Environmental Science and Policy 112 (2020) 107–116

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Review

Identifying principles for the design of robust impact evaluation frameworks for nature-based solutions in cities

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ARTICLE INFO

Keywords:
Nature-based solutions
Cities
Evaluation
Impact
Social cohesion
Well-being
Knowledge gaps

ABSTRACT

Cities all over the world are confronting intertwined environmental, social and economic problems and aim to become resilient to climate change and promote wellbeing for all their citizens. Nature-based solutions have been proposed as a promising policy approach to addressing urban problems for the potential they have to deliver multiple benefits and foster wellbeing for individuals and communities. However, the evidence for their multiple benefits is rather scarce and highly fragmented, and more robust frameworks for the monitoring and assessment of their impacts are needed to guide urban policy-making. This paper focuses on the current state of impact assessment of nature-based solutions in Europe and through a systematic review of the literature identifies four conceptual problems and three empirical gaps that impede the accumulation of solid evidence regarding of the impacts of different types of nature-based solutions for different social groups; as well as of the contextual conditions that contribute to their performance and delivery of multiple outcomes. Based on the identified mis-conceptualizations and gaps, we derive a series of principles that should guide the development of robust impact assessment frameworks for nature-based solutions. We discuss the policy implications of these gaps and principles. We conclude by making a series of recommendations that should inform the design of impact monitoring and evaluation frameworks in cities, in order to develop the comparative evidence base on the effectiveness of nature-based solutions. This, in turn, can inform urban decision-making on the appropriate design, implementation, and long-term regeneration of nature-based solutions, to ensure long-term delivery of important ecosystem services for different social groups.

1. Introduction

1.1. Rationale

Transforming cities into vibrant, sustainable and resilient living places has become a key global priority, reflected in numerous policy documents, and the global sustainable development goals (www.undp.org), that calls for design and implementation of innovative solutions to tackle multiple and intertwined problems. As the global urban population is estimated to raise to, or possibly exceed, 70% by 2050, this interest has been reflected in concerted efforts of diverse actors to find creative solutions to the manifold problems they confront. Against this background, the idea of nature-based solutions has been proposed as a sustainable approach to support transitions to vibrant, healthy, resilient and sustainable futures in cities (UN, 2013).

Nature-based solutions have been defined as "actions which are inspired by, supported by or copied from nature" (European Commission EC, 2015) and have recently emerged as one of the main policy drivers for transitioning cities for their potential to fulfil multiple, simultaneous objectives (Faivre et al., 2017). Nature-based solutions use natural features to address societal challenges (Balian et al., 2016) and mitigate the exposure of the population to environmental hazards and other risks related to climate change. Since nature-based solutions imitate and enhance natural processes and mechanisms, they contribute to dealing with environmental problems such as air pollution, ecosystem degradation (Goddard et al., 2010), and produce multiple ecosystem services such as the regulation of extreme climate events like floods and heat waves or soil protection and restoration (Keesstra et al., 2018). Overall, nature-based solutions aim to "positively exploit the ecosystem services for climate mitigation and adaptation as well as resource efficiency" (Fink, 2016, p. 2; Brindal and Stringer, 2013) and to reach desired social and climate objectives

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https://doi.org/10.1016/j.envsci.2020.05.024
Received 3 April 2019; Received in revised form 14 April 2020; Accepted 30 May 2020

simultaneously (Mayrhofer and Gupta, 2016). Examples include micro-scale interventions, such as pocket parks, medium-scale, such as nature-based sustainable urban drainage systems and green roofs, and large-scale projects such as green corridors or urban parks.

Existing research has supported the view that nature-based solutions have the potential to simultaneously provide social, environmental and economic benefits (Haase et al., 2014), such as improved quality of life, physical and mental health (Kabisch et al., 2017), social cohesion and well-being (Brink et al., 2016), social interaction and supportive relationships among neighbors and a sense of belonging and place (Hartig et al., 2014; Sullivan et al., 2004; Keniger et al., 2013; Gulsrud et al., 2018). Nature-based solutions seek a better synthesis of natural processes with architecture and urban infrastructure through acts of creation, preservation and ecological restoration (Hartig et al., 2014), and are thought to improve how quickly both nature and people might adapt to change, thus making cities more resilient (IUCN, 2012; Sussams et al., 2015; Maes et al.,2016).

However, research on their specific impacts is scarce and the evidence of the delivery of such multiple benefits by nature-based solutions is still rather fragmented (Brink et al., 2016). Single case studies, limited sets of impacts considered, one-time evaluations, or an over-emphasis on particular types of nature-based solutions characterize existing evaluations (Raymond et al., 2017; Samuelsson et al., 2018). Furthermore, the evidence reviewed shows that environmental impacts have been more extensively analyzed (e.g. Ellison et al., 2017; Xing et al., 2017), than social and health impacts, on which evidence is still scarce or fragmented (Brink et al., 2016), in great part due to fuzzy conceptualizations of the relationship between nature-based solutions and their multiple types of outcomes. A clear delineation of impacts of nature-based solutions, of synergies and trade-offs between different types of impacts, and robust, flexible and cost-effective methods for their monitoring and evaluation are essential to building an evidence base for their performance in cities.Developing robust monitoring and evaluation frameworks to assess impacts of nature-based solutions will allow cities to assess the strengths and weaknesses of specific interventions in achieving strategic city goals. Different categories of stakeholders are increasingly demanding more evidence for the effectiveness of policies, as part of a broader movement towards evidence-based policy and management (Miller et al., 2017). It will also provide an essential tool for adapting design and implementation features in real time, thus increasing their performance. It may also build the case for investments in nature-based solutions, since most medium-sized cities in Europe often struggle to convince investors that nature-based solutions can deliver on the multiple objectives and interests their stakeholders have. Finally, robust evaluation is necessary for a change in mainstream ways of planning for urban resilience and regeneration, still dominated by redundancies that derive from understanding ecological, social and economic objectives as separate and sometimes at odds with each other and reflected in the silo-thinking of urban policy practice.The design and selection of robust, context –sensitive evaluation frameworks for nature-based solutions has to start, in our view, from a good appraisal of both strengths and limitations of existing evaluation carried out and reflected in published studies. The current systematic review aims to fill a gap in the literature by identifying key conceptual problems and empirical gaps in the comprehensive evaluation of nature-based solutions impacts. We followed the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

1.2. Objectives

This review identifies and synthesizes both conceptual problems and empirical gaps in the comprehensive and robust evaluation of nature-based solutions in cities. It analyses the implications of these and then seeks to identify a series of principles that should guide the development of evaluation frameworks that are both scientifically robust and allow for practical implementation by policy-makers in cities.

2. Methods

2.1. Eligibility criteria

This review was performed according to the PRISMA guidelines. As a first step, we identified existing attempts at formulating integrated impact assessments frameworks for nature-based solutions (i.e – considering a diversity of impacts). Four recent attempts have been made to conceptualize nature-based solutions and their multiple functions/benefits (European Commission, 2015; Cohen-Shacham et al., 2017, European Commission, 2015) as well as to synthesize and organize the array of impacts and indicators that appear in the literature (Raymond et al., 2017; Kabisch et al., 2016). These have been taken as a starting point to identify the areas for which a relative scientific consensus existed on impacts of nature-based solutions. We identified four main categories of impacts of nature-based solutions, which guided our subsequent review of evidence: environmental impacts, and especially climate change mitigation and resilience; social impacts; health and wellbeing; and economic impacts that arise from their implementation.

All original articles focusing on impact evaluation and/or the development of indicators of nature-based solution impacts, and those that reported performed evaluations of green infrastructure projects were eligible for this review. Additional eligibility criteria we adopted were: i) publication date between 2014 and 2019; ii) reporting original empirical research or being a systematic review of such research; iii) written in English or Spanish; iv) published in an academic peer-reviewed journal; v) reported specific impacts that could be classified in one (or more) of the four impact categories selected; vi) identified interventions that could be considered nature-based solutions, using the classification of Eggermont et al. (2015). Articles were excluded if: i) the NBS evaluated did not fit the definition of an NBS; ii) impacts were not clearly identified or did not fit the four categories.

2.2. Information sources and search

We used SCOPUS, Web of Science and Medline databases to identify relevant papers (January 2014 – March 2019). Reference lists of the studies we retrieved were also hand searched, in order to include relevant references missing from the original search, when they fitted the inclusion criteria. Key words and combinations of key words were used: “nature-based solutions” OR “green infrastructure” OR “renaturing impacts”; “nature-based solutions impacts” OR “nature-based solutions indicators”; “green infrastructure AND evaluation”; “nature-based solutions AND evaluations”; “renaturing interventions”; “renaturing interventions AND impacts”; “renaturing interventions AND evaluation”.

2.3. Study selection and data collection processes

After the database searches were performed, each article was screened for eligibility by the first author, and the full-text version of each potentially relevant reference was retrieved. We present the process we used to select those that were included in the review by using the PRISMA flow diagram in Fig. 1. The 174 references deemed eligible were then analyzed and recorded by using a spreadsheet designed by the first author, which included data on: i) impacts considered or evaluated; ii) evaluation method/s used; iii) risk of bias in individual studies; iv) social groups evaluated; v) limitations, among others.

We identified the risk of bias in individual evaluation studies by using the Cochrane collaboration framework. We specifically assessed for i) selection bias (biased selection of interventions assessed); ii) attrition bias (i.e biases due to the amount, nature or handling of incomplete outcome data); iii) reporting bias (i.e bias resulting from the selective reporting of those interventions that were successful); and iv) measurement bias (i.e. bias due to inappropriate operationalization of

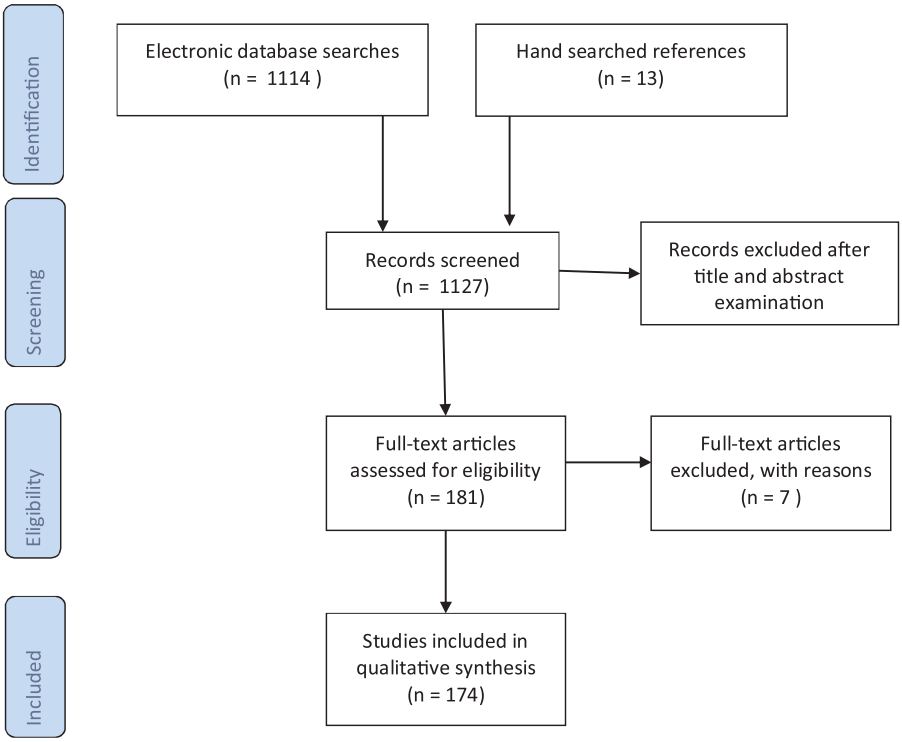

Fig. 1. PRISMA Flow Diagram for the selection process of articles.

concepts or use of measurement instruments) (Higgins and Green, 2011).

To analyze these contributions, a list of questions were developed on the basis of which we coded the articles. These were: a) which impact/s are specifically addressed?; b) Which impacts are catalogued as main impacts, and which ones are considered co-benefits? Are the latter assessed explicitly or only mentioned theoretically?; c) Are intermediary pathways or mechanisms made explicit for main and secondary impacts? d) When more than one impact is assessed, is there any analysis of trade-offs among impacts, and their distribution across social groups? e) Is evidence systematically gathered on the use of nature-based solutions by different social groups? f) Are disservices included in the analysis? g) Are impacts assessed at one time, or at multiple points in time? Each article was screened for answers to these questions.

3. Results: Conceptual problems and empirical gaps in existing evaluation schemes of nature-based solutions

Overall, our analysis reveals that impacts have been conceptualized and assessed on an ad-hoc basis, without systematic concern for clear conceptualizations of impacts or comparability across cases. Often, there is considerable conceptual fuzziness and/or overlap between the assessed dimensions. A critical synthesis and reflection of the literature review findings points to seven main problems in the design of evaluation schemes for nature-based solutions in cities. The following four can be considered conceptualization problems::

1 considering social cohesion and well-being impacts as indirect or secondary to environmental impacts of nature-based solutions;
2 mixing of process and outcomes (indicators) in evaluating nature-based solutions;
3 lack of explicit consideration of pathways through which nature-based solutions affect impacts, especially those related to human health and the social fabric;
4 lack of systematic mapping of synergies and trade-offs between different categories of impacts of nature-based solutions.

Additionally, the systematic review revealed three empirical gaps :

1 lack of evidence on the different uses of nature-based solutions by different groups, making it harder to assess differences in outcomes;
2 lack of inclusion of disservices in the evaluation of nature-based solutions;
3 lack of evidence regarding long-term effects of nature-based solutions.

We now turn to explaining these gaps in more detail.

3.1. Consideration of social cohesion and well-being impacts of nature-based solutions as indirect or secondary to environmental impacts

Certain direct environmental impacts of nature-based solutions have been extensively researched and documented (e.g. flood protection, habitat conservation), and often focus on the capacity and effectiveness of nature-based solutions to mitigate climate change effects on urban population (Cohen-Shacham et al., 2017; Raymond et al., 2017; Fini et al., 2017; Mexia et al., 2018). Existing reviews that look at the multiple functions of nature-based solutions give priority to environmental impacts (Fini et al., 2017; Brink et al., 2017), which is coherent with the fact that climate change has driven concerns about the loss of nature in cities, and the relatively straightforward ways in which such effects can be examined.

Our review found that environmental impacts are specifically addressed in 60% of the reviewed articles (101 of the total), while only about 30% address social and health-related impacts (51 of the reviewed articles), and about 10% address economic impacts (16 of the reviewed articles). When more than one impact is considered (134 references), many contributions consider impacts in the same category and environmental impacts are primarily addressed. From all the references addressing a secondary impact in a different category (71 articles of the 134 references), only in 2 references of those reviewed articles these (often called co-benefits) are measured explicitly, making them a rare exception. Thus the potential impacts of nature-based

solutions on environmental, social and economic outcomes remain understudied and not systematically evaluated.

What drives the consideration of social impacts of nature-based solutions as indirect or secondary is related to both the lack of a clear conceptualization of relationships between nature-based solutions and different types of social impacts such as social cohesion (Yan et al., 2018), as well as the pluri-determined nature of these, both contributing to difficulties in their operationalization and measurement, as well as in the attribution of causality of impacts.Interestingly, the same lack of focus on social impacts, as compared to environmental impacts has been observed in other, more established intervention evaluation areas, such as forest conservation, and attributed to the difficulty in the evaluation of wellbeing outcomes (with the exception of poverty alleviation), the lack of technological advancements in data collection characterizing the measurement of environmental impacts (i.e through remote sensing), as well as to that of using mixed methodologies, pertaining to different research traditions and disciplines (Game et al., 2018; Miller et al., 2017).

If we take the example of social cohesion, as a category of possible social impacts of nature-based solutions, we find that it has only poorly been addressed (Kabisch et al., 2015), and an urgent need to clarify whether social cohesion is either a real-life phenomenon (reflective construct) or a theoretical one has been signaled (Janmaat, 2011). Specifically, social cohesion is often used in ambiguous ways, which encompass dimensions that take the individual as a unit of analysis, such as positive perceptions of the neighborhood, and others that take the social group or community as the unit and consider manifestations of social cohesion to be related to frequency of interactions or density of networks. Others do not differentiate between conditions that can foster social cohesion (e.g. opportunities for contact and positive interactions) and the actual manifestations of this social phenomenon. Along the lines of Schiefer & der Noll (2017), we posit that properly assessing social cohesion among the impacts of nature-based solutions requires clear conceptualization of its dimensions. These dimensions include the quality of social relations (composed by social networks, trust, acceptance of diversity and participation); identification with the geographical unit or social entity; and orientation towards a common good (involving sense of responsibility, solidarity and compliance to social order). Moreover, characteristics of social cohesion should be differentiated from the conditions that might foster it, and from its outcomes on communities. Dimensions such as (a) shared values, (b) equality/inequality and (c) objective and subjective quality of life, can be considered either determinants or outcomes of social cohesion (Schiefer & der Noll, 2017). The use of mixed methodologies to gather impact data is becoming more common as cities strive to implement interventions towards achieving the sustainable development goals, and technological advancements in data collection are also being adopted in relation to social data. However, without clear conceptualizations of impacts, these advances will not lead to solid evidence generation on multiple types of impacts.

3.2. Mixing of process and outcomes (indicators) in evaluating nature-based solutions

Much of the research on nature-based solutions has been conducted on single case studies in which a diversity of process and outcome features coexist. In our review, only 8 of the total references reviewed used a comparison of two or more cases, and even for these, insufficient attention is given to differences in the process characteristics of design and implementation of nature-based solutions, and these are not systematically differentiated from expected outcomes. Such coexistence has made it impossible to systematically explore the effects of process features on the outcomes of nature-based solutions, and to isolate causality of the specific processes affecting the impact of these interventions. An additional layer of complexity is added by the fact that effective design and implementation of nature-based solutions requires a cross-disciplinary approach, with different types and sources of evidence to draw on for the evaluation of different categories of impacts, which is the case, more broadly, for all sustainability interventions (Game et al., 2018). The governance of the design and implementation of nature-based solutions can contribute to either enhancing services or disservices of nature-based solutions (Kabisch et al., 2016; Nesshöver et al., 2017). However, we argue that in order to understand what contributes to nature-based solutions performing at their highest potential, conceptual and empirical differentiation between process and outcomes is important (e.g. were relevant stakeholders involved in the process, or not; which actors were involved; how much ownership over the decision-making process did different actors have, selections of sites etc.), as a precondition for indicator development, identification of data gaps and robust, cost-effective and continuous data gathering methods to be put in place. Systematic comparison between different processes of design and implementation is needed, through appropriate case selection and evaluation methods.

3.3. Lack of explicit consideration of pathways through which nature-based solutions affect impacts, especially those related to human health and the social fabric

The existing knowledge on nature-based solutions underlines the fact that social and individual adaptive capacity must be enhanced for their potential impact to be maximized. For example, the creation of a park might generate easier access to exercise and restoration opportunities, but use of it by different social groups might depend on other mediating conditions such as the encouragement of healthy habit formation. Assessment and identification of such mediating conditions that could increase impact of nature-based solutions remain relatively unexplored and environmental management studies point to the difficulty in assessing these, due to their dependence on the complexity of human experience and behavior (Demuzere et al., 2014).

The associations between nature-based solutions and general health levels have been identified, as well as between green space availability and levels of physical activity (Egorov et al., 2018; Kondo et al., 2018; NICE, 2018; WHO, 2018). Our review indicates that there is increasing evidence pointing to the restorative effects of exposure to nature for humans and designing urban spaces that facilitate interaction with nature is seen to increase opportunities for wellbeing (Gillis and Gatersleben, 2015; Honold et al., 2016; Schipperijn et al., 2013). However, validated evidence on this subject is still rather contradictory, with some studies unable to find clear relationships (e.g. Hartig et al., 2014). Although green and blue spaces offer opportunities for the kinds of activities and lifestyle choices that prevent illness, it has not been shown that they directly influence behavior. In spite of the positive associations found between access to green spaces and different dimensions of health and wellbeing (World Health Organization Report, 2018; Panno et al., 2017), the causality between different types of nature-based solutions and well-being is still far from being elucidated.

Demuzere et al. (2014) also underlined that the salience of environmental benefits varies according to the spatial scale considered, and others stressed the need to consider that some biophysical processes that urban green areas generate particularly benefit residents while others such as carbon reductions are distributed at a city level (Kabisch, 2015).This points to the need to understand the complex interactions between opportunities created by environmental features of nature-based solutions and the social system characteristics that might contribute to their multiple functions.

Our review shows that from those studies focusing on health and social impacts of nature-based solutions, only 13 references, or about 20% of the total explicitly considered intermediary pathways. Thus, there is a significant lack of understanding regarding the conditions under which nature-based solutions achieve impacts, and especially social and health impacts. In the domain of conservation studies, it has been noted that traditional ecological assessments often omit impacts

on social systems, a tendency that should be corrected through the explicit mapping of causal chains in social-ecological systems (Qiu et al., 2018).We argue that systematic evaluation of the impacts of nature-based solutions should contribute to the understanding of the conditions under which different types of nature-based solutions lead to specific health and social outcomes, as nature-based solutions are understood to be, by definition, multifunctional. A clear differentiation between direct and indirect impacts, as well as of mediating conditions would support decisions on what constitutes appropriate and credible evidence from a cross-disciplinary perspective, as interventions addressing urban challenges normally span multiple disciplines and thus need to draw on multiple sources and types of evidence (Game et al., 2018).

3.4. Lack of systematic mapping of synergies and trade-offs between different categories of impacts of nature-based solutions

Different impacts interact with each other either in synergistic ways (in which a positive effect in one category also has a positive effect in another impact category) or, by being a trade-off (by which achieving a positive effect in one category brings a negative effect in another or a positive effect on a social group entails a negative effect for another). Although trade-offs and co-benefits are often mentioned in the literature (Nesshöver et al., 2017; Demuzere et al., 2014; Raymond et al., 2017; Liquete et al., 2016; Meerow & Newell, 2017; Schwarz et al., 2017), only few of these trade-offs and synergies are empirically documented (Mexia et al., 2018). Both depend on the characteristics of the nature-based solution itself, as well as on the process for their design and implementation. For example, evidence suggests that including rewilded areas within green areas has a positive effect on both biodiversity and psychological restoration, but they are also unsafe for particular social groups, such as women. Moreover, some effects are assumed to be positive, in the absence of evidence, or without considering alternative possibilities. For example, some nature-based solutions are assumed to promote improved social contact and this is assumed to be positive for intergroup relations and social cohesion. However, some evidence suggests that social contact among different socio-demographic groups might actually lead to the reinforcement of negative perceptions or to diminishing sense of place for particular groups (Dixon and Durrheim, 2004). It has also been suggested that nature-based solutions could lead to the creation of new conflicts of interest (Raymond et al., 2017).

Our review identified only 5% of the total contributions that (somewhat) systematically consider synergies and trade-offs. Only 8 references of the total reviewed ones systematically considered trade-offs in an evaluation process, and although theoretical references are made to trade-offs between social groups, only 2 of those explicitly documented such trade-offs., Evidence on trade-offs between categories of impact (i.e. between environmental and social effects, or environmental and economic) is rare (Hegetschweiler et al., 2017), and the main identified one is eco-gentrification (Curran and Hamilton, 2012; Kabisch & Haase, 2014; Haase et al., 2017), the phenomenon by which greening increases area attractiveness and property prices, leading to the exclusion of certain socio-economic groups. Further identification of synergies and trade-offs between different impacts is required, to understand which characteristics of nature-based solutions can act as enablers or amplifiers of effects, and which might act as buffers of negative trade-offs, thusincreasing the potential for multi-functionality and innovation.

3.5. Lack of evidence on the different uses of nature-based solutions by different groups, making it harder to assess differences in outcomes

From all the reviewed contributions, only 37 references (22%) analyzed how a particular impact is experienced by different social groups. The majority of these reported results only in terms of socio-demographic differences for men and women and, to a lesser extent, for different age groups, while other variables such as socio-economic status or different cultural backgrounds are largely ignored. Studies have shown that younger people (and especially men) use green spaces for physical activity, while older populations use them for socializing, relaxation or contact with nature (Schipperijn et al., 2013; Andersson et al., 2015; Sang et al., 2016; Raymond et al., 2017). Different income groups derive benefits from nature-based solutions through different mediating conditions: for example, higher income groups experience higher wellbeing through an increased sense of community because of green space availability and use, while lower income groups derive it from increased social contact (Maas et al., 2009; Forrest and Kearns, 2001). Social factors (e.g. loneliness, shortage of social support) mediate the relationship between green space availability and health levels (Maas et al., 2009). In order to understand the effect of nature-based solutions on social and health outcomes for different groups there is a need to understand how different groups use or interact with a particular nature-based solution. A lot of questions arise especially regarding what types of activities and behaviors they perform or adopt, and what their perception or subjective experience is when using nature-based solutions. A clear understanding of these will, in turn, will influence the potency and impact that scaling nature-based solutions in cities may have on particular demographies.

These examples illustrate a complex web of interdependencies between different uses of nature-based solutions by different groups that still requires a conceptual mapping and clarification. Developing profiles of uses of nature-based solutions may advance our examination of the co-benefits derived and recognized by these different user groups. Considering also how nature-based solutions are used by different groups can further inform management practices and planning for restoring and maintaining nature-based solutions in cities (Campbell et al., 2016).

3.6. Lack of inclusion of disservices in the design and evaluation of nature-based solutions

Disservices have been defined as “functions of ecosystem that are perceived as negative for human well-being” (Lyytimäki and Sipila, 2009, p. 311). They relate to human perceptions of risks and effects of nature-based solutions. For example, studies show that the higher the biodiversity of green spaces, the biggest their potential for improving visitors' wellbeing and for attracting people to spend time in them (Carrus et al., 2015; Sang and Ode Sang, 2015). However, dense vegetation areas can generate feelings of threat or lack of safety, which limit the restorativeness potential of green areas (Peschardt and Stigsdotter, 2013). Thus, while dense vegetation areas might have positive environmental effects, they might have reduced health-impacts, leading to avoidance of use (Nordh et al., 2009; Hegetschweiler et al., 2017). Our review indicates that the study of unintended effects or disservices (Haase et al., 2014) has not been properly integrated into the evaluation of impacts of nature-based solutions (Mexia et al., 2018; Lyytimäki and Sipila, 2009). To date, we have found limited evidence of systematic consideration of disservices, with only 8 (5%) of the reviewed studies assessing at least one type of disservice. It has already been in previous reviews that the focus on disservices has mostly been from an ecological perspective (Haase et al., 2014). Eco-gentrification and issues of justice in cities have been the exception, as social disservices of nature-based solutions (Haase et al., 2017). Kabisch & Haase (2014), for example, have pointed out that, while the distribution of green areas per capita can be seen as fair in Berlin, adding neighborhood density to the analysis shows that the population of denser areas had proportionately less access to green areas. Cohen-Shacham et al. (2017) discuss the implications of distributive justice (allocation of urban green areas proportionally to neighborhood density), procedural justice (opportunities for getting involved in decision-making processes) and interactional justice (quality of interaction with others, not

feeling excluded) for achieving desired impacts form the UN point of view. They suggest that taking them into account would maximize the co-benefits of nature-based solutions (see: Wolch et al., 2014). A minor effect in absolute terms (e.g. a 10% reduction in obesity) might be a very significant effect in terms of social justice, by reducing the gap between privileged and underprivileged groups. Indicators developed to assess justice in the distribution of green space in cities have focused on access and creating a standard that can be applied easily and inform decision making. The Green Vegetation Index has been proposed as a standard for optimal access, but some studies have shown that even in conditions of optimal access to green space, actual use and thus resulting benefits from it are unequally distributed. We therefore argue that evaluation plans of nature-based solutions should define and focus on both positive and negative effects and consider the magnitude of these effects for different demographic and ethnic groups. This will foster the identification of conditions of injustice and allow for policy corrective actions.

3.7. Lack of evidence regarding long-term effects of nature-based solutions

The issue of how impacts are experienced over time is not new in the urban sustainability policy arena, and nature-based solutions are not exempt from this. Immediate effects might depend on design and implementation, but long-term effects are likely to be more dependent on additional conditions, related to social uptake, sustainable mechanisms for their maintenance and use, and conditions that might foster continuous renovation and creativity around the use of nature-based solutions (Sullivan et al., 2004; Kabish & Haase, 2014; Nesshöver et al., 2017).

We found a repeated pattern of evidence of short-term evaluations of nature-based solutions given that most of the evidence is gathered in single case studies in cities or locations, handled on a short-term basis (e.g. at most 4 years evidence on the impacts of nature-based solutions, like in Fini et al., 2017), and that most case study research is project-based and rarely longitudinal, as it has already been noted (Wild et al., 2017; Braubach et al., 2017; Kabisch and van den Bosch, 2017). In our review, only 12% of the reviewed studies relied on longitudinal data to analyze particular effects (20 of the reviewed references), and only a handful (6 of the reviewed references) reported data collection at more than a one-time follow-up point. Additionally, most of these longitudinal studies use panel data collected at two or more points in time, which does not allow for the understanding of the dynamics influencing impact change from one data collection point to another, a problem also recently identified in a review of forest conservation evaluations (Miller et al., 2017).The limited research on cross-case study analyses still provide useful evidence on the impacts of nature-based solutions even though evaluation remains short-term (Buijs et al., 2016; Vierikko et al., 2016; Connop et al., 2016; Frantzeskaki et al., 2017). Short-term evaluation is appropriate for specific environmental impacts (e.g. improvements in air or water quality) but problematic for complex ones such as climate change resilience, which requires a longer-term approach. Estimations of climate change trends in rapidly expanding urban areas have shown that long-term effects such as increasing drought and heat risks in cities should be adequately measured and taken into account in urban planning (Scheuer et al., 2017). This need becomes even more apparent when we consider social impacts, some of which require a longer time span to develop (e.g. social cohesion or stress) (de Vries et al., 2013), or when attempting to evaluate multiple outcomes of nature-based solutions (Peters et al., 2010). Certain health-related impacts can only be evaluated over the longer term, such as changes in life expectancy or in the prevalence and incidence of certain diseases in a particular population. This results in significant gaps of evidence on how nature-based solutions impacts unfold over time, and it runs the risk of nature-based solutions being under-evaluated, in comparison to conventional grey infrastructure solutions (Raymond et al., 2017). These gaps in turn lead to difficulties in adjusting implementation and maintenance efforts for optimal outcomes of nature-based solutions and can contribute to losing opportunities for increased value and impact creation over time. The performance of nature-based solutions over the long term has been related to local capacities for regeneration and innovation. As the value of infrastructure remains stable or even decreases over time, their long-term performance depends on their capacity to accumulate social value (i.e. through co-ownership) (Cohen-Shacham et al., 2017; Demuzere et al., 2014; Nesshöver et al., 2017). Another important risk is the loss of opportunities for multiplying effects or reducing nature-based solution performance over time, through small additional interventions targeting their social uptake. The lack of evidence on longer-term impacts of interventions has been attributed to donor incentives, project-based cultures of interventions, the difficulty and costly nature of capturing impacts and their interactions over the longer term (Miller et al., 2017).

4. Principles to guide the design of evaluation schemes

For addressing these knowledge gaps, we now propose a set of principles to guide the conceptualization and design of evaluation schemes of nature-based solutions in cities. Some of these principles have already been suggested as relevant in a limited number of very recent published work on nature-based solutions and we propose them as a starting point for new dynamic and integrative schemes for evaluation.

4.1. Conceptualize and test clear hypotheses on the pathways through which nature-based solutions deliver outcomes

Evaluating multiple impacts of nature-based solutions requires the consideration of complex causality, as well as understanding of the nonlinearity of social and ecological systems (Walker and Meyer, 2004) Ecological, social and economic impacts are generally pluri-determined, and evaluating effects of particular features of nature-based solutions is challenging in real urban contexts, due to the presence of many factors operating at the same time. Although calls have been issued to consider the intertwined nature of sustainability challenges, and to reconcile ecological and human development needs (Qiu et al., 2008) in fields such as conservation studies, or adaptive management, it has also been noted that explicit consideration of both direct and indirect pathways is still rare (Qiu et al., 2018). Careful conceptualization of intermediate mechanisms should guide evaluation, which would also allow for the identification of gaps in evidence regarding particular pathways. Methodologies to assess the complex relations among immediate and more distal outcomes of nature-based solutions will facilitate the process of assigning impacts to specific nature-based interventions. The transdisciplinary mapping of causal chains has been proposed to map both direct and indirect pathways in conservation interventions that aim to assess effects on social-ecological systems, in order to foster the creation of an evidence-base for the impacts of such interventions (Qiu et al., 2018). Recent research from Samuelsson et al. (2018) shows the merits of such an approach including a conceptualization of experiences as a mediating factor between nature and well-being. In the same vein, Panno et al. (2017) also researched perception of heat and ego depletion as mediating factors between nature-based solutions and well-being. While existing research has investigated intermediate mechanisms between green spaces and health and well-being outcomes, including a systematization of pathways between these (Who Report, 2018), most evaluation designs of nature-based solutions still do not consider these.

Furthermore, the mapping of actual uses and experiences with nature-based solutions of different demographic groups should be included in evaluation design. Climate change effects, vegetation coverage, biodiversity, or green space accessibility are already mapped by different organizations (e.g. IPCC, EEA) and adding behavior and experience mapping would provide richer and more nuanced knowledge

on the performance of nature-based solutions for different urban policy and planning objectives. The use of geo-localization tools in surveys, and approaches such as participatory GIS assessments have started to facilitate mapping of uses, but studies reporting the use of these methodologies for impact assessment of nature-based solutions is still rare. As social and health impacts of nature-based solutions are evaluated less, we argue there is a need for conceptual development of the pathways through which different types and design features of nature-based solutions impact different social outcomes, as well as on the differences of impact for different demographic groups and the reasons underlying them. Moreover, additional work needs to be done on systematic reviews of evidence that identify which causal pathways are supported by evidence and which are not, as well as on cross-disciplinary identification of causal chains (Qiu et al., 2018).

Policy can benefit greatly from disentangling causal relationships and understanding which elements have the highest influence over specific objectives, to make cost-effective decisions, as well as to remodel nature-based solutions over time to optimize their performance. As part of the design of impact evaluation schemes, policy-makers should use tools to systematically map the theory of change they use, and explicitly consider the relationship between intervention features and outcomes. This is still a challenging yet necessary endeavor in practice, requiring collaborations among scientists, stakeholders, practitioners and policymakers (Qiu et al., 2018; Game et al., 2018). These networks benefit from persistence in time, which would foster necessary trans-disciplinary learning. They also benefit from all relevant disciplines being represented, and should help identify where assumptions are based on evidence, and where they are unfounded or constitute hypotheses that will be tested through the intervention.

Evaluation processes should also include iterative identification of additional impacts that might have been omitted in the initial steps, as well as feedback loops through which evidence is fed into the policy-making and future evaluation design. Finally, practical tools should be developed that guide city stakeholders in mapping the relationship between interventions and outcomes, as well as to support policy learning from one evaluation process to the next.

4.2. Evaluate interactions between different impacts and identify enablers/amplifiers, both environmental and social

Evaluation plans should systematically identify potential interactions or interrelations among different types of impacts and consider differential effects on socio-demographic groups. Social-ecological systems are characterized by complex interactions that generate thresholds and tipping points, as well as by non-linearity, which involves un-predictable interactions between outcomes (Walker and Meyer, 2004). Carefully designed interdisciplinary case studies that focus on uncovering the complex trade-offs and synergies between impacts of nature-based solutions is required, using not only statistical methods but also connecting quantitative approaches to rich qualitative evaluations and combining traditional andcitizen science approaches. For example, this can be performed by combining qualitative assessments on the social effects of nature-based solutions that focus on perceptions (Botzat et al., 2016; Buchel and Frantzeskaki, 2015; Cooper et al., 2016; Farjon et al., 2016; Fish et al., 2016) with quantitative assessments of outcomes. Examples of such combined indicator analyses are slowly showing in the literature (e.g. Panno et al., 2017 on participatory GIS assessments, Ladonrelle et al 2016 on combining policy priorities with ecosystem services assessments), but they are still far from being the norm. The need to mix quantitative and qualitative approaches to understand the nuanced impacts of interventions and their interaction over time, as well as to develop context-sensitive, cross-case indicators has already been identified in other evaluation strands with longer research traditions, such as those applied to forestry interventions (Miller et al., 2017). Careful planning of impact evaluation studies, that clearly identify interventions implemented, contextual characteristics of the implementation, types of impacts evaluated, and how they might be expected to interact, together with appropriate choices of mixed methodologies for evaluation, especially when performed across multiple implementation cases, can significantly contribute to the accumulation of evidence regarding outcomes and performance of nature-based solutions.

4.3. Include magnitude of impact for different groups and relative position change

The optimal performance of nature-based solutions depends on their social uptake and use over time. Certain social groups are sometimes excluded from engaging with nature-based solutions. To be effective, evaluation ought to include methodologies to assess magnitude of impact for different sought outcomes and relative position change of certain groups on these, as the same level of change in absolute terms will have different implications for different groups. Socio-demographic groups that start from a baseline of health and wellbeing that is already considered to be good might register a small improvement in qualitative terms, while the same level of change from the baseline for a deprived group might translate into significant health and wellbeing outcomes. Furthermore, climate change mitigation effects of nature-based solutions are not equally distributed among socio-demographic groups, and thus appropriate baseline measurements of different impact categories are very important when designing evaluation of nature-based solutions.

This would support policy-makers in deciding the distribution of different types of nature-based solutions across a city. It would also support efforts to identify additional interventions that might need to be put in place to address inequalities and foster the delivery of positive outcomes for those in situations of deprivation or marginalization.

4.4. Appropriate temporality and maintenance of evaluation

Evaluation design should include assessments of impacts over time, as appropriate for each type of outcome sought, to build a solid evidence-base across different cases of implementation in Europe. This requires the development of indicators that are robust yet flexible, the sequencing of outcomes and of the relationship between them over time, and data infrastructures that allow for continuous evidence gathering at reasonable costs. A focus on long-term impacts is closely related to the consideration of the nature of different impacts, the clarification of causal mechanisms or pathways between interventions and outcomes, and the factors that might influence their intensity and persistence over time (Miller et al., 2017). One way of ensuring long-term assessment is by including nature-based solutions indicators in European or national commitments to assess progress towards internationally agreed targets, such as the UN sustainable development goals. Integrating data from existing assessments such as MAES (Mapping and Assessment of Ecosystem Services) or the European Environmental Agency´s Urban Atlas into coherent evaluation plans for nature-based solutions has been identified as a challenge for the immediate future by the Urban Agenda Partnership for the European Union. Another proposed approach has been to identify indicators that are predictive of longer-term impacts, through the clear articulation of the theory of change explaining why predicted outcomes are to be expected. (Miller et al., 2017).

Long-term evaluation should also extend beyond the use of panel data to case-based long-term evaluations that would shed light on the specific interplay between outcomes over time. This requires stepping out of a project-based mentality to a focus on fostering urban resilience and sustainability, which benefits from incremental policy and ongoing evaluations. Cities could establish ongoing evaluation programmes for a range of interventions, which would contribute to the creation of a rich evidence base for urban cases while allowing for inter-city and inter-case comparisons, provided that considerations of comparability are

included in impact evaluation design and methodologies from the beginning.

5. Discussion and conclusion

Renaturing cities in an era of increased environmental, social and economic risks is a promising avenue for the fostering of urban resilience. The creation of a solid evidence base on the multiple outcomes of nature-based solutions may support policy-makers in their design and implementation efforts as well as harness investment, as their real potential and effectiveness is documented. The review of existing evaluation frameworks and cases of nature-based solutions has revealed a series of conceptual problems and empirical gaps that should be addressed for a solid and usable evidence base to develop in the following years, and to inform policy decisions in European urban projects. Although both the demand and the practice of evaluation are not new, the reflection on what constitutes robust evaluation in cross-disciplinary interventions is a recent phenomenon, prompted by a growing culture of evidence-based policy-making and the intertwined and complex nature of sustainability challenges (Miller et al., 2018; Qiu et al., 2018). Based on the principles we outline, we find that nature-based solutions projects would benefit greatly from the development of clear conceptualizations of impacts, as well as of the understanding of positive and negative interactions between them and their distribution across diverse socio-demographic groups. Outlining these causal chains would support a more nuanced, nonlinear view of the interactions between social and ecological systems, and the recognition of thresholds or tipping points that can inform decision-making in cities (Qiu et al., 2018). Moreover, more theoretical work is needed to outline the pathways connecting different types of nature-based solutions to impacts, especially focused on intermediary mechanisms and the dependence of the performance of nature-based solutions on the characteristics of the social system in which they are embedded. These will greatly inform the design of impact monitoring and evaluation frameworks and allow comparisons across case and urban sites.

The empirical gaps identified point to the need for new approaches in designing case study research and the gathering of convincing evidence on the impact of nature-based solutions, but also to how the evidence gathered can be further systematized and enriched with the use of comparative design and meta-analyses. Systematic evidence on smaller scale, localized cases is useful for a deeper understanding of the causal relationships between different elements of an intervention and a set of outcomes. Also, insight into how particular nature-based solutions work in particular contexts can contribute to a better understanding of when particular types of nature-based solutions should be the solutions of choice. However, evaluation designs that fostercross-case comparability allow for lessons on nature-based solutions to be extracted and then transformed into decision-making tools that can support cities in making more socially, environmentally and cost-effective choices. If evaluation is designed carefully from the start and considers multiple cases, a good balance can be found between the depth that can be achieved through local case-study evaluations, versus the breadth provided through the use of indicators and data collection methods with a higher level of generality (Qiu et al., 2018). The richer, qualitative understanding of outcomes in single, localized cases, together with systematic cross-case comparisons that can identify regularities in sets of conditions leading to particular outcomes, can significantly advance our knowledge base on outcomes of interventions. Different types of evidence can build on each other in an iterative process, enabling a broader understanding of the multiple outcomes of nature-based solutions and their distribution across social groups. For the consolidation and openness of these data, the considerate design of data platforms is important, so as to ensure that both rich descriptions and systematic quantitative data, as well as systematic reviews of evidence are made available and transferable across cities/localities.

Moreover cities would benefit greatly from a more thorough understanding of the factors and conditions that contribute to diverse outcomes for different social groups and over time. Beyond the mapping of distribution of and access to nature-based solutions, and the assessment of their environmental benefits, behaviors, uses and experiences of different urban social groups should be studied and mapped, to achieve social justice in the distribution of costs and benefits of nature-based solutions. More nuanced understanding will support policy choices of the types of nature-based solutions and the sites and scale of their implementation. Finally, evaluation of impacts over the long term can inform strategies for preservation and regeneration of nature-based solutions as well as continuous and dynamic innovation for higher resilience and wellbeing in cities.

Declaration of Competing Interest

The authors of the article with the reference number: ENVSCI_2019_300, titled “Identifying principles for the design of robust impact evaluation frameworks for nature-based solutions in cities”, Adina Dumitru, Niki Frantzeskaki and Marcus Collier, declare there are no competing interests to declare.

Acknowledgements

The research of this paper is part of the Connecting Nature project, and has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement No 730222. Authors are thankful to Helena Martinez for her assistance in the initial literature search on social cohesion, well-being and nature-based solutions and to Giorgia Silvestri for organizing the expert elicitation process that supported the findings of this paper.

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