two urban ecosystem services assessments. With notable exceptions (Gómez-Baggethun & Barton 2013, Raymond et al. 2017, Kabisch et al. 2015), few studies investigated co-benefits or tradeoffs among services. Not accounting for a comprehensive suite of urban ecosystem services, particularly unintended consequences that may differentially affect vulnerable populations in urban areas, risks undervaluing or overestimating benefits and may suggest interventions that put people or property at risk (Ruckelshaus et al. 2016).

Worldwide, numerous projects and networks focus on nature-based solutions research (**Fig. 2** [p 7]). By integrating and sharing knowledge and expertise, these networks have the potential to address core questions about how the interacting benefits affect efficacy and value of nature-based solutions in multiple contexts and spatial and temporal scales. **NATURA will offer an opportunity to examine— across the network of networks—how ecosystem services bundles can be leveraged in planning, management, and for creating policy to advance nature-based solutions for urban resilience.**

2. *Second, there is limited understanding of how and when social factors, which vary both within and among cities, moderate exposure, access, and value of nature-based solutions.* Social and cultural norms, income and demographics, governance, financial capacity, and community buy-in are the dominant social moderators that influence cities' ability to fund, implement, and maintain nature-based solutions (Lawrence et al. 2013, Matthews et al. 2015, Keeler et al. 2019). Yet, the nuances of these social moderators are not contextualized nor understood sufficiently to maximize benefits and ensure proper implementation. For example, less-developed urban areas may have fewer financial resources, and nature-based solutions with typically lower implementation costs than traditional gray infrastructure may be more appealing (Royal Society 2014). However, maximizing the benefits will depend not only on implementation, but also the community's capacity for upkeep and maintenance, which may further burden lower-income communities and result in tradeoffs rather than net gains.

Nature-based solutions also have the potential to provide additional benefits across communities with multiple needs. Demographic and income characteristics affect vulnerability to risk. The distribution of benefits and access to nature-based solutions is particularly important for susceptible, high-risk populations restricted in their ability to relocate, evacuate, or cope with stress from heat waves, floods, or pollution (Cutter et al. 2003, O'Neill et al. 2005). Recent research highlights differential health benefits for disadvantaged communities with access to nature (Mitchell & Popham 2008). However, the extent to which the benefits of nature-based solutions are dependent on other factors like cultural norms requires a stronger synthesis of case studies across diverse cities. **NATURA will synthesize the value and benefits of urban nature across global social contexts and share best practices for research, practice, and implementation of nature-based solutions to improve community and urban resilience.**

3. Of the numerous ecological factors that influence the value of urban nature, vegetation structure and function, topography and landscape position, and geologic and soil characteristics are the most frequently documented biophysical moderators (Keeler et al. 2019). However, *there are few generalizations of how ecological-biophysical context affects the efficacy and impact of nature-based solutions in addressing urban resilience.* By understanding the impact of structure and form of urban vegetation and green infrastructure, the resilience-building benefits of nature-based solutions can be maximized through urban heat mitigation, carbon sequestration, coastal protection, and flood mitigation. For example, canopy density, productivity, and rates of evapotranspiration enhance the effect of tree cover on shade provision, urban heat mitigation, and urban energy consumption (McPherson & Kendall

2014; Hamstead et al., 2016). The traits of different species, such as leaf area, stomatal potential, or rooting depth may influence other services like modulation of overland flow and stormwater nutrients (Berland et al. 2017) or infiltration of stormwater runoff. While much is known about individual species or habitats from key case studies, it is not clear if varying (and sometimes synergistic) benefits based on species and habitat characteristics can be generalized across diverse biophysical contexts.

Likewise, the potential for implementing nature-based solutions is highly dependent on available physical space, configuration, and landscape position of green infrastructure. For example, protecting coasts against storm surge and treating stormwater with green infrastructure (e.g., via coastal wetlands and bioswales, respectively) requires more available space than comparable gray approaches (Narayan et al. 2016; Koch et al. 2009), but space constraints vary with surrounding city infrastructure and environmental hazards. Coastal habitats are more effective at stabilizing shorelines when located along sheltered coasts subject to lower-intensity hazards (NRC 2007) while wetlands and floodplains located downstream of major sources of runoff and with less compact soils are most effective at modulating high flows. Despite case studies that point to key characteristics, we do not have sufficient evidence to predict how these characteristics and physical space requirements of nature-based solutions will impact urban resilience. **With integration of researcher and practitioner knowledge and case studies from the NATURA network, we will gain a stronger synthetic understanding of best approaches for scaling up investments in nature-based solutions to maximize efficacy and impact on urban resilience.**

4. The ability of nature to provide services in cities also depends on technological, engineered (gray) infrastructure (McPhearson et al. 2016; Ramaswami et al. 2012). Patterns of urban development and existing infrastructure, such as stormwater and sanitary sewers, modify the supply, demand, and value of key services that can also be provided by green infrastructure. Despite two decades of research on urban ecosystem services (Haase et al. 2014), *we still know little about how historic and current gray, engineered infrastructure modifies the impact, as well as supply, demand, and value of current nature-based strategies*. The extent, quality, and type of infrastructure moderates the value and demand of nature-based solutions. For example, the existence of flood-control infrastructure such as levees or bank armoring can reduce the demand or value of flood-damage mitigation services provided by urban nature. Specific types of infrastructure within or connected to urban nature also affect how these spaces are used and valued. Built infrastructure can improve access to urban green and blue spaces—for example via walking paths—but it may also impede access to recreation opportunities, limit connectivity or, if improperly maintained, serve as a deterrent to park use (Cohen et al. 2017, Kondolf et al. 2017). Thus, the effectiveness of nature-based solutions is likely to be maximized under specific infrastructure conditions, but what these specific conditions are remains to be compared and synthesized across different urban contexts. For example, during extreme rain events, cities with combined sewer infrastructure have greater risk of sewage overflows into streets and receiving urban waterways. In these cities, combinations of bioswales, street trees, and rain gardens can intercept, evaporate and infiltrate stormwater before it reaches sewer systems (Walsh et al. 2016). Yet the precise combination and configuration of green and gray infrastructure to maximize benefits and meet demands in different cities is unknown. Both older cities with aging infrastructure and rapidly urbanizing areas may see the greatest benefits from urban nature, relative to cities where heavy investments in infrastructure upgrades have been previously made (Nagendra et al. 2018). Indeed, past infrastructure investments may create path dependencies that ultimately limit the physical space available for green infrastructure or reduce demand for the services provided by natural infrastructure. **Synthesis of case studies by researchers and practitioners will improve understanding and application across diverse gray-green infrastructure configurations and be a key outcome of network exchange in NATURA that will influence what planners, designers, and managers can expect from implemented nature-based solutions for resilience.**

5. Nature-based solutions are increasingly considered an alternative to traditional gray, engineered infrastructure and a core "tool in the toolkit" for improving well-being and resilience in the face of pressing and rising urban challenges. The value of nature-based solutions is not only affected by social (S), ecological (E), and technological (T) contexts, but by the interactions among SET contexts. Yet, *we still know very little about how interacting SET contexts affect individual and bundled benefits from*
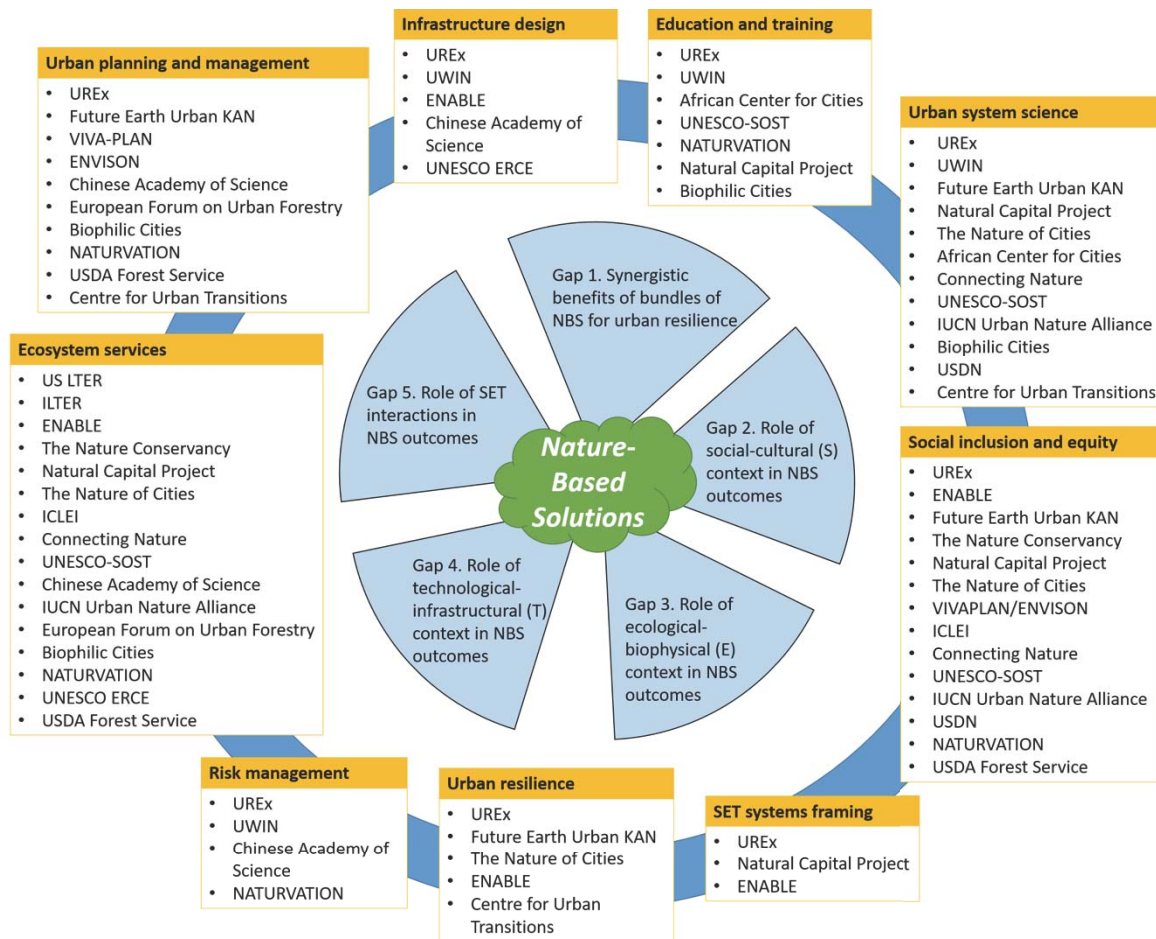
nature-based solutions. Interactions among social, ecological, and technological factors in diverse world cities affect the subsequent value of urban ecosystem services. For example, trees can shade buildings reducing the need for mechanized cooling which, in turn, may indirectly improve air quality by decreasing emissions from energy production. Putting nature on a level playing field with other interventions to advance resilience to a growing and intensifying set of urban threats requires comparative information that allows decision-makers to juxtapose costs and effectiveness of different urban development pathways. This comparison must incorporate sufficient information to consider potential co-benefits and disservices to human well-being at different scales (Wachsmuth et al. 2016). Likewise, recommendations need to be flexible in their relevance to individual cities and even neighborhoods within cities. Decision makers may not need detailed cost–benefit assessments for all alternatives, but it is important to build a knowledge base that illuminates which approaches are most likely to succeed under certain conditions and when nature can be an effective solution to urban sustainability challenges (Pincetl et al. 2013). As the local, case study-driven evidence base of nature-based solutions grows through research and practice, **NATURA will promote sharing knowledge between often-disconnected researchers in very different regions and urban contexts (as well as between research and practitioners), training a new generation of researchers, and identifying core knowledge gaps that are critical to scaling up nature-based solutions in ways that can offer real advances for building resilience in complex S-E-T urban environments.**

NATURA's Transdisciplinary, global approach

As this review of knowledge and gaps makes clear, the challenge of understanding and building urban resilience to the shocks and stresses associated with climate and other global changes through integration of nature-based, social, and technical solutions is one that requires diverse knowledge, experience, and perspectives (**Fig. 2**). Furthermore, across the world's cities, there is an uneven distribution of economic, social, and natural capital, meaning that knowledge and action must be place-sensitive. Concepts that contribute to our collective network vision include ecosystem services, resilience, risk management, infrastructure design (including safe-to-fail), social-ecological-technological systems (SETS) framing, and of course, nature-based solutions. These concepts arise from disciplines of ecology, urban system science, engineering, physical science, social science, and urban planning and from sectors including city planning, management, finance, and engineering. Because ecosystem services are at the core of nature-based solutions, most participating networks work with this concept, but many also work on issues of social inclusion and equity and several networks bring expertise on infrastructure design and risk management (**Fig. 2**). Thus, the suite of concepts covers a range of social, ecological, and technological perspectives and is relevant to newly emerging framings of cities as SETS (Grimm et al. 2016, McPhearson et al. 2016, Depietri & McPhearson 2017, Grimm & Schindler 2018).

Research in the UREx SRN has ranged from projection of future climate extremes, to developing the SETS concept, to working with practitioners to envision positive futures for cities. Working closely with practitioners is an important element of UREx that will be highlighted in NATURA, an approach that is similarly embraced by a number of our network partners, especially those like the Nature Conservancy's North American Cities Network that represent boundary organizations between city and officials and academics (**NATURA Goal 3**). This transdisciplinary work is the best way to ensure that research to be synthesized is relevant and used in implementing resilience strategies that are so urgently needed (**NATURA Goal 5**).

The ability to compare and synthesize research, strategies, data, and challenges is critical for building knowledge both within and across networks. The NATURA global network of networks will identify areas of important and novel research and establish mechanisms for substantive collaborations involving US and foreign stakeholders on nature-based solutions (**NATURA Goals 1 and 2**). The potential for the linkages among networks to catalyze novel research and collaborations and lead to new knowledge is enormous because a shared vision, expressed simply as "imagine a city that is a part of nature not apart from nature" (The Nature Conservancy Cities Network), unites the multiple threads of research (**Fig. 2**) and is similar to other overarching goals: "understanding ecosystems and providing the prerequisites for

Infrastructure design
- UREx
- UWIN
- ENABLE
- Chinese Academy of Science
- UNESCO ERCE

Education and training
- UREx
- UWIN
- African Center for Cities
- UNESCO-SOST
- NATURVATION
- Natural Capital Project
- Biophilic Cities

Urban planning and management
- UREx
- Future Earth Urban KAN
- VIVA-PLAN
- ENVISON
- Chinese Academy of Science
- European Forum on Urban Forestry
- Biophilic Cities
- NATURVATION
- USDA Forest Service
- Centre for Urban Transitions

Urban system science
- UREx
- UWIN
- Future Earth Urban KAN
- Natural Capital Project
- The Nature of Cities
- African Center for Cities
- Connecting Nature
- UNESCO-SOST
- IUCN Urban Nature Alliance
- Biophilic Cities
- USDN
- Centre for Urban Transitions

Ecosystem services
- US LTER
- ILTER
- ENABLE
- The Nature Conservancy
- Natural Capital Project
- The Nature of Cities
- ICLEI
- Connecting Nature
- UNESCO-SOST
- Chinese Academy of Science
- IUCN Urban Nature Alliance
- European Forum on Urban Forestry
- Biophilic Cities
- NATURVATION
- UNESCO ERCE
- USDA Forest Service

Social inclusion and equity
- UREx
- ENABLE
- Future Earth Urban KAN
- The Nature Conservancy
- Natural Capital Project
- The Nature of Cities
- VIVAPLAN/ENVISON
- ICLEI
- Connecting Nature
- UNESCO-SOST
- IUCN Urban Nature Alliance
- USDN
- NATURVATION
- USDA Forest Service

Nature-Based Solutions

Gap 1. Synergistic benefits of bundles of NBS for urban resilience

Gap 2. Role of social-cultural (S) context in NBS outcomes

Gap 3. Role of ecological-biophysical (E) context in NBS outcomes

Gap 4. Role of technological-infrastructural (T) context in NBS outcomes

Gap 5. Role of SET interactions in NBS outcomes

Risk management
- UREx
- UWIN
- Chinese Academy of Science
- NATURVATION

Urban resilience
- UREx
- Future Earth Urban KAN
- The Nature of Cities
- ENABLE
- Centre for Urban Transitions

SET systems framing
- UREx
- Natural Capital Project
- ENABLE

Figure 2. The five key gaps in current knowledge-practice on nature-based solutions and the diverse expertise and concepts/ areas of study the NATURA network of networks will bring to address these gaps. NATURA network partners are listed in white boxes. Acronyms defined in Table 2.

knowledge-based solutions" (ILTER), "building knowledge and tools to accelerated real-world transitions towards cities that are sustainable and livable" (Future Earth Urban KAN), "improving the well-being of all people and nature by motivating greater and more targeted natural capital investments" (Natural Capital Project), "realizing the potential of nature-based solutions for responding to urban sustainability challenges by working with communities and stakeholders" (NATURVATION), and "promoting the transition to cities of the future that are resilient by virtue of their flexible, adaptable, socially equitable, and ecologically based infrastructure in the face of a higher incidence of extreme events" (UREx). And because the earth is a heterogeneous place—in terms of its people, its ecosystems, and its level of technological development—we need to synthesize our knowledge about nature-based solutions by going way beyond the boundaries of a single nation, even one as biophysically and culturally diverse as the US.

Network Activities

 NATURA includes 26 networks within and across five global regions (see *Facilities* for regions). A proliferation of networks in Europe signals the embrace of nature-based solutions in research, policy, and management in that region, whereas African and Latin American networks are relatively sparse. Each region will have a regional node leader and representatives of the regional networks will meet quarterly.

 We propose *collaborative and educational activities* that involve virtual and in-person interactions (**Table 1**). For virtual meetings, we have successfully used Zoom software for more than two years in delivering webinars, holding sometimes large (>75 people) meetings from international locations, conducting meetings with virtual break out rooms, and holding routine coordination meetings for the

UREx SRN and Intergovernmental Panel on Climate Change (urban chapter). Our collaborative activities will kick off with a <u>virtual All-Hands Meeting</u> upon inception of the project and an <u>in-person All-Hands Meeting</u> midway through Year 1, to which all participating networks will be invited. The virtual meeting will provide a chance for all the networks to revisit the common visions and goals identified in preparing this proposal, to establish the regional nodes, and to learn about (and adjust, if needed!) the proposed structure of NATURA. For the in-person All Hands Meeting, attendance will be sponsored by NATURA for at least one representative from each network. Information about research and practice activities within the networks, regional nodes, and developing progress in NATURA over the first four to six months will be presented at the in-person All Hands Meeting. Small workshops initially centered on the five research gaps we have identified in this proposal will be organized, but with ample opportunity for new ideas to bubble up from attendees. This first All Hands Meeting will be an important jumping-off point for working groups to emerge on specific themes, which can form into <u>thematic nodes</u>. Subsequent All-Hands Meetings, both virtual (every year) and in-person (Years 3 and 5) will expand upon this model by incorporating outcomes and progress from smaller-group activities, described below.

Table 1. Collaborative and educational activities of the NATURA program.			
Activity	**Participants**	**Type**	**Timeline**
Collaborative activities			
Regional node meetings	One rep per network per node	Virtual, or at AHM	Quarterly
All Hands Meetings	All networks	Virtual	All years
All Hands Meetings	At least one rep per network; all networks	In person	Y 1, 3, 5
Thematic node/working group meetings	Grass roots	Virtual	Y 2–5
Thematic workshops	Determined by prospectus	Up to two in-person	Y 2–5
Faculty and practitioner network exchanges	Open to all, by proposal	In person, 6-week visits	Y 2–5
NATURA AccelNet database	All networks	Database product	Y 1–5
Webinars, newsletters	NATURA Coordinating Committee, Future Earth Urban KAN	Communications	Y 1–5
Student and early-career activities			
Student and postdoctoral network learning exchanges	Open to all, by proposal	In person, 6- or 15-week visits	Y 2–5
Graduate seminar	Open to all	Virtual	Weekly, Y 2, 4
Student reading group	Open to all	Virtual	Weekly, Y 1–4
Student research	Open to all, by proposal	Small awards for research	Annually, Y 2–5

As a result of the first All Hands Meeting, we expect several thematic nodes to emerge, which will form into <u>thematic working groups</u>. Leadership of these thematic groups will be determined when the group forms; there may be more than one working group taking on a particular theme. For example, knowledge gap #4 about efficacy of hybrid gray-green infrastructure that includes built elements and nature-based elements may be addressed by a single thematic node, but several thematic working groups may form for example around hybrid infrastructure for heat or flooding, or around biophysical (e.g., coastal or inland arid cities) or cultural (e.g., Asian or Latin American) contexts. We will facilitate meetings of thematic nodes or working groups (virtual) and invite applications to hold <u>thematic in-person workshops,</u> which will be five-day, eight-person events that must result in a synthesis product. This structure calls upon participants to work within their groups/networks to bring data and knowledge to the table in support of a broader synthesis. Outputs will include scientific publication but may also be policy briefs and other high-level summaries useful to practitioners in the networks.

A centerpiece of NATURA collaborative activities will be <u>network exchanges</u> for faculty (emphasizing early-career faculty) and practitioners. Nearly all of our networks have indicated a willingness to host a visiting faculty member or practitioner for a six-week visit, during which the visitor

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will develop a better understanding of the research objectives and practices of their host network that they can bring home to their own network or organization. Some networks have already offered reciprocal funding to support exchanges for individuals from their home networks and institutions to study and train at US institutions. NATURA will seek to leverage funding for network exchanges from existing funded projects and networks, while providing core funding to support US students, faculty, and practitioners at other participating network institutions. We do not anticipate that these visits will be research-based, but will encourage synthesis activity, such as a paper or comparative analysis of existing data and knowledge, between the networks undertaking the exchange. Further, we believe NATURA will provide a unique opportunity for practitioners that is not otherwise available: to spend time with a research group focused specifically on nature-based solutions that they may be trying to implement in their own cities.

NATURA will develop and execute through an online platform the NATURA AccelNet Database for coordinating information exchange and to build the NATURA data and informatics basis for cross-city and case-specific comparisons and synthesis research. The database will be a key tool for individuals and groups of researchers in the networks to contribute to, and draw from, case studies for synthetic and interdisciplinary research to fill identified research gaps. The NATURA AccelNet Database will be built from existing databases within initial networks, including from UREx, UWIN, The Natural Capital Project, The Nature Conservancy, NATURVATION, ENVISION, The Nature of Cities, BES and CAP LTER, IUCN and ICLEI. However, we will also seek to expand the database by incorporating data shared from specific network projects, as well as data contributed through thematic workshops, All Hands Meetings data jams, and new networks who may join NATURA in subsequent years. We expect the database will be an important product of research synthesis but also a focal point for engaging practitioners with research outputs. The Urban Systems Lab at The New School is known for strong data science and data visualization and will work with ASU to leverage and build on existing eRAMs platform used in the UREx and UWIN sustainability research networks.

Webinars and newsletters will be important ways to communicate across the networks. Our global partner Future Earth Urban KAN will take the lead in developing NATURA webinars and newsletters, as part of a broader communication strategy.

Educational activities centered on students and postdoctoral scholars (Table 1) will prominently feature network learning exchanges. Students and postdocs will be invited to apply for 6- or 15-week stays in NATURA networks. We expect the longer stays to involve some research and/or implementation activity in addition to the training provided. All exchanges, funded by competitive bi-yearly NATURA travel grants (and stipends for students), may be proposed by students, postdocs, or junior scholars, or may be initiated by a practitioner, institution, or senior scholar interested in hosting. Additional planned educational activities are described in the *Student and Early-Career Development Plan.*

We have described here the collaborative and educational activities that this AccelNet grant will support, but our international partner networks will also participate in network exchanges and network learning exchanges by sending their faculty, students, postdocs, and practitioners to us. Because all of our founding networks are funded (see *Facilities*), we look forward to fruitful exchanges of scholars, practitioners, ideas, and information for many years to come.

International Collaborations and Contributions

There are 26 founding networks in the NATURA networks of networks (**Table 2**) and we will seek to deepen connections with all founding networks, as well as expand networks in each of the global regions, to strategically increase the number networks, participating individuals, and institutions over time. Founding networks span five global regions including North America, Latin America (Caribbean, México, Central and South America), Europe, Africa, and Asia and Pacific regions. These 26 initial networks include some if not most of the leading networks in the world working at the intersection of resilience and nature-based solutions in urban contexts.

Our European networks are already well situated, with strong membership, a diverse and scientifically strong set of institutions, and excellent and continuing funding (in most cases through the European Commission Horizon 2020 program). These networks have already developed tools, databases,

and case study-driven local research projects that will be leveraged for mutual benefit in NATURA. **Table 2** details the key attributes of all NATURA founding networks. Our US networks are similarly robust, with strong representation from the NSF-funded US LTER network (especially the urban Baltimore Ecosystem Study and Central Arizona–Phoenix sites) and UREx (which spans North American and Latin American cities) and UWIN SRNs; The Nature Conservancy, which acts as a practitioner-researcher boundary organization with its North American Cities Network; and strong local nodes of global networks, including The Natural Capital Project based at Stanford University, The Nature of Cities homed in New York City, and the Biophilic Cities network based out of the University of Virginia. All US networks are currently funded and all are formal networks, in some cases with vast networks of their own. The Nature of Cities, though less formalized than the LTER networks, is nonetheless one of the global central hubs for connecting researchers and practitioners working on nature-based solutions, boasting 650 active participants from 27 countries and six continents the Global North and South. IUCN's

Table 2. Founding network characteristics, resources, and planned participation in NATURA

LEGEND — Individuals: ~100, ~100-500, >500. Institutions: ~10, ~10-50, >50.

REGION — Africa; Asia – Pacific; Europe; North America; Latin America; Global.

#	Network title	# individuals	# institutions	Major research resources	Database	Education & training program	Participating in All Hands Meetings?	Hosting thematic workshops?	Hosting US students /postdocs?	Hosting faculty /practitioners?	Supporting your scholars to visit US?
1	African Center for Cities	●	●	Interdisciplinary research and teaching program	√	√	√	√	√	√	√
2	Biophilic Cities	●	●	Collaborative research, dialogue and exchange, and teaching	√	√	√	√	√	√	√
3	Centre for Urban Transitions	●	●		√	√	√	√	√	√	
4	Chinese Academy of Sciences	●	●	Research projects on implementing nature-based solutions, e.g., sponge city project	√	√	√	√	√	√	√
5	Connecting Nature	●	●	Peer to peer learning and capacity building among cities	√		√	√	√	√	√
6	East Asia-Pacific Long-term Ecological Research (LTER)	●	●	Ecological site based long-term research and large-scale experiments			√				
7	ENABLE	●	●	Design and implementation of green infrastructure via case study			√	√	√	√	√
8	ENVISION	●	●	Participatory scenario modeling and protected area management			√	√	√	√	√
9	European Forum on Urban Forestry	●	●	Knowledge sharing via annual forum			√	√	√	√	√
10	European LTER	●	●	Ecological site based long-term research and large-scale experiments			√	√	√	√	√
11	Future Earth Urban Knowledge Action Network (KAN)	●	●	Knowledge sharing via research network			√	√	√	√	√
12	ICLEI: Local Governments for Sustainability	●	●	Knowledge sharing via network of local government professionals			√				
13	International LTER (ILTER)	●	●	Ecological site based long-term research and large-scale experiments	√		√	√	√	√	√
14	IUCN Urban Nature Alliance	●	●	Knowledge sharing and natural resources index development	√		√				
15	Natural Capital Project	●	●	Natural resources assessment tool and decision support software development	√	√	√				
16	NATURVATION	●	●	Nature-based solutions value assessment, business model development and citizen engagement	√	√	√				
17	Recycling the City Network (RECNET)	●	●	Participatory community development			√			√	
18	The Nature Conservancy North American Cities Program	●	●	Evidence-based science research projects on natural resources conservation	√	√	√				
19	The Nature of Cities	●	●	Knowledge sharing via city network			√	√			
20	UNESCO Chair on Sustainability (UNESCO-SOST)	●	●	Knowledge sharing via city network and education program			√	√	√	√	√
21	UNESCO European Regional Centre for Ecohydrology (ERCE)	●	●	Research projects on ecohydrology and knowledge sharing via network			√	√	√	√	√
22	Urban Resilience to Extremes Sustainability Research Network (UREx)	●	●	Urban resilience research network	√		√	√	√	√	√
23	Urban Sustainability Directors Network (UCDN)	●	●	Knowledge sharing via network of local government professionals		√	√				
24	Urban Water Innovation Network (UWIN)	●	●	Urban water systems integration modeling	√	√	√				
25	US LTER	●	●	Ecological site based long-term research and large-scale experiments	√		√	√	√	√	√
26	VIVA-PLAN	●	●	Spatial planning and citizen engagement	√		√	√	√	√	√

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Urban Nature Alliance is based in Brussels, is relatively new and being piloted in five European cities, but has a global network base of 1,300 member organizations and the input of some 13,000 experts. Similarly, ICLEI's focus is well aligned with NATURA, exemplified by the central focus on nature-based solutions and urban resilience at its 2018 World Congress in Montreal. NATURA proposed to connect with the Brussels office of ICLEI, the center for ICLEI's European activities. Based on internal planning after the initial All-Hands Meeting, ICLEI will decide which of its global networks will participate.

Our Latin American node encompasses networks in the Caribbean, México, and Central and South America and features numerous projects under the UNESCO-SOST (Chair on Sustainability) based in Barcelona, with additional urban projects in RECNET and UREx. Key nodes in our Africa network include the Natural Capital Project, Future Earth Urban KAN, and the African Center for Cities, which will be the regional node lead for Africa and through which we seek to expand networks in Africa over the first years of NATURA. Our Asia–Pacific node is anchored by nature-based solutions research projects situated and funded within the Chinese Academy of Sciences, with strong central and collaborative funding from the Chinese NSF. This Asia-Pacific network is complemented by Natural Capital Project projects active in China, the East Asia-Pacific LTER, and the Secretariat of the Future Earth Urban KAN, based jointly in Tokyo and Melbourne. **The Future Earth Urban KAN is additionally important to ensure the long-term continuity of NATURA and has agreed to eventually become the institutional home for NATURA,** given Future Earth's core mandate and central funding for developing, hosting, and coordination global networks of networks for local and global sustainability transformations.

All networks have been strategically chosen to align with overall vision and five goals of NATURA. Most networks have enthusiastically agreed to attend All Hands Meetings, host network exchanges and workshops, and support their own students and early-career scholars to spend short stays with US networks (**Table 2**). There is genuine enthusiasm among the leaders and urban representatives of these networks, who are named in the *Facilities* section and have provided Letters of Collaboration, to join together to create an active and highly functional network that will propel forward the science and practice of incorporating nature into urban areas to promote resilience in the Anthropocene.

NATURA Coordination Plan

The Co-Directors (***Grimm and McPhearson)*** will lead intellectual direction and inspiration for all NATURA activities. NATURA will bring together networks of physical scientists, ecologists, engineers, social scientists, and practitioners from around the globe integrating green infrastructure and nature-based solutions in research and practice. We use the approach of team research (Stokols 2008) to integrate across networks, disciplines, roles, and tasks of our researchers and community practitioners. NATURA will be organized into regional nodes, the Network Coordination Committee, and thematic groups.

Participating networks for NATURA include 26 funded networks of researchers and practitioners focused on Europe, South Africa, China, North America, Latin America, and globally. Regional nodes will be led by co-PIs or core personnel; ***Grimm*** will lead and coordinate the regional North America network node, ***McPhearson*** will lead the Europe network node, ***Cook*** will lead the Latin America network node, ***Anderson*** will lead the Africa network node, and ***Zhou*** will lead the Asia and Pacific network node. ***Kim*** will have the essential role of coordination and communication across all networks. Together, this group brings substantial experience in academic and research administration at the project, network, and university levels and strong experience working in an interdisciplinary environment on urban nature-based solutions. The regional leads will be responsible for ensuring their networks remain active and integral to NATURA's full suite of networks. The regional leads will organize quarterly virtual meetings for their networks to share updates and propose new cross-network collaborations.

The Network Coordination Committee will carry the overall responsibility for the integration and collaboration of diverse global networks of nature-based solutions. The Network Coordination Committee will comprise regional leads plus other core personnel (***Bulkeley, Collier, Kim, Morató, and van Ham)***. The Network Coordination Committee's primary goals are to (a) implement the proposed plan, (b) facilitate communication and collaboration between networks, regional groups, thematic groups, as well

as scientists, practitioners, post-docs, and students, (c) recruit additional networks and collaborators to actively participate in NATURA, (d) manage transitions in students, staff, and scientists, (e) support dissemination of synthesis and results, (f) meet obligations to NSF and the scientific community, and (g) ensure accountability and efficiency of resource utilization. To meet these goals, the Network Coordination Committee will meet monthly via video conferencing (e.g., Zoom) to prioritize and support NATURA collaborative activities, research themes, and virtual and in-person exchanges (e.g., thematic synthesis writing workshops, All Hands Meetings, learning and network exchanges, research grants).

The Network Coordination Committee will be responsible for allocation of project funding and NATURA activities. The Network Coordination Committee will draft semiannual network-wide requests for proposals (RFPs) for new thematic groups, workshops, and learning exchanges for students and postdocs and network exchanges for faculty or practitioners, and establish annual review committees from across the networks to evaluate proposals. Funded proposals will prioritize synthesis of data and knowledge on nature-based solutions across multiple global networks, diverse disciplinary perspectives, as well as the integration of team members from diverse career stages and practitioners.

From NATURA's strong network of networks, key research and practice themes are expected to emerge and form thematic nodes or thematic working groups. Thematic working group leads will be chosen organically. Coordination of thematic group efforts and integration of tasks will be conducted through myriad avenues: telephone and/or videoconferences, in-person meetings, and online and/or email correspondence. To advance their work, thematic groups may apply for workshop funding.

To ensure meaningful collaboration among NATURA members from diverse networks, regions, and disciplines, NATURA will develop a set of Collaboration and Inclusion Guidelines. The guidelines will set clear expectations for all NATURA members, in order to foster an operating climate that maximizes collaboration, trust, and inclusivity throughout the network. The guidelines will establish a mechanism by which information, ideas, and concerns can be voiced, shared, and transmitted to the Network Coordination Committee and appreciated across the network.

For network-wide coordination and communication, the Network Coordination Committee will be responsible for organizing the annual virtual and three in-person All Hands Meetings (**Table 1**) to present updates in each of the integrated themes, synthesize cross-city and cross-region achievements, and refine and develop next steps. Recognizing the difficulty of holding meetings across world time zones, all virtual meetings will be recorded and accessible through our web site. Additionally, the Network Coordination Committee will work with the Future Earth Urban KAN to suggest quarterly webinars and presentations by regional and thematic nodes to ensure that all personnel are informed about progress on all parts of the project, and will provide information for newsletters to be developed by that partner.

Data sharing and idea dissemination will also take place online through the NATURA AccelNet Database, as well as other traditional mechanisms, such as journal articles and conference talks (see Data Management Plan for details). The NATURA team will develop the NATURA AccelNet Database with global best practices for nature-based solutions and supporting data for their application in an open-source, online platform for network collaboration and data visualization. Via the online platform, participating networks will be able to arrange thematic groups for collaboration, share data, manage documents, and publish their resources. NATURA will establish an authorship policy to address from the outset the disparate disciplinary and cultural principles for authorship on journal articles, symposium, and other publications. The NATURA Authorship Policy will be an inclusive opt-in strategy for scientists, post-docs, students, and practitioners that establishes clear criteria for authorship, ensures high-quality publications, and emphasizes professional development of early-career scholars.

Student and Early-Career Development Plan

NATURA will educate a diverse team of undergraduate and graduate students, postdoctoral fellows, and early-career scholars in inter- and trans-disciplinary science on nature-based solutions (**NATURA Goals 4 and 5**). The NATURA network will train students and early-career members as interdisciplinary scholars through virtual and in-person cross-network and cross-disciplinary learning, exchanges, and professional development (**Table 1**). First, NATURA will develop a virtual graduate seminar (3 credits)

on addressing urban resilience with nature-based solutions that will be offered across multiple participating NATURA institutions (Years 2 & 4). While the virtual course will be organized and hosted by the core team (NATURA Coordinating Committee), the seminar will engage regional and thematic node leads, as well as other global network partners, in regular guest lectures and discussions. The course will offer students a structured opportunity to participate in cross-network synthesis on nature-based solutions across diverse global contexts.

Second, students and postdocs affiliated with NATURA networks will be invited to participate in a virtual interdisciplinary reading group led by the NATURA postdoctoral fellow (Years 3 & 5), which allows follow-up to the more structured seminar. The reading group will be a forum for (a) presenting and receiving feedback on emerging and established research ideas, (b) forming a global network of new colleagues and collaborative research, and (c) informally exchanging ideas and knowledge with a broad range of scholars of nature-based solutions. The NATURA reading group will also train students and postdoctoral fellows in science communication and clear dissemination of deliverables to the broader community of scientific and non-science partners.

Third, in addition to virtual exchanges, students, postdoctoral scholars, and other early-career scholars affiliated with NATURA will be eligible for in-person network learning exchanges to advance peer learning and even to implement research advances. Because these are a central component of NATURA, they are described in more detail in the *Network Activities* section (above). We will make small research awards available to students in the network based on excellent proposals; as required by NSF these awards will represented <5% of the budget. The research proposals may result from ideas developed in the seminar, reading group, or network learning exchanges. Proposals for all exchanges will be reviewed by the Network Coordination Committee and prioritized based on diversity goals, potential to advance the student or early-career scholar's career, or prospects for advancing the goals of NATURA through establishing new cross-network collaborations and synthesis on nature-based solutions.

Finally, a network of postdoctoral and early-career fellows will be formed with early-career members from participating global networks. The NATURA Early-Career Network (ECN) will be an opportunity to collaboratively develop relationships across the network (Years 1-5). In Year 2, the NATURA ECN will be invited to a planned UREx early-career symposium. A mentoring program associated with the ECN will rotate among senior faculty members or practitioners, with the goals of providing the skills, knowledge, and experience needed for the fellows to succeed in their chosen career paths. Learning objectives are: (a) participating as interdisciplinary and transdisciplinary researchers; (b) increasing professional networks for scientific collaboration; (c) advancing science communication skills both within and outside the scientific community; and (d) enhancing skills for interacting with practitioners.

Broadening Participation Plan

Targeted efforts will be made to ensure and increase participation of underrepresented groups in all NATURA activities at all levels. We will work with established programs for students through US universities (e.g., Arizona State University and The New School), US-based networks including the Long Term Ecological Research program, and scientific societies, such as Society for the Advancement of Chicanos and Native Americans in Science (SACNAS), the Ecological Society of America's Strategies for Ecology, Education and Diversity in Science (SEEDS), and the Western Alliance to Expand Student Opportunities program in western universities, to name a few. We also are developing programs for cross-cultural interaction between all NATURA networks across all five global regions, with a focus on including opportunities for student, scholar, and practitioner exchanges at Global South institutions through network partners, as well seeking representation in thematic workshops that fosters participation from graduate students and junior scholars based at partner institutions in the Global South.

Evaluation

The assessment of NATURA will use formative and summative evaluation tools to evaluate how well NATURA has done in reaching its five goals. A subset of the Network Coordination Committee will establish an Evaluation Team to conduct annual evaluations that will be used to adaptively manage

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network activities. Specific objectives, data sources, and outcome indicators have been identified and will be used to accomplish self-evaluation. An example for one goal is shown in **Table 3**.

Table 3. An example of evaluation methods to be used for assessing NATURA activities.

Goal 3: Establish and maintain lines of **communication among research and practitioners** in global networks to propel improvements in professional capacity and cross-sectoral collaboration		
Objective	**Data source**	**Outcome indicator(s)**
• Researcher and practitioners are informed about networks in NATURA	• Network surveys • Webinars, blogs, workshop proposals from member networks	• Size, connectivity, centrality of NATURA • Number of communication items produced by member networks
• Collaboration between scientists and practitioners increases	• Network exchanges • Publications • Implementation projects	• Number of practitioners involved in exchanges • Co-authorship by practitioners • Participation by network members in implementation projects

Social network analytical tools are useful to analyze, diagnose, and prescribe management interventions for successful network research. Quantitative analysis of the whole research network provides structural insights into the patterns of interaction and collaboration of knowledge-action networks, including composition, diversity, and density of the network (**Fig. 1**; Muñoz-Erickson and Cutts 2015). By observing the network-of-networks through a social network map we will make visibly apparent the new relationships and information flows across the networks and be able to evaluate the extent to which network governance activities are effective or require adjustments. We will apply a framework to social network analysis that has already been implemented by collaborator Tischa Muñoz-Erickson in UREx in the context of transdisciplinary urban research (Muñoz-Erickson et al. 2017).

Additionally, the Evaluation Team will assess our success in meeting Goals 4 and 5 (education and practitioner networking) based on the following short-term outcomes and indicators: 1) Increase in early-career scholars' interdisciplinary and communication skills (*Indicators:* reported confidence based on surveys, projects and publications across disciplines); 2) increase in early-career scholars' transdisciplinary skills (*Indicators:* reported confidence based on surveys; practitioners' assessment based on interviews; placement in practitioner positions); 3) increase in practitioners' access to and understanding of latest science on nature-based solutions (*Indicators:* number of practitioners applying for exchanges; reported confidence based on interviews with practitioner participants in exchanges). We will consider NATURA educational goals a success if students seek out research and educational opportunities across global networks beyond the proposed learning exchanges, such as through professional presentations, co-authorship of publications, and opportunities for further training in inter- and trans- disciplinary approaches. We will evaluate our practitioner engagement by considering the extent to which NATURA synthesis and thematic group materials are applied in city and community planning activities, as well as through direct interaction with practitioner and community leaders. We will develop a tracking database for all early-career and practitioner participants in NATURA activities and follow up with these individuals for a period of at least two years following the end of this grant.

Expected Outcomes

The international NATURA network of networks will bridge research and practice to synthesize and advance theoretical and practical applied knowledge on nature-based solutions to improve urban resilience across diverse contexts. NATURA will have five key outcomes (aligning with five goals):

- **Shared knowledge and best practices** (e.g., via NATURA AccelNet Database, Webinars, and virtual and in-person network exchanges) from diverse socio-cultural, ecological-biophysical, and technological-infrastructural contexts across the research–practice divide;
- **Synthesis of state-of-the-science knowledge** about the role of nature-based solutions in social, ecological, and technological strategies for urban resilience challenges disseminated through academic publications, conference and workshop presentations, and implementation projects;

- International network of **researchers and practitioners** from over 25 global networks including North America, Latin America, Europe, Africa, and Asia–Pacific (linking >3500 individuals and >350 institutions) to advance cross-sectoral collaboration and synthesis;
- **Early-career urban scholars trained in inter- and trans- disciplinary research** on resilience concepts and nature-based solutions;
- Established international **practitioner network** to exchange and improve planning and decision-making on nature-based solutions in their cities.

Intellectual Merit: NATURA will advance theory and research on nature-based solutions by exchanging knowledge and best practices across diverse global social-biophysical contexts, and promote scientific synthesis on how nature-based solutions can meet urban resilience challenges. NATURA will connect over 25 international networks and create databases, foster collaborations, and produce syntheses of nature-based solutions. The US, represented by existing Sustainability Research Networks (SRNs), the Long-Term Ecological Research (LTER) network, the Natural Capital Project, the Nature Conservancy North American Cities Network, and the Urban Sustainability Directors Network, will benefit from connections to international networks adopting similar approaches.

Broader Impacts: Many of the networks in NATURA have practitioner members who are implementing nature-based solutions in their cities. Our collaborative activities include opportunities for students and early-career scientists to work with practitioners in learning exchanges, and for practitioners to embed within networks for short visits, which will enhance their understanding of knowledge bases for implementation. NATURA will train postdoctoral scholars and graduate students through learning exchanges to networks around the globe. Through collaboration with our partners, international students will be invited to participate in these exchanges, hosted by US networks. In all, the activities proposed for NATURA will enhance connectivity among the world's urban scholars and practitioners and improve the prospects for global urban sustainability.

Results of Prior NSF Support

Grimm, McPhearson, Cook: **Urban Resilience to Extremes Sustainability Research Network (UREx SRN; NSF 1444755, 2015–2020, $12M).** Grimm (co-director) and McPhearson are co-PIs and Cook is a collaborator (no other NSF funding) on this collaborative, multi-institutional, transdisciplinary research network funded by NSF's SEES SRN program (now defunct). Ten continental US and Latin American/Caribbean cities are part of the network, which is conducting research through eight working groups focused on theoretical development of the social-ecological-technological (SETS) framework; comparisons among cities in vulnerability, resilience, and adaptation to extreme events; projections of future climatic and hydrologic extreme events; computation and visualization; co-production of future scenarios with practitioners from nine network cities; implementation of infrastructure redesign projects that are based in the SETS approach to enhance transitions to a more resilient infrastructure; and education and diversity. Intellectual merit: The SETS framing has already begun to permeate discussions of urban system science, with the strong recognition that wicked problems such as coping with climate change-driven extreme events in an uncertain future in cities with aging infrastructure require the integration of ecological, social-behavioral, and technological-engineering domains. An effective network has been built and researchers are communicating among disciplines and across institutions, cities, and cultures. Broader impacts: The network so far has engaged over 70 researchers and more than 100 practitioners across 10 cities. Fourteen postdoctoral fellows and over 50 graduate fellows and associates are participating; >70% are women and nearly 50% underrepresented minority. Eight theses or dissertations have been completed and five graduate or postdoctoral fellows have moved into postdoctoral or faculty positions. Publication and Dissemination: UREx scientists have led several Webinars on SETS approaches, data, and visualization, produced 12 episodes of the Future Cities Podcast (created by graduate fellows), given numerous presentations at meetings, and published nearly 60 articles, books, and book chapters (listed in *Literature Cited*) and nine fact sheets and six workshop reports for dissemination to practitioners. Over 120 decision makers and community leaders per year have engaged in UREx participatory workshops.

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FACILITIES, EQUIPMENT, AND OTHER RESOURCES
Underscore denotes individual providing a Letter of Collaboration; * denotes early
career; †denotes practitioner

ARIZONA STATE UNIVERSITY

Arizona State University's design principles favor interdisciplinary, socially embedded research and the institution is highly supportive of collaboration across units and with external partners. This project will be administered within the **School of Life Sciences (SoLS)**, the first and largest interdisciplinary school in the university. SoLS facilities are spread across five campus buildings and include several conference rooms equipped with videoconferencing equipment, classrooms, and laboratories, and access to other university facilities needed for the workshops and conferences can be arranged through the PI's position in SoLS. Two interdisciplinary centers relevant to this project, the Global Drylands Center and the Center for Biodiversity Outcomes, are housed within SoLS.

The **Global Institute for Sustainability (GIOS)** is an interdisciplinary research center with a long history of involving academics, government, industry, and the community in mutually beneficial projects. GIOS is home to several multi-year, urban-focused projects. The *Urban Resilience to Extremes Sustainability Research Network* (URExSRN), described below, is led by ASU, with 30 researchers, 23 graduate, and six postdoctoral fellows based at ASU. The *Central Arizona–Phoenix Long-Term Ecological Research* (CAP LTER) project is one of only two LTER sites charged with monitoring and assessing long-term ecological change in an urban area. In its >20-year history, hundreds of faculty members, graduate students, undergraduate students, K-12 teachers, and community partners have worked together to assess the effects of urban development on the ecosystem of the Sonoran Desert and the reciprocal effects of ecological conditions on urban development. Finally, the research program of the *Decision Center for a Desert City* (DCDC)establishes relationships between climatic conditions and water decision making and is organized around three sets of research questions addressing the sources and influence of regional climate variation and change, water management decision-making, and risk assessment of the impact of those decisions. Longer-term modeling efforts have produced alternative visions of the region's future.

GIOS offers support to host visiting scientists, workshops, and all hands meetings, with conference rooms and video-conferencing and computer presentation capabilities (interactive whiteboard). The *GIOS Informatics Lab* staff includes a full-time systems administrator, 2 senior scientists, 2 software developers, and a GIS technician. Computing resources include a local network containing 5 dual-processor servers (Windows and Linux), 2 development servers, 1 backup server, and more than a dozen workstations. Services include an online metadata catalog and data-access application, database, and GIS archives for over 200 datasets, integrated query into biological collections, bibliographies, and a taxonomic name directory for Arizona. Over 400 GB of storage space are available for research and data archives.

Nancy B. Grimm (Co-PI, Virginia M. Ullman Professor of Ecology) will participate in this project through research time associated with her professorship with SoLS and as a Senior Sustainability Scientist with GIOS. **Yeowon Kim*** (Senior Personnel, currently postdoctoral scientist with UREx SRN), a **TBN program manager**, and Grimm all will be located in the Life Sciences A wing in a complex of offices, conference room, and laboratory. Grimm's Urban and Stream Ecosystems Laboratory (USEL) is equipped for ecological and biogeochemical research, sharing some equipment with an adjacent terrestrial ecosystems/biogeochemistry lab (combined space, >1800 ft^2). In addition to standard biogeochemical instrumentation, several offices for data analysis, map analysis, and graphics preparation are available, equipped with PC and Mac computers, laser and color printers, and high-speed connection to various university servers for file sharing and database access. Software includes word processing, statistical, spreadsheet, graphics, modeling, ArcGIS, R, and communications. The conference room is fitted with a large screen and sound system for Zoom meetings and holds up to 12 people.

Additional university resources are available to project faculty and students. The *University*

Technology Office administers the general-purpose computing system at ASU. It provides a well-supported campus-wide network of microcomputers with an extensive statistical library, including standard software like SAS, SYSTAT, SPSS, and BMDP. The *ASU Library* has more than 2.6 million volumes and is the 27th largest research library in the USA and Canada.

UNITED STATES RESEARCH AND PRACTICE NETWORKS

The **UREx SRN** is the lead network for this proposal. Established in 2015, UREx has grown to encompass over 20 academic institutions, 78 faculty researchers, over 80 graduate and postdoctoral fellows, and over 100 practitioners. Urban resilience, social-ecological-technological systems (SETS), concern for equity, inclusion of Latinx perspectives, and work with practitioners are key elements of this large network of ten cities (Baltimore, MD; Hermosillo, Mexico; Mexico City, Mexico; Miami, FL; New York, NY; Phoenix, AZ; Portland, OR; San Juan, PR; and Valdivia, Chile). In addition to co-PIs Grimm, McPhearson, and Cook* and senior personnel Kim*, individuals with interests in nature-based solutions for urban resilience will be participating in NATURA, including Charles Redman (ASU), UREx PI and co-director who studies urban equity and resilience to extreme heat and Tischa Muñoz-Erickson (USDA Forest Service), UREx co-PI, who focuses on Caribbean cities, governance, and social networks and will be responsible for social network analysis for NATURA. Frequent communication by the UREx project manager and through its website and newsletter will ensure that NATURA is well advertised within the network.

A second sustainability research network, the **Urban Water Innovation Network (UWIN)** will be a research partner. UREx and UWIN already have collaborated on a shared database postdoc to merge data from the two projects into the eRAMS data management and sharing system developed by UWIN PI Mazdak Arabi. This database will be an important resource for NATURA in providing a platform for sharing of urban data across networks. UWIN also has a green infrastructure working group (Grimm is a member) that will be invited to participate in NATURA activities.

The **US LTER** network is a network of 28 research sites with a focus on long-term data collection to generate the understanding necessary to conserve, protect, and manage the nation's ecosystems, their biodiversity, and the services they provide. Of these, two sites are explicitly urban-focused and 4-5 others (Cedar Creek, MN; Florida Coastal Everglades, FL; Plum Island Ecosystem, MA; Santa Barbara Coastal, CA; Luquillo, PR) have some urban research components. The LTER Network Communications Office and its director Frank Davis ensure communication and interaction within the network. Davis, along with lead PIs for the two urban sites, Dan Childers (Central Arizona–Phoenix) and Emma Rosi (Baltimore Ecosystem Study) will communicate NATURA opportunities to researchers and practitioners in the urban sites and broader LTER network.

The **Natural Capital Project** works to influence policy and decision-making using the latest science, particularly ecosystem services and natural capital. Although not exclusively urban, Bonnie Keeler* and other members of the project are developing an urban version of their signature model, INVEST. The Natural Capital Project also hosts annual meetings, an opportunity for NATURA to hold 'side events' with its broader membership.

The **Nature Conservancy North American Cities Network** has the explicit goal of incorporating nature-based solutions into cities. UREx has developed partnerships with The Nature Conservancy Cities Program in Phoenix and New York City, and NATURA will help to expand those to the network through the involvement of North American Cities Network Program Director Emy Rodriguez†.

Biophilic Cities project, funded by the Summit Foundation, advances the theory and practice of urban planning with nature through a combination of collaborative research, dialogue and exchange, and teaching in the U.S. and globally. Its sixteen partner cities are distributed across the globe. J. D. Brown (University of Virginia) is program manager.

Urban Sustainability Directors Network (USDN) and its key practitioner Kristen Baja†, who is also involved in UREx SRN, is a peer-to-peer network of local government professionals from communities across North America for implementation of urban sustainability solutions.

USDA Forest Service (USDA FS) Urban Research Program focuses on urban natural resource

stewardship to improve community well-being and urban resilience. Tischa Munoz-Erickson† leads research in San Juan, Puerto Rico and other US cities and is also co-PI of the UREx SRN.

EUROPEAN RESEARCH AND PRACTICE NETWORKS

NATURVATION, funded by European Commission's Horizon 2020, is a network of European cities developing nature-based solutions for responding to urban sustainability challenges. It is led by Harriet Bulkeley (Durham University) and has over 60 members representing more than 14 institutions, including collaborators Marcus Collier and Christopher Raymond.

The **ENABLE** network of five cities in Europe plus New York City focuses on nature-based solutions and equity and is funded by Diversa. Its lead PI, Erik Andersson of the Stockholm Resilience Center is a close collaborator of Co-PI McPhearson (who is lead for the New York City portion of the network) and will publicize NATURA and host visiting NATURA scholars and/or practitioners in network exchanges.

VIVA-PLAN and **ENVISION**, both led by Christopher Raymond (University of Helsinki), develop a sustainable spatial planning framework for revitalising in-between spaces for social inclusion, biodiversity, and well-being. VIVA-PLAN has three demonstration sites in Copenhagen, Malmö, and Södertalje for nature-based solutions implementation projects, and will host U.S. students, postdocs, and practitioners for the NATURA network learning exchanges.

Connecting Nature, funded by European Commission's Horizon 2020, works with 31 partners from industry, local authorities, communities, NGOs and academics on implementing large-scale nature-based solutions projects in urban settings of 16 countries and fostering peer-to-peer learning among cities. It is led by Marcus Collier (Trinity College Dublin) and will host thematic workshops for sharing European best practices for nature-based solutions with NATURA.

European Forum on Urban Forestry, led by Natalie Gulsrud* and funded by Swedish Kroner project, will provide NATURA researchers a place for thematic workshops through its annual forums on urban forestry, urban greening and green infrastructure.

The **International Union for Conservation of Nature (IUCN) Urban Nature Alliance**, led by Chantal van Ham, raises awareness of the value of ecosystems in urban areas, and of how these ecosystems can help address urban challenges. NATURA will collaborate with IUCN for developing City Nature Index, providing a standardized way for cities to measure the quality of their underlying stock of natural resources, which will be piloted in five European cities but has a global footprint and mandate.

The **European LTER** network consists of several national networks with similar objectives to those of the US LTER network, although they have several LTSER (Long-Term Social-Ecological Research) platforms. There are explicitly urban research sites in Lodz, Poland and France (two sites), including the LTSER platform in Strasbourg led by Sandrine Glatron (Université de Strasbourg).

The **European Regional Centre for Ecohydrology (ERCE),** a part of the UNESCO Water Network directed by Maciej Zalewski (University of Lodz), works on nature-based solutions surrounding water.

AFRICAN RESEARCH AND PRACTICE NETWORKS

African Center for Cities is an interdisciplinary research and teaching program led by Pippin Anderson (University of Cape Town), focused on the dynamics of unsustainable urbanization processes in Africa and systemic responses while enhancing the value of nature. African Center for Cities will host thematic workshops for NATURA as well as nature-based solutions network learning exchanges for students, postdocs, and practitioners.

The **Natural Capital Project** (described earlier) works in several locations in Africa.

ASIAN AND PACIFIC RESEARCH AND PRACTICE NETWORKS

Research Center for Eco-Environmental Sciences (RCEES) Chinese Academy of Sciences, led by Weiqi Zhou*, works on green infrastructure-based and "spongy city" projects, as well as urban greenspace optimization for heat mitigation and adaptation. This strong network of researchers and

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practitioners and projects is well funded by the NSF-China, the Chinese Academy of Science, and the Department of Ecology and Environment, Shenzhen City and multiple other cities in China.

Centre for Urban Transitions, with our collaborator Niki Frantzeskaki (Swinburne University of Technology), is based in Australia and works on identifying the changes that need to be made within urban areas, focusing on how to make those transitions and creating national and international links with researchers and policymakers around the world.

The **Natural Capital Project** (described earlier) has urban projects in China.

The **East Asia-Pacific LTER network** features multiple long-term research sites in eight countries, with urban sites in China and Japan.

LATIN AMERICAN AND THE CARIBBEAN RESEARCH AND PRACTICE NETWORKS

The **UNESCO Chair on Sustainability (UNESCO-SOST)**, led by Jordi Morató (Polytechnic University of Catalonia), is an international center for multi-networking collaboration between different institutions in Europe, Latin America, and the Caribbean, focused on knowledge and best-practices transfer in sustainable human development, from local to global scales. UNESCO-SOST will share its innovative education program in nature-based solutions by hosting graduate students and early career scientists in network learning exchanges at their institutions. UNESCO-SOST also coordinates an urban network, **Recycling the City Network (RECNET)**, with many projects in Latin America.

The **UREx SRN** (described above) includes four cities in Latin America.

GLOBAL RESEARCH AND PRACTICE NETWORKS

The **International Long-Term Ecological Research (ILTER)** network is a globally distributed network of 44 member networks and infrastructure of long-term research sites for multiple use in the fields of ecosystem, biodiversity, critical zone, and socio-ecological research. ILTER aims to secure the highest quality interoperable services in close interaction with related regional and global research infrastructures and networks. It has networks in all five regions. Although the networks are not primarily urban, there are urban sites in the US, Europe, and Asia (see above). Michael Mirtl (Environment Agency Austria) is a co-chair of the ILTER.

Future Earth's Urban Knowledge-Action Network (Urban KAN) is a global network of researchers and other innovators in policy, business, civil society and more working to solve the most pressing challenges facing cities worldwide. They "build new knowledge and tools to accelerate real-world transitions and transformations toward cities that are sustainable and livable." Giles Sioen (Future Earth, Tokyo Office) is the lead, and co-PI Timon McPhearson is a member of the network.

The Nature of Cities is an international platform based in Dublin, Ireland and New York City, USA led by David Maddox for sharing of diverse, transformative ideas about cities as ecosystems of people, nature, and infrastructure with partner organizations around the world. The Nature of Cities will facilitate expanding NATURA through their project cities and serve as an outlet for NATURA publications and online blogs.

ICLEI - Local Governments for Sustainability is the leading global network of 1,500+ cities, towns and regions committed to building a sustainable future. Urban systems are part of a broader city-region territory. Local and regional governments and their urban systems are interconnected. They "address city-to-city and rural-urban linkages to create a multiplier effect." Our contact at ICLEI is Wolfgang Teubner of the European Secretariat; following the initial All Hands Meeting the organization will decide whether this or other regional secretariats or the global secretariat will join NATURA.

U.S.	European	Asian and Pacific	Latin American and Caribbean	African
❑ ASU SoLS ❑ ASU GIOS ❑ The New School Urban Systems Lab ❑ UREx ⊕ ❑ UWIN ❑ USDN ❑ US LTER ❑ The Nature Conservancy North American Cities Network ❑ Natural Capital Project ⊕ ❑ Biophilic Cities ❑ ICLEI ⊕ ❑ Future Earth Urban KAN ⊕ ❑ USDA Forestry Service ❑ The Nature of Cities ⊕	❑ IUCN Urban Nature Alliance ⊕ ❑ NATURVATION ❑ ENABLE ❑ VIVA-PLAN ❑ ENVISION ❑ UNSECO-SOST ⊕ ❑ Connecting Nature ❑ European Forum on Urban Forestry ❑ European LTER ❑ UNESCO ERCE ❑ ICLEI ⊕ ❑ Future Earth Urban KAN ⊕ ❑ Natural Capital Project ⊕ ❑ The Nature of Cities ⊕ ❑ Biophilic Cities ⊕	❑ Chinese Academy of Sciences ❑ Natural Capital Project ⊕ ❑ East Asia-Pacific LTER ❑ ICLEI ⊕ ❑ Future Earth Urban KAN ⊕ ❑ The Nature of Cities ⊕ ❑ Biophilic Cities ⊕ ❑ Centre for Urban Transitions	❑ UNESCO-SOST ⊕ ❑ UREx ⊕ ❑ ICLEI ⊕ ❑ Future Earth Urban KAN ⊕ ❑ Natural Capital Project ⊕ ❑ The Nature of Cities ⊕ ❑ Biophilic Cities ⊕ ❑ ILTER ⊕	❑ African Center for Cities ❑ Natural Capital Project ⊕ ❑ ICLEI ⊕ ❑ Future Earth Urban KAN ⊕ ❑ Biophilic Cities ⊕ ❑ ILTER ⊕

⊕ Indicates the network covering multiple regions

Total 26 networks & 29 facilities