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Short communication

Nature-based solutions for resilient landscapes and cities

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ABSTRACT

Nature-based solutions (NBS) are increasingly applied to guide the design of resilient landscapes and cities to enable them to reach economic development goals with beneficial outcomes for the environment and society. The NBS concept is closely related to other concepts including sustainability, resilience, ecosystem services, coupled human and environment, and green (blue) infrastructure; however, NBS represent a more efficient and cost-effective approach to development than traditional approaches. The European Commission is actively engaged in investing in NBS as a driver in developing ecosystem services-based approaches throughout Europe and the world. The pool of knowledge and expertise presented in this Special Issue of Environmental Research highlights the applications of NBS as 'living' and adaptable tools to boost the capacity of landscapes and cities to face today's critical environmental, economic and societal challenges. Based on the literature and papers of this Special Issue, we propose five specific challenges for the future of NBS.

1. Introduction

Governments and organizations worldwide, with the help of academia, are turning to nature to mitigate the pressing environmental, economic and societal challenges caused by the industrialization era. They have understood the necessity of passing from building 'gray' to building 'green' infrastructure to restore ecological balance within the urban landscape for the dual purpose of developing resilient ecosystems and healthier societies. This thinking is based on the fundamental role that nature plays through the provision of ecosystem services in supporting the economy as well as the livelihood of citizens (e.g., Cohen-Shacham et al., 2016; Lafortezza and Chen, 2016; Maes et al., 2016; Kabisch et al., 2017a; Raymond et al., 2017). In this regard, the advantages of applying an ecosystem services-based approach using green infrastructure have been widely described in the scientific literature. For example, Elmqvist et al. (2015) state that the benefits of investing in restoring green (and blue) infrastructure in urban areas may not only be ecologically and socially desirable but also economically advantageous. In its Green Infrastructure Strategy report, the European Commission (EC) states that green infrastructure helps to avoid reliance on infrastructure that is costly to build when nature can provide less expensive and long-lasting solutions, as well as deliver health-related and ecological benefits (EC, 2013).

Acknowledging the important role that green infrastructure and ecosystem services provide for the environment and society, the EC's Directorate-General (DG) Research and Innovation recently launched the concept of 'nature-based solutions' (NBS) as a way of making natural ecosystems an integral part of sustainable development (EC, 2015). Indeed, the strength of the NBS concept lies in its integrated perspective in addressing societal challenges. The DG Research and Innovation commissioned an interdisciplinary Expert Group on 'Nature-Based Solutions and Re-Naturing Cities' to define and operationalize the concept and to identify research needs and priorities (EC, 2015). The Expert Group delivered its report in 2015 and defined NBS as "living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits" (see also Faivre et al., 2017 in this Special Issue).

NBS has largely evolved from previous concepts and/or principles (e.g., sustainability, resilience, ecosystem management, ecosystem services, coupled human and environment, and green (and blue) infrastructure) (Forest Ecosystem Management Assessment Team FEMAT, 1993; Millennium Ecosystem Assessment MEA, 2005; Chen and Liu, 2014; EC, 2015; Cohen-Shacham et al., 2016; Potschin et al., 2016; Davies and Lafortezza, 2017), but with a central focus on the multiple

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co-benefits for the environment, economy and society in urban (and to some degree rural) landscapes. The fundamental belief is that NBS can represent more efficient and cost-effective solutions than traditional approaches to development. NBS can be linked to the sustainable use of nature and ecosystems protection, to the sustainability and multifunctionality of ecosystems, and to the design and management of new ecosystems (EC, 2015). Innovative uses of existing ecosystems should also be considered (e.g., the role of urban woodland and street trees in climate change adaptation and the role of urban parks in building social cohesion). In light of the above, growing attention is being given to NBS as a tool whereby ecosystems and the services they provide are directed at addressing the increasing challenges (e.g., climate change, food security, or economic competitiveness to develop more sustainable and resilient cities) societies face (Maes and Jacobs, 2015).

The NBS approach focuses on the benefits to individuals and their environment, allowing for sustainable solutions that can respond to environmental change and hazards in the long-term. Thus, NBS can help us remain within a safe operating space for humanity, improve local ecological and social sustainability, and guarantee long-term productivity. Countries worldwide have the opportunity and responsibility to apply NBS as a guiding economic strategy toward modifying their use of natural resources for the benefit of nature and society (Maes and Jacobs, 2015). Despite its different scope and ambitions, the NBS approach should not be considered in isolation, given that it has evolved from the 'green infrastructure' concept (Davies et al., 2006; Lafortezza et al., 2017; Pauleit et al., 2017). NBS is also contingent on other concepts, such as ecosystem-based adaptation, urban green infrastructure and ecosystem services, inasmuch as these three are subsets of NBS leading to maximize its benefits and integration (Pauleit et al., 2017). Hence, NBS functions as an umbrella to the other concepts, but with a particular focus on the deployment of actions inspired by nature (e.g., urban forests) on the ground compared to high-tech solutions.

2. NBS applications across scales

Having recognized NBS as one of the most comprehensive approaches for developing resilient landscapes and cities, governments and scientific communities are currently faced with the challenge of moving from general pronouncements to practical applications. The EC (2015) has proposed a suite of actions for re-naturing cities through the implemention of NBS. These include: (i) identifying obstacles (e.g., regulatory) and enabling factors (e.g., leverage of funding) to the delivery of NBS; (ii) raising citizens' awareness, engagement and empowerment; (iii) integrating research, policy and the economic sector to provide the evidence base for NBS; (iv) scaling up NBS across Europe through a more comprehensive evidence base; (v) developing new business and investment models as well as legal and institutional frameworks for NBS; and (vi) developing and deploying NBS that maximize cost-effectiveness and co-benefits. In addition, four principal goals that can be addressed by NBS have been identified:

1. Enhance sustainable urbanization through NBS to stimulate economic growth as well as improve the environment, making cities more attractive and enhancing human wellbeing;
2. Restore degraded ecosystems using NBS to increase their resilience, enabling them to deliver vital services and withstand other societal challenges;
3. Develop climate change adaptation and mitigation strategies using NBS to provide more resilient responses and enhance carbon storage; and
4. Improve environmental risk management and resilience using NBS to produce greater benefits than conventional methods and offer synergies in reducing multiple risks.

Based on these four goals, seven main NBS actions are recommended to be taken forward: (1) urban regeneration through NBS; (2) NBS for improving wellbeing in urban areas; (3) establishing NBS for coastal resilience; (4) multifunctional nature-based watershed management and ecosystem restoration; (5) NBS for increasing the sustainable use of matter and energy; (6) NBS for enhancing the insurance value of ecosystems; and (7) increasing carbon sequestration through NBS.

In the various reports and publications issued by the EC, a range of examples of NBS have been presented; these include, but are not limited to: urban agriculture for local food production and social cohesion; green roofs for climate adaptation; regeneration of abandoned industrial land by afforestation or park creation; rain gardens for stormwater regulation; green spaces for promoting human health; and the use of permeable surfaces and vegetation in urban settings.

The EC's documents, coupled with the scientific literature, demonstrate how the main goals and re-naturing actions are considered in tandem for the advancement and application of the NBS approach. For example, the EKLIPSE Expert Working Group (Raymond et al., 2017) focuses on *Restoring degraded ecosystems* (goal) and *Establishing NBS for coastal resilience* (action) in their 'NBS Impact Assessment Framework', where the actions are viewed as challenges to be addressed. Although these sources consider all the goals and re-naturing actions in a broad sense, each one discusses a select number from a more targeted perspective. To showcase the suggested goals and actions of NBS, we have selected case studies from different regions around the globe. We explored a number of different sources, including official reports from international organizations and expert working groups as well as publications from scientific journals. Table 1 illustrates the results of this search, in chronological order. For each source we have identified the geographic location and/or scale of application (i.e., Global, Europe, etc.) and the main thematic goals and re-naturing actions dealt with, based on the EC's classification (EC, 2015). In addition, we examined the main impacts of each NBS application and the key lessons that could be learned. For example, at the global scale, one of the most seminal works is the World Bank (2008) on biodiversity, climate change and NBS. This report focuses on three of four thematic goals and four of seven re-naturing actions. The impacts center on the need to support innovative ways for improving the management of natural habitats through Bank-funded energy and infrastructure projects as well as development policy lending (Table 1). The key lessons are drawn from single case studies and can be scaled up to foster new NBS strategies. More recently, the IUCN Report (Cohen-Shacham et al., 2016) approaches NBS through three thematic goals and four re-naturing actions to address societal challenges by unifying NBS interventions within a single operational framework. An important lesson to be learned from this source is that NBS could enable vulnerable societies to better adapt to water, food and energy shortages resulting from climate change. At European scale, besides the main reports from the EC (2013, 2015), additional information regarding NBS applications could be derived from two most recent publications: Nikolaidis et al. (2017), who focus on new approaches to improve regulatory instruments, share best commercial practices and demonstrate the long-term value of NBS, and Kabisch et al. (2017b), who provide a compendium of contributions looking at NBS for climate change adaptation in urban areas.

We also uncovered a report from the Asian Development Bank (2016) highlighting the capacity of NBS in building resilience in towns and cities in the Greater Mekong Subregion (Southeast Asia). Among the impacts foreseen by this study is the need to leverage partnerships for creating policy shifts, innovation in planning, design and implementation of NBS in the Mekong towns.

3. NBS at a glance

In a global context of mounting challenges (e.g., climate change) and human activities (e.g., rapid urbanization), this Special Issue of Environmental Research attempts to lay the theoretical and applicative foundations of the NBS concept by focusing on the most recent

Table 1
Suite of case studies from different regions around the globe where nature-based solutions (NBS) have been applied.

Source	Title	Geographical region/Scale	NBS Thematic goals[a]	Re-naturing Actions[a]	Impact(s)	Key lesson(s)
Kabisch et al. (2017b)	Nature-Based Solutions to Climate Change Adaptation in Urban Areas – Linkages Between Science, Policy and Practice. Theory and Practice of Urban Sustainability Transitions	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Enhancing the insurance value of ecosystems; Increasing carbon sequestration; Urban regeneration; Improving human wellbeing in urban areas	Connect citizens to nature, trigger socio-ecological reconfigurations that promote ecological functions; Initiatives contribute to sustainability transitions by spreading NBS thinking and doing, mobilizing people and money, and changing governance institutions	The success of strong bottom-up collaborative partnerships leads to the successful implementation of NBS and the replication of initiatives
Wamsler et al. (2017)	Mainstreaming Nature-Based Solutions for Climate Change Adaptation in Urban Governance and Planning	Europe	Developing climate change adaptation and mitigation; Restoring degraded ecosystems; Enhancing sustainable urbanization; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Urban regeneration	The mainstreaming of NBS for climate change adaptation can support incremental and transformative changes that address the root causes of risk and lead to sustainable development; Key principles show how adaptation mainstreaming can be achieved in urban governance and planning	Mainstreaming strategies must be implemented at the local, institutional and interinstitutional levels in order to ensure the sustainable implementation of on-the-ground measures; Adaptation mainstreaming is a potentially effective way to foster urban resilience; Measures and strategies can only lead to sustainable change in combination
Nikolaidis et al. (2017)	Nature-based solutions: Business	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Urban regeneration; Improving human wellbeing in urban areas	Europe's ThinkNature project aims to promote NBS across research, policy, non-governmental organizations and businesses. ThinkNature seeks to improve regulatory instruments, share best commercial practices and demonstrate the long-term value of NBS	ThinkNature, which is funded by the EU's research programme Horizon 2020, will transform the market potential for NBS by using prevailing knowledge and performance data on pioneering practices to identify commercial opportunities and innovation in policy and practice
Nesshöver et al. (2017)	The science, policy and practice of nature-based solutions: An interdisciplinary perspective	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Improving human wellbeing in urban areas	Implications for science, policy and practice of the recently introduced concept of NBS	NBS hold potential for both stimulating and preventing economic development; To realize their full potential, NBS must be developed by including the experience of all relevant stakeholders such that 'solutions' contribute to achieving all dimensions of sustainability
Raymond et al. (2017)	An impact evaluation framework to support planning and evaluation of nature-based solutions projects	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Increasing carbon sequestration; Urban regeneration; Improving human wellbeing in urban areas	The document explores the multiple dimensions of impact that NBS projects may have when implemented at different scales, from building to regional; The EWG recognizes that the type and intensity of NBS impacts (e.g., extremes of temperature, wind, drought and flooding) may vary according to the characteristics of the NBS and the context in which they are applied	It is important to assess the impacts of NBS across aspects of multiple systems, including socioeconomic, socio-cultural and ecosystems; The applicability of indicators can vary across geographic scales; Synergies and trade-offs can be associated with NBS impacts, hence, NBS impacts are likely to be multi-directional and complex; Investment in NBS can maximize the benefits for the provision of environmental, socio-cultural and economic services if multiple challenge areas are considered concurrently and stakeholders are involved in planning and implementation
Asian Development Bank (2016)	Nature-based Solutions for Building Resilience in Towns and Cities: Case	Southeast Asia	Enhancing sustainable urbanization; Restoring	Increasing the sustainable use of matter and energy; Multifunctional	Application of the principles of green infrastructure, measures for	Main lessons must be shared with urban and infrastructure planners; Lessons

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Table 1 (*continued*)

Source	Title	Geographical region/Scale	NBS Thematic goals[a]	Re-naturing Actions[a]	Impact(s)	Key lesson(s)
	Studies from the Greater Mekong Subregion		degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	watershed management and ecosystem restoration; Coastal resilience; Increasing carbon sequestration; Urban regeneration; Improving human wellbeing in urban areas	building resilience and NBS of relevance to Mekong towns grouped in the categories of water and flood management, slope stabilization, and pollution management; Leveraging partnerships would extend to create policy shifts, innovations in planning, design and implementation along with continued training and capacity building	provide directions for changing current strategies in urban planning and policy in the Mekong Subregion; Need to recognize rehabilitating natural systems with NBS as key for building sustainability and resilience in urban areas
Cohen-Shacham et al. (2016)	Nature-based solutions to address global societal challenges	Global	Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Multifunctional watershed management and ecosystem restoration; Coastal resilience; Enhancing the insurance value of ecosystems; Increasing carbon sequestration; Improving human wellbeing in urban areas	By unifying NBS interventions under a single operational framework, it becomes possible to scale up implementation of these interventions and strengthen their impact in mitigating the world's most pressing challenges	NBS will make a direct contribution to global efforts, enable vulnerable societies around the world to better adapt to the adverse effects of water and food insecurity and climate change, and help reduce the impacts of natural disasters
Kabisch et al. (2016)	Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation	Multifunctional watershed management and ecosystem restoration; Urban regeneration; Improving human wellbeing in urban areas	Explore examples of good practices of NBS to climate change mitigation and adaptation in Europe's urban areas and their surrounding landscapes, and to identify indicators of success for NBS, challenges of implementation, and other knowledge gaps; focus on implementation aspects of NBS and bring this solution-concept to urban governance and practice while opening the debate on social, economic, and ecological aspects	NBS can serve as climate mitigation and adaptation tools that produce additional co-benefits for societal wellbeing, thereby serving as strong investment options for sustainable urban planning
Liquete et al. (2016)	Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits	Europe	Enhancing sustainable urbanization; Developing climate change adaptation and mitigation; Improving risk management and resilience	Multifunctional watershed management and ecosystem restoration; Urban regeneration	The study demonstrates the effectiveness of investments on NBS, the potential of green infrastructures to deliver a broad range of ecosystem services, and the utility of integrating different value systems and stakeholders' viewpoints to support environmental decision-making; Results could be used prospectively to appraise new proposals of constructed wetlands under similar circumstances	Green infrastructure performs equal to, or even better than, the gray infrastructure alternative for water purification and flood protection; it has a similar cost and provides additional benefits (e.g., wildlife support and recreation)
DG for Research and Innovation – European Commission (EC) (2015)	Nature-Based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'. Directorate-General for Research and Innovation–Climate Action, Environment, Resource Efficiency and Raw Materials	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Enhancing the insurance value of ecosystems; Increasing carbon sequestration; Urban regeneration; Improving human wellbeing in urban areas	Increased ecosystem services: e.g., water purification, flood regulation, and natural habitat, contributing to residents' livelihood through recreational and educational services; More informed decisions; Mitigation of water-related issues	NBS address a variety of societal challenges in sustainable ways, with the potential to contribute to green growth, 'future-proofing' society, fostering citizen wellbeing, providing business opportunities and positioning Europe as a leader in world markets
Eggermont et al. (2015)		Global	Enhancing sustainable urbanization; Restoring	Increasing the sustainable use of matter and energy; Urban	The paper proposes a typology of NBS and reflects on its added value	NBS approaches can promote the development and management of urban

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Table 1 (*continued*)

Source	Title	Geographical region/Scale	NBS Thematic goals[a]	Re-naturing Actions[a]	Impact(s)	Key lesson(s)
	Nature-based Solutions: New Influence for Environmental Management and Research in Europe		degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	regeneration; Improving human wellbeing in urban areas	with respect to existing terms and concepts, its possible drawbacks in case of misuse, and perceived future challenges for research and management	ecosystems to offer sustainable and cost-effective solutions to societal challenges like global warming, water regulation and human health, while enhancing biodiversity
Maes and Jacobs (2015)	Nature-based solutions for Europe's sustainable development	Europe	Enhancing sustainable urbanization; Restoring degraded ecosystems; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Coastal resilience; Enhancing the insurance value of ecosystems; Urban regeneration; Improving human wellbeing in urban areas	Imposes a change in thinking in the political, economic and scientific spheres; Considers larger temporal and spatial scales and integrates diverse values	NBS could offer a transition path with realistic, incremental steps toward a sustainable economy
Davis et al. (2015)	Coastal Protection and SUDS — Nature-Based Solutions	Global	Enhancing sustainable urbanization; Developing climate change adaptation and mitigation; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Coastal resilience; Urban regeneration; Improving human wellbeing in urban areas	Discussion of NBS in two different application areas: (1) coastal protection and (2) urban drainage systems	NBS can offer multiple benefits in parallel, e.g., improvements in public health, biodiversity conservation and recreational opportunities for the urban population; Though frequently implemented in isolated cases, the full potential of NBS has not been reached due to a number of existing barriers (e.g., uncertainty about their long-term performance and cost-effectiveness)
Sutherland et al. (2014)	Solution scanning as a key policy tool: identifying management interventions to help maintain and enhance regulating ecosystem services	Global	Restoring degraded ecosystems; Improving risk management and resilience	Multifunctional watershed management and ecosystem restoration; Coastal resilience; Increasing carbon sequestration	The paper aims to provide a comprehensive list of possible interventions and investments that can enhance ecological infrastructural capacity and positively influence the conservation of the range of regulating ecosystem services identified by the Millennium Ecosystem Assessment	Solution scanning is important for questioning existing knowledge and identifying the range of options available to researchers and practitioners, and serves as the basis for assessing cost-effectiveness and guiding implementation strategies; it is recommended to become a routine part of decision making
European Commission (EC) (2013)	Green Infrastructure (GI) – Enhancing Europe's Natural Capital	Europe	Developing climate change adaptation and mitigation; Restoring degraded ecosystems; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Increasing carbon sequestration	Green infrastructure boosts disaster resilience and reduces vulnerability to risks by supporting local livelihoods and economies	Ecosystem-based approaches are among the most widely applicable, economically viable and effective tools to combat the impacts of climate change. Green infrastructure can contribute significantly to achieving many of the EU's key policy objectives
MacKinnon et al. (2011)	Natural solutions: protected areas helping people to cope with climate change	Global	Developing climate change adaptation and mitigation; Restoring degraded ecosystems; Enhancing sustainable urbanization; Improving risk management and resilience	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal resilience; Enhancing the insurance value of ecosystems; Increasing carbon sequestration; Urban regeneration; Improving human wellbeing in urban areas	Emphasis is on the necessity to expand and improve the management of protected areas. This, in turn, contributes to mitigation and adaptation strategies by addressing the causes of climate change and helping societies to respond and adapt to ongoing changes	Consolidating, expanding, and improving the global protected area system is a response to climate change and biodiversity loss. Achieving these objectives requires actions: 1) More and larger protected areas and buffer zones; 2) Connecting protected areas within landscapes/seascapes; 3) Protected area governance types; 4) Increasing the level of protection; 5) Improving management in these areas
The World Bank Report (2008)	Biodiversity, Climate Change and Adaptation: Nature-Based Solutions from the World Bank Portfolio	Global	Developing climate change adaptation and mitigation; Restoring degraded ecosystems;	Increasing the sustainable use of matter and energy; Multifunctional watershed management and ecosystem restoration; Coastal	Investment dedicated to protected areas, with a focus on improving natural resource management and mainstreaming biodiversity into	The mission is to alleviate poverty and support sustainable development. The conservation and sustainable use of natural ecosystems and biodiversity are

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Table 1 (*continued*)

Source	Title	Geographical region/Scale	NBS Thematic goals[a]	Re-naturing Actions[a]	Impact(s)	Key lesson(s)
			Improving risk management and resilience	resilience; Increasing carbon sequestration	forestry, coastal zone management, and agriculture; Support innovative modalities for improved management of natural habitats through Bank-funded energy, infrastructure projects and development policy lending	critical to fulfilling these objectives; Information on projects and programs emphasize biodiversity–climate change linkages

[a] Based on the EC Classification of the Directorate-General for Research and Innovation (2015). Nature-Based Solutions & Re-Naturing Cities. Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'. Available at: https://publications.europa.eu/it/publication-detail/-/publication/fb117980-d5aa-46df-8edc-af367cddc202.

innovative strategies and scientific advances for building resilient landscapes and cities. The topics covered include the four principal goals defined by the EU: (i) enhancing sustainable urbanization; (ii) restoring degraded ecosystems; (iii) developing climate change adaptation and mitigation strategies; and (iv) improving risk management and resilience. The author contributions to this issue represent a diverse international community and provide examples of NBS theories and methods by generating and analyzing ecological and social datasets, developing integrated modeling techniques, and presenting state-of-the-art research results. For example, Shao et al. (2017) quantified carbon sequestration using eddy covariance towers to demonstrate how grassland ecosystems of the Mongolian Plateau respond differently to climate change and can be considered as NBS in support of a climate adaptation and mitigation strategy for nomadic herdsmen. An analysis by Tomao et al. (2017) on per-capita forest area in Attica, Greece, identified priorities for NBS at metropolitan level to promote sustainable urbanization. Bellamy et al. (2017) provide a modeling framework to inform green infrastructure planning as NBS with related social and ecological benefits. In addition, NBS underpinned by an ecosystem services-based approach are proposed as facilitating the adoption of a proactive urban forest strategy (Davies et al., 2017). Fini et al. (2017) concluded that a network of vegetated, porous sidewalks may constitute a new artificial ecosystem (i.e., type III NBS) that contributes to improve living conditions while reducing the risk of extreme stormwater events.

Other successful cases include environmental and social research aimed at improving the implementation capacity and evidence base of NBS to benefit landscapes and their inhabitants. For example, in a study in Cambodia, Lin and Qi (2017) discovered that a hydro-dam, as an NBS, provides resilient responses and enhances sustainable urbanization for social development. The role of urban parks as NBS to provide multiple ecosystem services and improve the design and management of green infrastructure, emphasizing vegetation structure, composition and management is reported by Mexia et al. (2018) and Vieira et al. (2018). Similarly, a study in Brazil (Lamano Ferreira et al., 2017) on heavy metal concentrations in peri-urban forests suggests that NBS at city level disperse air pollutants. In a study conducted in Africa, Peter et al. (2017) maintain that perennial grains as an NBS offer smallholder farmers a sustainable solution for enhancing resilience and minimizing risk in confronting global change, while mitigating social and edaphic drivers of low and variable production. Furthermore, Zölch et al. (2017) provide evidence on the effectiveness of urban green infrastructure as NBS to regulate stormwater and assist planners/operators of sewage systems in selecting the most effective measures for the implementation and estimation of their effects.

Specific contributions of this Special Issue focus on the public health impact of NBS. The work by Panno et al. (2017) reveals that NBS in Italy are associated with greater wellbeing through less ego depletion during periods of heat stress. A similar study by Vujcic et al. (2017) demonstrates that recuperation from stress, depression and anxiety was possible and much more complete when participants were involved in horticulture therapy as an NBS for improving mental health. Two analogous studies (Wai et al., 2017a, 2017b) investigate the impacts of NBS on pollutant-related health risks in China from leafy vegetables and ambient aerosols. Kabisch et al. (2017a) reviewed health outcomes from access to green/blue spaces as NBS to help reduce urbanization-related risk factors. In their review of public health literature, van den Bosch and Ode Sang (2017) offer guidelines on how wellbeing could be integrated into the implementation of NBS for resilient and liveable urban landscapes and health in a changing climate.

Other case studies in this issue investigate the economic and inherent value of NBS through business and investment models. Denjean et al. (2017) propose a conceptual framework to systematize the use of NBS by integrating their resilience potential into Natural Assurance Schemes, centering on insurance value as a cornerstone for both awareness-raising and valuation. Instead, Wild et al. (2017) focus on

Table 2
Nature-based solutions (NBS) applications presented in this Special Issue.

Author(s)	Title	Geographical region/Scale	NBS Application(s)	Impact(s)	Key lesson(s)
Bellamy et al. (2017)	A spatial framework for targeting urban planning for pollinators and people with local stakeholders: A route to healthy, blossoming communities?	Scotland (UK)	Pollinator species	A quantitative, spatially explicit and transferable approach provides a useful decision-making tool for targeting NBS to improve biodiversity and increase environmental stewardship, with the aim of providing a more attractive city to live, work and invest in	A modeling framework informs green infrastructure planning as an NBS with social and ecological benefits
Cariñanos et al. (2017)	Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health	Spain	Urban and peri-urban forests	NBS are used as corrective measures to mitigate the impact of pollen emissions	NBS allow reducing the impact of allergens on public health
Chen and Bridgeman (2017)	The reduction of Chlorella vulgaris concentrations through UV-C radiation treatments: A nature-based solution (NBS)	USA	Algae	The reduction of algal bloom using NBS can have a major impact on the public by providing people with safe drinking water	UV radiation is an effective NBS to treat algae-polluted water
Davies et al. (2017)	Challenges for tree officers to enhance the provision of regulating ecosystem services from urban forests	UK	Urban and peri-urban forests	The is the first study that sheds light on whether and how regulating ecosystem services influence urban forest management in Britain and what socio-political constraints local authority tree officers face in using NBS to solve the heat, flood and air quality problems associated with densely populated cities	The adoption of a proactive urban forest strategy, underpinned by valued urban forest-based ecosystem services data and innovative private sector funding mechanisms, can facilitate a change to a proactive, ecosystem services-based approach of urban forest management
Denjean et al. (2017)	Natural Assurance Scheme: A level playing field framework for Green-Grey infrastructure development	Global	Green infrastructure	Natural Assurance Schemes highlight the advantages of investing in the protection, enhancement and restoration of natural capital as an effective climate change adaptation strategy	The study provides the possibility for both planners and investors to design no-regret NBS and mixed gray-green infrastructure systems
Faivre et al. (2017)	Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges	Global	Green roofing, floodplain restoration, pocket parks	Research & Innovation actions at EU level that promote systemic NBS and their benefits to cities and territories may improve the implementation capacity and evidence base for deploying NBS and developing future markets	The EC initiative on NBS consolidates several EU policies and actions under a common R&I agenda; R&I actions to promote NBS include i) developing the knowledge and evidence base, ii) creating a nature-based solutions community and iii) creating awareness
Fan et al. (2017)	Nature-based solutions for urban landscapes under post-industrialization and globalization: Barcelona versus Shanghai	Spain, China	Urban green spaces	Using quantitative modeling to link green space development with drivers of economic development can give new insights to policy makers	NBS planning is used as a place-making tool to strengthen city image and attract global investment
Fini et al. (2017)	Nature based solutions to mitigate soil sealing in urban areas: Results from a 4-year study comparing permeable, porous, and impermeable pavements	Italy	Soil, leaf growth	Enhancing evaporation from paved soil by using porous pavements may contribute to mitigating urban heat islands	The restoration of natural processes by integrating NBS can mitigate the impact of urbanization; A network of vegetated, porous sidewalks may constitute a new artificial ecosystem (i.e. type III NBS) that contributes to improve living conditions while reducing the risk from extreme events
Gulsrud et al. (2018)	Innovative urban forestry governance in Melbourne?: Investigating "green placemaking" as a nature-based solution	Australia	Urban forest; Urban green infrastructure	This study reveals and analyzes new and/or unique phenomena within the context of NBS to climate resilience and ecosystem services delivery through urban re-naturing; it provides valuable insight for the broader urban green infrastructure governance field regarding the opportunities and challenges associated with a socio-cultural approach to urban re-naturing and ecosystem services delivery	Melbourne's Urban Forest Strategy governance process fosters green placemaking by re-focusing climate adaptation solutions from technological strategies to situated socio-ecological principles, such as human wellbeing and community-based decision making; Green placemaking should be seen as a NBS to urban climate resilience
Jerome et al. (2017)	Re-defining the characteristics of environmental volunteering: Creating a typology of community-scale green infrastructure	UK	NBS, synonymous with green infrastructure (i.e., forests)	Community-Scale Green Infrastructure (CSGI) activity with a focus on NBS planning allows for a greater awareness of the benefits that can be delivered in a local environment; CSGI provides opportunities for analyzing the long-term	Conceptualizing GI as an activity related to social determinants and as a cost-effective approach to NBS may have greater significance than ongoing discussions of the principles of green infrastructure

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Table 2 (*continued*)

Author(s)	Title	Geographical region/Scale	NBS Application(s)	Impact(s)	Key lesson(s)
				management of GI at a site, neighborhood, and city scale; this contributes to understand how actors remain engaged in the decision-making processes of GI management and maintenance	
Kabisch et al. (2017a)	The health benefits of nature-based solutions to urbanization challenges for children and the elderly – A systematic review	Global	Urban green and blue spaces	More knowledge is required on the impact of the quality, amenities and accessibility of green/blue spaces to provide valuable evidence for urban planning	Existing studies on urban green/blue spaces as NBS for improved health among children and the elderly provide inconsistent results; More research and evidence are needed to optimize NBS for human wellbeing while also maintaining healthy ecosystems
Lamano Ferreira et al. (2017)	Air contaminants and litter fall decomposition in urban forest areas: The case of São Paulo - SP, Brazil	Brazil	Urban and peri-urban forests	The impact is on municipal management to seek efficient and cost-effective NBS that compensate for the residues produced by urbanization processes, such as air pollution	An alternative to maintaining greater control of precipitation in cities, which limits air pollutant dispersion, is to increase the number of urban green areas as a major NBS
Lin and Qi (2017)	Hydro-dam – A nature-based solution or an ecological problem: The fate of the Tonlé Sap Lake	Cambodia	Freshwater lake	The importance of using tradeoffs in assessing the ecological value of NBS	Trade-offs should be evaluated to help establish an optimized NBS; As an NBS designed for climate change adaptation, a hydro-dam provides more resilient responses and enhances sustainable urbanization for social development
Mexia et al. (2018)	Ecosystem services: Urban parks under a magnifying glass	Portugal	Urban and peri-urban forests	Practitioners can use the knowledge to promote the role of urban parks as an NBS to provide multiple ecosystem services and ultimately improve the design and management of green infrastructure	The management and planning of urban parks can make use of simple practical measures as NBS to promote ecosystem functioning in urban areas and to manage green spaces for the provision of specific ecosystem services; The type of vegetation matters for the provision of ecosystem services and trade-off analysis
Panno et al. (2017)	Nature-based solutions to promote human resilience and wellbeing in cities during increasingly hot summers	Italy	Urban and peri-urban forests	The study enhances understanding of whether, and how, spending time in urban green spaces considered as a type of NBS helps the recovery of cognitive resources and wellbeing	NBS are positively related to human wellbeing as well as to the conservation of human self-control resources
Peter et al. (2017)	Nature-based agricultural solutions: Scaling perennial grains across Africa	Africa	Cultivation of perennial grains	Importance of using perennial grains in locations where biophysical and social constraints reduce agricultural system efficiency, and where conditions are optimal for crop growth	As NBS, perennial grains and long-duration varieties improve farm productivity and smallholder livelihoods in suboptimal agricultural areas
Shao et al. (2017)	Grassland productivity and carbon sequestration in Mongolian grasslands: The underlying mechanisms and nomadic implications	Mongolia	Steppes	Predicting grassland productivity can impact how nomadic groups plan out their agricultural activities; The study helps predict which grasslands are more resistant, or less sensitive, to climate changes	Grassland ecosystems respond differently to climate change and can be seen as NBS in support of climate change adaptation and mitigation strategies; Lessons learned may provide the first palpable data for nomadic societies to use when developing future management strategies
Tomao et al. (2017)	Resilient landscapes in Mediterranean urban areas: Understanding factors influencing forest trends	Greece	Urban and peri-urban forests	Implications for landscape studies, forest policy and planning in the NBS framework; Results support effective NBS planning and identify priority areas for enhancing green infrastructure	The adoption of a proactive urban forest strategy, underpinned by valued urban forest-based ecosystem services data and innovative private sector funding mechanisms, can facilitate a proactive, ecosystem services-based approach of urban forest management
van den Bosch and Ode Sang (2017)	Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews	NA	Green and blue outdoor natural environments (e.g., urban forest, park, water)	Incorporation of nature-health evidence in the NBS agenda can enhance knowledge of co-benefits to the environment by greening for health (e.g., climate change mitigation and adaptation), and provide trade-off estimates; Framing the nature-health relation in an NBS context can also reduce the science-policy gap	There is strong evidence for a positive effect of green spaces on improved affect as well as on heat reduction; How NBS can be optimally related to health in an urban nature context needs to be further explored
van der Jagt et al. (2017)		Europe	Implementation of allotment gardens, land plots, raised beds	An increased awareness of environmental issues and healthy nutrition; enhanced citizen	There is clear potential for CUG as an NBS if managed with sensitivity to the local context;

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Table 2 (*continued*)

Author(s)	Title	Geographical region/Scale	NBS Application(s)	Impact(s)	Key lesson(s)
	Cultivating nature-based solutions: The governance of communal urban gardens in the European Union			engagement in management and political decision-making processes; creation of a business model	Financial support mechanisms are necessary for successful NBS initiatives
Vieira et al. (2018)	Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks	Portugal	Urban and peri-urban forests	Study allows to understand the contribution of vegetation structure, composition and management in providing air purification and climate regulation in urban green spaces - often overlooked in the case of urban parks	Vegetation structure, composition and management are important to optimize the capacity of green infrastructure to purify air and regulate climate; Managed at high spatial resolutions, green infrastructure can optimize ecosystem services in urban areas and contribute to enhance human wellbeing
Vujcic et al. (2017)	Nature based solution for improving mental health and well-being in urban areas	Serbia	Botanical gardens	Assessing the impact of an NBS tool along with socio-demographic factors allows to understand the link between gender and improved mental health as well as appreciate an NBS therapy program	Nature-based therapy is recommended to psychiatric patients as a form of occupational or supportive therapy; Recuperation from stress, depression and anxiety was possible and much more complete when participants were involved in horticulture therapy as an NBS for improving mental health
Wai et al. (2017a)	Public health risk of mercury in China through consumption of vegetables, a modelling study	Eastern China	Leafy vegetable	Regional maps of Probable Daily Intake (PDI) of total mercury and methylmercury over a studied area allow researchers and policy-makers to evaluate risk and propose mitigation measures	Results improve understanding of how to manage public health risk in large cities with large populations, contributing to enhance sustainable urbanization as a principle goal within the NBS framewok
Wai et al. (2017b)	Aerosol pollution and its potential impacts on outdoor human thermal sensation: East Asian perspectives	China	Urban and peri-urban forests	Understanding the interaction between ambient aerosols and outdoor thermal environment is an important step towards effective mitigation measures, such as urban greening, to reduce the risk of heat stress	Aerosols affect insolation and, in turn, human thermal comfort; The study is an important step toward understanding the health risk of heat stress and enhancing human wellbeing as one of the main goals of NBS
Wild et al. (2017)	Comprehending the multiple 'values' of green infrastructure – Valuing nature-based solutions for urban water management from multiple perspectives	UK	Streets and park schemes include green infrastructure in the form of, e.g., bioretention and green roofs	The study has a relevant impact for authorities and communities, which play a vital role in investing in the common goods of green infrastructure	Economic valuation represents an important tool to support decision-making in strategic green infrastructure planning; Investing in green infrastructure may be a successful place-making strategy to complement an integrated approach to urban regeneration
Zölch et al. (2017)	Regulating urban surface runoff through nature-based solutions – An assessment at the micro-scale	Germany	Green roofs, trees, and an integrated hydrological model	The study fills the gap between assumptions on the capacity of urban green infrastructure to regulate surface runoff and studies on the hydraulic behavior of green roofs by successfully applying a complex modelling setup at a new temporal and spatial scale	The study provides empirical support to the effectiveness of urban green infrastructure as an NBS to regulate stormwater

the multiple 'values' of green infrastructure by comparing the benefits of urban greening options of NBS with those of other, more conventional forms of infrastructure integrating both 'green and gray' interventions. These as well as other case studies (i.e., Jerome et al. (2017), van der Jagt et al. (2017) and Gulsrud et al. (2018) on NBS management and community-based governance models, respectively) can be utilized as sound reference material for disseminating knowledge on the effectiveness of NBS, which in turn may help their future uptake.

Overall, this Special Issue includes 26 contributions spanning more than 20 countries around the globe (Table 2). NBS applications range from the micro-scale (e.g., UV radiation as NBS to treat algae-polluted water; Chen and Bridgeman, 2017) to the macro-scale (e.g., grasslands as NBS supporting climate change adaptation on the Mongolian Plateau; Shao et al., 2017). The impacts are varied and include mitigation measures (e.g., Cariñanos et al., 2017), health benefits, as well as the ecological and economic value of NBS. We also present lessons learned from these sources to provide a more comprehensive evidence base for NBS applications (e.g., 'NBS planning is used as a place-making tool to strengthen city image and attract global investment'; Fan et al., 2017).

The knowledge compiled in this Special Issue on the effectiveness of NBS in addressing pressing environmental, economic and societal issues proceeds from diverse, though inter-related fields of study. While sound evidence exists on the benefits associated with NBS, particularly in highly dense cities, we believe that more applicative studies are needed to address the following challenges: (i) to understand the linkages between NBS and associated ecosystem services within the four main categories of provisioning, regulating, cultural and supporting across different scales (e.g., from the "core" urban area to the wider peri-urban landscape); (ii) to assess NBS using a multitude of sensors and data sources including remotely sensed images (i.e., high-resolution satellite sensors, field sensors, airborne LiDAR) and field data (Giannico et al., 2016; Lafortezza and Giannico, 2017); (iii) to scale up NBS benefits to the global level and provide evidence metrics or indicators that managers and policy makers can easily access and use; (iv) to actually implement NBS in the future planning and management of green (blue) landscapes; and (v) to include institutional changes (e.g., policy, governance, and culture) for future refinements of the NBS concept and its applications in both rural and urban landscapes (Chen et al., 2015; EC, 2015; Asian Development Bank, 2016; Wamsler and Brink, 2016; Wamsler et al., 2017).

We believe that this Special Issue will make important contributions to the literature, helping to identify research gaps and future research needs and broadening our understanding of how NBS provision contributes to resilient urban and other landscapes. Responsible actions to deploy NBS are urgently needed in this historic period impacted by increasing climate change, an accelerated transformation of the urban/peri-urban landscape and their related risks.

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