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What hinders implementation of Nature Based Solutions

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Resumo:

Nature-Based Solutions (NBSs) are nature-inspired approaches aimed at solving environmental-, social- and economic issues, such as unsustainable living and climate change. Nature-Based Solutions (NBSs) are nature-inspired approaches aimed at providing solutions to intricate social, environmental and economic challenges, such as climate change, air quality, water flow control and unsustainable living. NBSs refer to methods such as restoration or creation of waterbodies or green systems that aim at, for example, climate change mitigation, air purification, water flow control and water treatment. In this study, deeper focus was set on green solutions (urban trees, green walls and green roofs). Currently the concept of NBS is at its development stage as it is relatively new and still loosely defined. Based on a literature review, we propose that NBS is used as an umbrella concept for similar concepts (e.g. green-blue infrastructure, ecological engineering), with the additional remark that it should have an instrumental value for solving current problems in a sustainable way. This requires validating and evaluating NBS results in order to assure their comparative efficiency/benefits in comparison to traditional approaches. This, however, is still to be developed and is today an important weak point of the approach, which prevents its spread. Although there are several reports claiming NBSs are efficient for multiple purposes, the results are generally not statistically valid. Among other factors, low number of replicates, lack of proper indicators for impact evaluation and lack of comparative studies between traditional and NBS-approaches are a cause of concern. Hereby, we conclude that there is a need for further studies on NBSs before they can be considered as practical solutions. In order to hasten future research, we identified the major weaknesses, knowledge gaps, impacts, impact mechanisms and the most influential factors that affect impact effectiveness regarding NBSs.

WHAT HINDERS IMPLEMENTATION OF NATURE BASED SOLUTIONS

INTRODUCTION

The pursuit of a sustainable future implies solutions for various pressing issues such as climate change, air pollution, water availability and quality. These issues are a result of human activities which, by accumulation along a period of time, have reached a planetary scale. Climate change threats biodiversity and ecosystem function, degrade habitats and increase the probability of extreme events (such as storms, floods, droughts) causing water scarcity issues among other issues (Kabisch et al., 2016). Poor air quality, mostly caused by greenhouse gas emissions and other air pollutants (e.g. PM_{10}, $PM_{2.5}$, NO_2, O_3, CO, SO_2) released from human activities (Raymond et al., 2017a; Sicard et al., 2018) negatively affects human health (Raymond et al., 2017a; Sicard et al., 2018; Yli-Pelkonen et al., 2017; Viecco et al., 2018) and can be associated with around 8 million deaths/year worldwide (Sicard et al., 2018). Water, once regarded as an unlimited resource, has now both quantity and quality under pressure. This is due to direct drivers such as pollution and indirect climate change associated effects, such as changes in temperature and rainfall patterns, which can result in flooding (and run-off problems connected to them) or droughts. (Raymond et al., 2017a). Urban settlements are major contributors to freshwater availability and quality stress; particularly impermeable surfaces that are typical for urban areas lead to increased volumes of surface water run-off and to degradation of water source quality (Jartun et al., 2008; McDonald et al. 2014). Only to a certain extent, have technology so far been able to replicate the services that are freely provided by nature such as air and water purification. And, to this date, there is no substitute for climate regulation. The increasing awareness of the limited capacity of human-made artefacts in solving planetary issues coupled with the urgency to deliver feasible solutions has made the term coined Nature-Based solutions (NBSs) a promise towards solving these issues. Nature-Based Solution (NBS) became "mainstream" in the scientific literature in the early 2000s, aiming at creating more focus on sustainable development. It is an "umbrella concept" including various concepts that are similar, but have slightly different approaches (Potchin et al., 2016). Nature- Based Solutions (NBSs) are generally defined as actions that "aim to help societies address a variety of environmental, social and economic challenges in sustainable ways. They are actions which are inspired by, supported by or copied from nature" (European Commission, 2015). These solutions include various methods that non-human organisms use to survive, such as the ability to store carbon or the ability to regulate water flows (European Commission, 2015).

Typically, NBSs can be divided into green and blue solutions. While green solutions mainly have a role in climate change mitigation, urban regeneration and air purification, blue solutions refer to methods that affect run-off management, water purification and water supplies (restoration/creation of wetlands and urban waterbodies, and overall use of vegetation for water management). NBSs brings and links together many established ecosystem-/nature-based approaches, such as "ecosystem services", "green-blue infrastructure", "ecological engineering", "ecosystem-based management", "natural capital" (Raymond et al. 2017a), "nature-based infrastructure" and "engineering with nature" (Nesshöver et al., 2017). However, the wide variety of similar terms creates confusion among researchers and decision-makers, creating a need for further clarification of the term NBS as well as its expected contribution to a sustainable pathway (Potchin et al., 2016).

Even though several studies (European Commission, 2015; Fernandes et al., 2018[1]; Nesshöver et al., 2017; Potchin et al., 2016) have attempted to provide a more refined definition, the term NBS remains quite loose. The dilemma is that while vague concepts are important (e.g. the concept of sustainable development), concepts that are too broad that anything can fit may become banal and often a rhetoric tool. Thus, further work to better sharp the concept is needed in order to help advance its implementation. Furthermore, there are few practical examples describing major flaws while there is abundance of studies that describes NBS more idealistically. We argue that a critical analysis of NBS, including the main factors that impact its efficacy and those that hinder its implementation, could provide important guidelines for further studies, and ultimately, better NBS results.

This study attempts to provide a depth understanding of the term nature-based solution and a framework to assist the implementation of NBSs in practice. Recent case studies are analyzed in order to provide an overview of: (1) what is currently considered as NBS, (2) what are the major problems hindering NBS implementation and (3) how should further studies be "initialized".

METHODOLOGY

We conducted a literature review by first searching for the commission and expert group summaries (EU, IUCN, ELKIPSE), followed by a search of recent scientific articles according to the following steps. Firstly, we used the advanced search tool on Google Scholar to look for papers including the term "nature-based solution" for the timeframe 2013-2018. This search resulted into 394 articles (including green and blue solutions). As our aim is to analyze green systems ((use of vegetation, mainly urban trees, green walls and roofs), we excluded the articles on blue solutions. We also excluded other papers which content was considered unsuitable. Additionally, we expanded our list by using a "references of references" approach. This process resulted in 25 articles, which are presented in Table 1.

Table 1. Literature used in this article, their type and location of research. Literature tagged by "NBS" refers to literature that treats NBSs from a general viewpoint, whereas "green

1 Fernandes et al. (2018) presented the following criterion for using the NBS concept: (1) the methods must offer simultaneous benefits to society, economy and nature; (2) the methods must include experiences gained from existing concepts, such as "blue-green infrastructure" or "ecosystem services" and; (3) the methods should be introduced gradually for proper evaluation in real-life settings.

space" refers to research on specific applications of NBS such as urban trees, parks, forests and vegetation related to these environments.

Author	NBS implemented	Location	Study
European Comission, 2015	NBS	Review	General NBS overview
IUCN, 2012	NBS	Review	General NBS overview
Kabisch et al., 2016	NBS	Review	NBS in climate change mitigation and adaptation in urban areas
Nesshöver at al., 2017	NBS	Review	General NBS
Potschin et al., 2016	NBS	Review	General NBS
Raymond et al., 2017a	NBS	Review	General NBS overview
Raymond et al., 2017b	NBS	Review	Assesment and implementation of NBS co-benefits
Baró et al., 2014	Green space	Barcelona, Spain	Air quality and climate change mitigation
Cariñanos et al., 2017	Green space	Spain	Allergenicity
Chen et al., 2016	Green space	Nanjing, China	Air quality ($PM_{2.5}$)
Manes et al., 2015	Green space	Italy	Air quality (O_3 and PM_{10})
Marando et al., 2016	Green space	Rome, Italy	Air quality (PM_{10})
Reynolds et al., 2017	Green space	Medellin, Colombia	Carbon dioxide
Van den Bosch and Ode Sang, 2017	Green space	Review	Public health
Yli-Pelkonen et al., 2017	Green space	Helsinki, Finland	Air quality
Charoenkit and Yiemwattana, 2016	Green walls	Review	Thermal comfort and carbon emission
Coma et al., 2017	Green walls	Catalonia, Spain	Energy savings
Lee and Jim, 2017	Green walls	Hong Kong, China	Thermal effects
Manso and Castro-Gomes, 2015	Green walls	Review	Charasteristics
Medl et al., 2017	Green walls	Review	Recent technologies and research advancement
Viecco et al., 2017	Green walls and roofs	Semiarid climates	Air quality
Wang et al., 2017	Green roofs	Review	Sink or source
Castellar Da Cunha et al., 2018	Wetwall	Review	Water treatment
Jartun et al., 2008	Supplementary		Runoff
McDonald et al., 2014	Supplementary		The Future of Global Urbanization and the Environment

GREEN SOLUTIONS AND THEIR BENEFITS

Large green natural systems are providers of ecosystem services such as temperature and pollution control. Urban areas, however, may lack the space for an urban forest, creating an increasing need to give a green use to vertical spaces and roofs. Both green walls and green roofs have been framed as NBSs approaches (Charoenkit and Yiemwattana, 2016; Manso and Castro-Gomes, 2015).

Alike NBS, there are various terms that refer to all kinds of green vertical systems, such as "green walls", "vertical greening systems", "green facades" and "living walls". Generally, the terms have a slightly different meaning, but sometimes they are used interchangeably. In this study, the term "green wall" is used as the "main headline" to refer to different types of vertically growing vegetation.

Green walls can be divided into more simple systems where climbing and hanging plants simply attach and grow on building surfaces (or support structures, referred to as "green walls" or "green facades") and to more complex continuous or modular systems including irrigation systems, support structures and/or growth medium (Charoenkit and Yiemwattana, 2016; Manso and Castro-Gomes, 2015; Medl et al., 2017). Continuous living walls (also known as LWs or vertical gardens) make use of lightweight and permeable screens, to allow growth, whereas modular systems consist of different elements such as trays, vessels, planter tiles, flexible bags, etc., and include growing media. Continuous LWs are commonly based on hydroponic methods where, in order for the plant to grow in the absence of soil, an irrigation system with nutrient enriched water is put in place to keep the screens constantly moistered (Manso and Castro-Gomes, 2015; Medl et al., 2017). Although a highly useful technique, hydroponic irrigation creates a demand for treatment of the nutrient-rich (nitrates and phosphorous) “wastewater”, as excess water is often discharged into the environment (Castellar da Cunha et al., 2018).

Generally speaking, LWs enable e.g. a larger variety of usable plants and options to replace unhealthy plants (Charoenkit and Yiemwattana, 2016). There are also alternative and novel ways to utilize LWs. Castellar da Cunha et al. (2018) mentions that there are studies about the application of alternative water sources for modular LWs; reuse of wastewater or greywater with less treatment needs (“less filthy” water, such as shower water). They also report the use of LWs for greywater treatment. Furthermore, they propose a “hybrid” NBS that includes principles of both modular LWs and constructed wetlands, providing a method to treat secondary wastewater (focused mainly on removal of nitrates and phosphates), such as hydroponic wastewater used in the irrigation of green walls. They called this a “Wetwall”.

As mentioned by Mendl et al. (2017), the literature on benefits of green walls, often refers to general benefits of vegetation, without presenting rigorous data that could support credibility. Due to this, and because they have almost identical effects, green walls and other vegetation types (green roofs, urban parks, trees and forests) are considered in this study under the term “green solutions” .

Green solutions are reported to impact the environment in multiple ways. This includes, for example, reducing urban temperatures through shading, evapotranspiration and wind cover (Charoenkit and Yiemwattana, 2016; Coma et al., 2018; Manso and Castro-Gomes, 2015; Medl et al., 2017; Raymond et al., 2017a), biodiversity benefits (Manso and Castro-Gomes, 2015; Medl et al., 2017; Raymond et al., 2017a; IUCN, 2012), water flow and flood control (Manso and Castro-Gomes, 2015; Raymond et al., 2017a; Reynolds et al., 2017), air quality by removal of air pollution (Manes et al., 2015; Marando et al., 2016; Manso and Castro-Gomes, 2015; Medl et al., 2017; Sicard et al. 2018), mitigation of noise pollution (Manso and Castro-Gomes, 2015; Medl et al., 2017; Raymond et al., 2017a; Sicard et al., 2018), mitigation of Urban Heat Island effect (Castellar da Cunha et al., 2018; Manso and Castro-Gomes, 2015; Medl et al., 2017; Sicard et al., 2018), overall energy savings (Castellar da Cunha et al., 2018; Medl et al., 2017; Sicard et al., 2018), improvement of psychological well-being (Manso and Castro-Gomes, 2015; Sicard et al., 2018), improvement of image and value of property (Manso and Castro-Gomes, 2015) and reduction of carbon emissions (Castellar da Cunha et al., 2018; Charoenkit and Yiemwattana, 2016; Mendl et al., 2017; Reynolds et al., 2017) directly via sequestration and indirectly via reducing the need for fossil fuel. These examples are reported to generally lead to environmental, social and economic benefits.

Furthermore, Reynold et al. (2017) estimated that about 35% of the benefits related to urban trees are related to storm water regulation, 31% aesthetics, 28% shading, 5% air quality and 1% direct CO2 sequestration through growth. The claimed high beneficial effect of urban forests by water regulation is also supported by McDonald et al. (2014), who state: “Urban landscapes with 50 to 90 percent impervious cover can lose 40 to 83 percent of rainfall to surface runoff compared to 13 percent in forested landscapes”.

Despite of multiple benefits, green solutions also have drawbacks. For example, they can produce pollen, causing allergenic reactions and health issues in those who suffer from allergies, generating significant economic, social, environmental and health costs (Cariñanos et al. 2017; Reynolds et al., 2017; Sicard et al., 2018). They can release to the atmosphere the carbon stored in them when decomposed/burned (Reynolds et al., 2017). They can produce biogenic volatile organic compounds (BVOCS); the volatile organic compounds (BVOCs and AVOCs) together with nitrous oxides (NO + NO2) play a role in the formation of ozone (Yli-Pelkonen et al., 2017). And, they can lead into increased maintenance and management costs (Reynolds et al., 2017). These drawbacks are explained in the next section.

GREEN SOLUTIONS AND THEIR DRAWBACKS

The removal of the PM10 fraction (the subscript refers to the diameter of the particulate matter in µm) is supposedly dependent on the species of vegetation and the species-specific traits such as Leaf Area Index (LAI), vegetation physiology, length of leaf season and type of leaves (Manes et al., 2015; Marando et al., 2016). For example, some structures, like hairs and waxes on the leaf surface, can enable some species to capture particulate matter more effectively (Manes et al., 2015; Viecco et al., 2018). Marando et al. (2016) report that due to higher leaf area index (LAI), deciduous (tree) species have an elevated efficiency in PM10 removal during the spring and summer months. However, when observing the annual PM10 removal efficiency, the evergreen species were more efficient in PM10 removal than the deciduous broadleaves. This could indicate that evergreen species might have a greater impact in air quality improvement at longer time-scales (Marando et al. 2016), even though PM10 deposition efficacy is mainly dependent on LAI (Manes et al. 2015).

Similar effects have been found in removal of finer PM2.5 by Chen et al. (2016) who reported that green cover negatively correlated with PM2.5 concentrations, meaning that increase in green space reduced the PM2.5 concentrations. Furthermore, when the PM2.5 concentrations exceeded 75µg m-3, there was no significant correlation between green space and PM2.5 anymore (Chen et al., 2016). This may suggest that the relative contribution of green spaces in PM2.5 reduction might be low in highly polluted areas. As vegetation properties change under different seasons, micro-climatic conditions and varying pollution levels, further research to reveal the effect of these factors at the local scale is needed (Manes et al., 2015; Viecco et al., 2018).

Ozone (O3) removal is dependent on vegetation physiology and surface cover (Manes et al. 2015), including many different factors, such as stomatal conductance (stomata are the pore structures that are used for gas exchange and water transpiration) LAI, the amount of air pollution, the amount of precipitation, dry deposition velocity and length of the growing season (Sicard et al., 2018). Generally, deciduous species are more effective in O3 removal (largely due to higher stomatal conductance), but when spectating the annual O3 removal, once again, evergreen species seem to have a stronger overall impact (Manes et al. 2015; Sicard et al., 2018). Additionally, high diversity seems to lead to increased O3 removal rates, although this is still controversial (Manes et al. 2015).

Temperature reduction is one of the most important and desired effects of green systems in general and for green walls in particularIt has been the focus part of most studies on green walls. Thermal benefits are gained mainly by four different mechanisms; wind cover,insulation, evapotranspiration and shading(Coma et al., 2018), being the two last mechanisms the most influential factors (Charoenkit and Yiemwattana, 2016). Shading effect reduces heat transfer to buildings by absorption and reflection of solar radiation by both plants and their substrate (also additional insulation effect). The amount of absorptance, reflection and transmission vary with the species as leaf size, density, color, water content, thickness, hairiness etc. are influential factors. Additionally, there is heat transfer between the different layers. Evapotranspiration (evaporation + transpiration) further strengthens the plants ability to reduce the temperatures by dissipating heat through loss of water, assuming there is no water stress. (Charoenkit and Yiemwattana, 2016). Furthermore, there is a relationship between daily average solar irradiation and green walls' performance on energy savings of. Thus, solar irradiation is a essential parameter for the use of green walls. Therefore orientation and placement of greenwalls will affecttheir beneficial cooling effect is at its strongest when greenwalls are exposed to the highest amount of sunlight (Charoenkit and Yiemwattana, 2016; Coma et al., 2018). Still, decisions on the orientation and placement of greenwalls should be based on species-specific characteristics (sensitivity).

There are many different additional factors that affect the thermal performance of greenwalls, such as: plant characteristics,especially LAI or foliage thickness,(Charoenkit and Yiemwattana, 2016; Coma et al., 2018), type of substrate,especially moisture content and thickness, possible use of air cavities (empty space between the wall and vegetation) and the amount of stress the environment causes to the vegetation (e.g. high wind speeds and water scarcity can lead to reduced growth, and finally to smaller LAI) (Charoenkit and Yiemwattana, 2016).

PRACTICAL CONSIDERATIONS ON POLLUTION MITIGATION AND TRADEOFFS

LAI can be considered the most important factor affecting particle deposition rates; it can be used to describe the vegetation structure and canopy density, upon which the deposition rates of particles largely depend. High LAI values can be connected to higher air turbulence and, consequently, to higher pollution deposition. The second most influential factor is stomatal conductance associated to gas exchange. According to Manes et al. (2015) both LAI and stomatal conductance are key to determine NBS efficacy.

When deciding the optimal vegetation structure to use (tall or short, dense or sparse), location specific characteristics should be considered. If green solutions are misapplied, they might even induce a local increase in pollutant concentrations. Optimal results also require that air ventilation is well planned: vegetation used should be porous enough and correctly spaced to allow penetration of the air stream, whilst dense enough to offer a large deposition surface area. Planning an efficient green solution also involves consideration on, for instance, the maintenance of certain species (aiming at species that are resistant, self-sufficient and long living), emission characteristics of VOC and pollen (emphasis on low emissions) and irrigation demands (aiming at species of low water need) (Sicard et al., 2018).

Pollen emissions are highly dependent on the species used. Furthermore, air pollution can even increase the development of allergenic pollen (Sicard et al., 2018). Wind-pollination, long pollen seasons and pollen allergenicity are identified as important factors influencing NBS benefits to people (Cariñanos et al., 2017). Identifying and evaluating tradeoffs involved in NBS, such as health (allergenic) risks, is of fundamental importance for the success of the initiative. It is also important to plan for alternatives that can minimize any potential risk. For example, Cariñanos et al., (2017) prescribes a few actions that might reduce allergen emissions: increasing the number of female specimens, introduction of species with short pollen season, allow for a wide diversity of species, introduction of species that are insect-pollinated, pruning (limits growth and reduces the amount of pollen producing floral buds) and controlled/limited watering as it limits flower production). (Cariñanos et al. 2017).

VALIDITY

Even though urban vegetation is often reported and claimed to improve air quality due to their ability to absorb and capture pollutants (Viecco et al., 2018), Yli-Pelkonen et al., (2017) reveals that, in fact, this might not always be the case. In their research (in Finland) they found a significant tree-cover impact on (coarse) reducing local particle pollutant levels. They also found that there was no significant difference in local gaseous air pollution (NO2, O3, AnthropogenicVOC, BiogenicVOC, PM) levels between tree-covered and open areas, indicating that urban vegetation might be inefficient in removing air pollution. Furthermore, the reduction in particle levels in tree-covered areas did not relate to vegetation properties (e.g. volume and structure of vegetation). This result is even more alarming as the lack of evidence of NBS efficacy is reported in multiple studies. The lack of precise studies was also noticed by Yli-Pelkonen et al., 2017, stating: “Only a few studies exist in which pollutant levels have been measured locally, e.g. within a forest or park canopy and compared to pollution levels in adjacent open areas”.

Even though different types of green walls are often reported to result in multiple benefits, Medl et al., (2017) mentions that only the direct green facade (no support structures, climbing or hanging plants with adhesive root structures) might be economically sustainable. The argument is based on the high environmental burdens related to installation and maintenance of other green wall types. By using more sustainable materials and reducing overall initial costs, this drawback could be reduced, and the use of green walls widened. Furthermore, comparison of studies and their results remains difficult as plant species used, climate, construction system/materials and other parameters (orientation, LAI, etc.) are not consistent (Coma et al., 2018). Sicard et al. (2018) even suggested that green roofs mainly have a supplementary role in air quality improvement due to their relatively weak air purification abilities compared to urban trees. In addition, management practices play a significant role, in, e.g., insufficient irrigation or too high temperatures, which might affect vegetation functionality in a negative way (Charoenkit and Yiemwattana, 2016).

Furthermore, green roofs are believed to have abilities in degradation or filtration of pollution, enabling improvement of runoff water quality. Green roofs, while primarily functioning in rainwater retention and storm water runoff mitigation, can also absorb atmospheric pollutants and particulate matter just as other vegetation types do. Still, in situations (storms) where rainfall intensity exceeds the retention capacity, green roofs can possibly act as pollution sources instead of sinks. This is due to leaching into runoff water; pollution absorbed into vegetation and substrate layer can leech and end up in an unwanted place, such as drinking water supplies. Plant species, rooftop materials, components of the substrate, depth of the substrate, irrigation, fertilizers, atmospheric deposition, age of the green roof among are among the attributes that affect green roofs' ability to act as either pollution sink or source (Wang et al., 2017).

DISCUSSION: a guideline for future studies based on vegetation properties

Based on aforementioned factors, further studies on NBS are needed. We recommend that start from situations where the species tested for optimal efficacy should have the following attributes: High LAI for efficient deposition properties, high stomatal conductance for efficient gas exchange and removal of air pollutants like ozone, leaf properties such as a wax layer or hairs to increase deposition. The vegetation should preferably be evergreen to maximize annual performance, and should have optimal (more research needed) substrate/growing media. The species chosen should be porous enough to enable sufficient air ventilation (not necessary for green walls), and dense enough for surface are. The placement of green walls should follow the sunny side, and it should have properties that minimize disservices, such as pollen production. Furthermore, if multiple species are used, high diversity might improve the results.

When talking about Nature Based Solutions, the consideration of "what is nature?" is important as it is a vital part of the NBS concept (Nesshöver et al., 2017): Can any organism or ecosystem process be considered as "natural" or "nature" when there is human intervention (e.g. genetic manipulation)? There has been much debate over this, but current NBS exclude methods that artificially alter nature, such as genetically modified organisms (European Commission, 2015). When considering a "nature-based" approach, it must be clear that the approach taken is alternative to general methods that tend to have a low level of "naturalness" (Fernandes et al. 2018). Because NBSs involve the use of living organisms, some level of unpredictability is expected, making management of this dynamic and evolving "material" hard and unstandardized. Using NBS thus involves the usage of multi-disciplinary knowledge, concepts and methods that deal with uncertainty, complexity, ambiguity and conflicts to achieve reasonable trade-offs and acquire multiple benefits (Nesshöver et al., 2017).

To maintain optimal efficacy, NBSs usually need a certain level of surveillance, maintenance and "repair" to keep the characteristics needed at a certain level (e.g. the organisms are not allowed to evolve to a higher successional stage, such as a certain branch dimension). These surveillance and maintenance procedures, that could enable long-term safety and efficiency, require a large amount of investments that are not always available. All the aforementioned factors create limitations and uncontrollable factors that need to be considered for the implementation of NBSs. Furthermore, utilization of NBSs also includes a need for a radical mindset change where plants and other living organisms should be trusted like the traditional techniques and materials are (Fernandes et al. 2018).

As Fernandes et al. (2018) highlights; “All these areas of application demand strong and reliable engineering approaches based on a replicable knowledge of the way each plant, organism, or complementary construction material behaves in each particular soil, geologic, climatic, biological, and cultural context”, which creates a demand for more research about the limitations (including disservices and other issues) of each solution in each particular context.

EVALUATION OF EFFICIENCY/APPLICATION

Gaining stronger evidence about NBS efficiency for the previously mentioned aims, and increasing overall awareness (e.g. the effects of climate change and NBSs role in lessening the impact) is one of the main “practical” objectives in NBS based research (Kabisch et al., 2016). One of the problems lies in the evaluation of this NBS efficiency; there is a lack of comprehensive evidence about the effectiveness of NBSs and a lack of comparisons between the NBSs and traditional methods (European Commission, 2015). Assessment of possible co-benefits, and their impact, is even harder, as there is a severe lack of tools of evaluation (Raymond et al., 2017b). To even consider possible efficacy and applicability, the effect of NBS should be measurable verifiable and repeatable, as stated by IUCN (2012). In theory, environmental performance can be assessed e.g. by spectating the amount of pollutants captured by vegetation, amount of carbon sequestration, temperature reduction, biodiversity, reduction in risk of floods, etc., whereas health-related performance can be assessed by spectating physical and mental health related indicators and access to green areas. Still, the causal relationship between urban green spaces and positive effects on human health/well-being is hard to validate as the trade-offs and synergies between different factors remains unclear. These synergies and trade-offs are also largely location-specific. That is, the interactions between factors in one area are not necessarily the same in a different area (Raymond et al., 2017a). These limitations are further deepened by the lack of a knowledge base by which information on NBSs ca be shared in the most optimal way (Kabisch et al., 2016).

Knowledge gaps

Information scarcity and different knowledge gaps regarding NBSs have been reported by most of the authors writing on the subject. This chapter mentions a few of the identified knowledge gaps, namely: lack of information about time dependency, spatial impact scale, cost-efficiency, unknown effects, legal instruments and substrate effect. Evaluation of efficiency was presented in the previous chapter, as it can be considered as one of the most important knowledge gaps.

Currently there is little information about the time it takes for a certain NBS approach to become fully effective (e.g. when natural flows or functions are restored fully), which makes choosing the most suitable NBS approach difficult (Raymond et al., 2017a). Fulfilling knowledge gaps in further studies (e.g. long-term data collection) can assist decision makers on choosing the most suitable solution to a certain problem. There is a particular need for information regarding implementation and maintenance after a NBS projects end (Kabisch et al., 2016), and especially for information about the lifespan of the methods (Manso and Castro-Gomes, 2015).

Different NBSs affect different special scales. These scales could be roughly divided into: micro (at the street level), meso (at the urban or regional level) and macro (at the national) level. In many cases, measuring the impact on a larger scale is not rational, because the effect of a single NBS is usually irrelevant on a national or even regional scale. However, even though the impact of a single NBS might be limited on larger scales, the combined effect of several NBSs might be significant. Still, measuring this combined impact is virtually impossible, making the spatial scale of the impact a sensitive matter (Raymond et al., 2017a). For example, Manes et al., (2015), suggests that urban forest have an impact on local scale but that broader scale impacts need more quantification.

One of the indirectly most important factors to consider in promoting of the use of NBS is cost-efficiency. After all, “economic efficiency largely influences what mitigation approach a government, business, or non-governmental organization may take” (Reynolds et al 2017). Knowledge gaps related to such a vital part of implementation is certainly of concern, as decision-makers are likely to move towards more traditional approaches, which impacts and cost-efficiency are sufficiently known. Furthermore, there is generally a focus on economic growth that hampers the overall ability of NBSs to attract interest as well as funding (Kabisch et al., 2016). Unknown, or not well-known effects might have a surprising contribution in the outcome of NBSs For example, Baró et al. (2014) reports that very high pollutant concentration could severely damage vegetation, reducing air pollution removal ability. This raises questions such as: is vegetation least effective where it is needed the most? Or - considering that wild areas might be effective in removing air pollution (Baró et al. 2014) - what is the impact that proper management has on the efficiency of parks’ for “air purification”?

There is much unclarity about what kind of NBS best fits a city's development goals. This results in conflicts of interests; how to compare to competing uses of land with different goals? Urban managers may also lack information on legal instruments and requirements to solve land-use conflicts (Kabisch et al., 2016). Furthermore, legislation needs to reach the level of NBSs as there is a possible need for laws regarding, for example, the use of invasive species that can supersede native species and cause biodiversity loss (Fernandes et al. 2018).

As most of the studies focus on the green-part of the whole systems itself, there is very limited information about the substrate/growing media/soil properties (Charoenkit and Yiemwattana, 2016; Medl et al., 2017). The below-ground portion of the process includes many important subprocesses, e.g. decomposition of plant residues, production of microbial biomass, mortality of biomass and the soil respiration connected to all of this. Especially carbon flux is highly impacted by these processes (Charoenkit and Yiemwattana, 2016).

Because substrate properties and processes strongly affect growth rates, growth habits, total leaf areas, plant health and insulation ability, among other things, more information about it is crucial (Medl et al., 2017). In theory, an ideal substrate would be light-weight (weight loading restrictions), have adequate water and nutrient holding capacities, would be able to remove water excess, would be physically stable and have suitable acidity (pH) for plant growth. Mostly inorganic (organic part 0 – 20%) materials with high porosity and low density are suggested for this (Charoenkit and Yiemwattana, 2016). Putting this raw theory into practice is still a promise, as data, comparisons and results are missing. This opens up possibilities for upcoming research projects that would study different substrates in NBSs and their impact.

Discussion about the potential of NBS

Environmental authorities set different objectives and obligations for actions that produce environmental stressors. One of them is Directive 2008/50/EC (for EU) that sets threshold values for air quality and climate change related outputs. To meet these environmental standards or policy targets, NBSs could be of great assistance, but many current NBSs are still not seen as efficient methods (unless novel and newly designed) to tackle these problems and are often neglected in policy-making. (Baró et al., 2014). For NBSs to be acknowledged as efficient tools for sustainable living, the newly introduced concept still needs further specification as discussed earlier. As long as there is a lack of long-term data about the efficacy, spatial scale of the effects, cost-efficiency, substrate effects, necessary tools for utilization and about the time it takes for a certain NBS to be most effective, the decisions enabling production of legal framework considering NBSs cannot be established. Furthermore, "NBS implementation requires political, economic and scientific challenges to be addressed simultaneously" (Raymond et al., 2017b). This includes consideration of multiple factors in a multi-disciplinary and location (city) specific way, that is socially comprehensible and acceptable to a range of stakeholders. A collaborative effort from teams including researchers and academics, policy makers, planners and entrepreneurs is needed to make this goal of increased NBS implementation possible. However, city-officials have a leadership role in this as they have to ensure that NBS actions align with current urban planning strategies and governance processes (Raymond et al., 2017b).

Most of the studies focus on similar NBSs, such as green spaces and urban waterbodies, leaving only little attention to hybrid ideas like: Green walls for agriculture, which Manso and Castro-Gomes (2015) mentions as a possibly very interesting point of development for reducing food production and distribution related environmental impact, or application of modern sensors (to measure e.g. moisture and nutrient content) to further improve the efficacy of many NBSs. These could be good starting points for further studies with e.g. the aim of research being: Applicability of NBSs (Green Walls) in urban agriculture or Utilization of sensors in improvement of NBS.

Further questions are raised of the applicability of vertical greening systems (VGSs, or green walls in this study) in rural contexts. Even though rural areas are promising areas for application of VGSs (and other NBSs), surprisingly, almost all of the research focuses on urban contexts. (Medl et al., 2017). This could possibly be further connected to the efficacy of vegetation in different levels of pollution: If vegetation's ability to purify the air is impacted by high pollution levels, can vegetation be expected to be more efficient in rural (presumably less polluted areas), where lies this threshold of functionality and furthermore, does this imply a stronger global impact? This could be a starting point for further studies with the research questions of: In stressful (highly polluted) environments, vegetation's ability to purify air is (presumably) impacted in a negative way; what are the threshold concentrations where this happens and how much does the choice of “which species to use” affect this? Or Are green walls more effective in rural areas?

Manso and Castro-Gomes (2015) and Medl et al., (2017) present direct green facades (the simplest of green wall types without support structures or soil, largely climbing or hanging plants with adhesive root structures) as relatively sustainable and economic solutions due to their small environmental burden. Whereas the other green wall types might not be sustainable due to the high environmental burden related to installation and maintenance (Medl et al., 2017). This way of thinking has to include consideration of life-cycles; how many years of functionality is needed to exceed the construction costs of e.g. a stainless-steel support structure, irrigation and other maintenance actions that can be included in utilization of the more complex living walls? Life-cycle assessment is yet another aspect that should be included in decision-making, but currently there is no information to base decisions on. Hence, it is recommendable that NBS life-cycle analyses are done in the future, so that e.g. alternate, lower-impact construction materials (fulfilling the principles of circular economy) could be used in the future.

Even though multiple authors have acknowledged the potential NBSs have on climate change mitigation/adaptation, water management and air quality purification, there is a debate about their efficiency. Most of the criticism related to NBSs are on the fact that currently there is no fully “fool-proof” way to measure or evaluate the impacts that the methods really have. Even though the effect is probably positive (many studies imply that implication of NBSs results in many benefits), it needs a lot of additional validation. Similar observations were also made by Medl et al., (2017): “it was striking that many authors still refer to commonly known benefits of vegetation (e.g. urban habitat biodiversity, faster stress recovery, glare reduction) or green roofs (e.g. retention of rain water) without having any proof if this can also be applied to vertical greening systems.” Furthermore, these “commonly known benefits” are case-specific; different conditions (e.g. high variation in pollution levels) can lead into completely different results, and statements based on other studies should not be lightly presented. Reports of possibly insignificant results is a cause of concern and should provide a starting point for a multitude of new research projects, ultimately resulting in comparability and results that can be validated. E.g. studies involving green walls or roofs generally include only a very low number of replicates; This directly results in statistical tests producing insignificant results, and thus, the possibility that variation in performance is only due to stochasticity (randomness), cannot be fully neglected until the size of replicates in increased.

It is estimated that the effect of a single NBS is probably relatively small on larger scales. This means that for NBSs to be effective in making the global situation better, there has to be a multitude of local (optimized for that certain place) NBSs all over the globe. Furthermore, location-specificity makes development of universally effective approaches impossible. Additionally, research is expensive, and the knowledge gained about certain NBS approaches in wealthy countries is not always applicable in less wealthy countries where the spatial context (environment etc.) is different. This can slow down the progress of NBS implementation. Reynolds et al. (2017) also highlights that NBSs have been discussed mostly in the European Union and in the United States of America, leaving even more important areas (with socio-economic disparities and high proportion of vulnerable populations), like the Latin America, out of the "hottest" discussion. Examples from the developing world are needed, as it is likely that the NBSs desirable impacts are most needed in those regions.

One should keep in mind that even though mitigation is vital, the ultimate solution to sustainability issues is the elimination of the factors that cause the issues (source of emissions). For example, climate change mitigation should primarily concentrate efforts on that. Circular economy (reuse, recycling and reducing), should be considered as the secondary objective. Further, development of NBSs and integration of the principles of circular economy might enable solving the biggest challenges related especially to the utilization of green walls; reusing wastewater and waste materials might just be the step needed for stronger performance (Castellar da Cunha et al., 2018). In that way, NBSs, or mitigation actions in general, should be considered as a tertiary option to general lifestyle changes and circular economy, which could enable a lessened need for materials and depletion of Earth's resources.

The future of NBSs should lie in validation of the performance, before the increase of implication itself. This could include single parameter tests that include testing of single parameter (lets suggest LAI, as it is one of the most important factors) while other properties are kept in a static state, preferably in laboratory conditions before practical conditions. Furthermore, more comparisons against current/traditional methods and comparisons between NBS and no-NBS (e.g. comparison between green wall and bare wall) should be executed. And, above all, "NBS" should be used as an umbrella term, that includes all the current differently named methods that are inspired by nature and have similar objectives.

However, to support public policies for the implementation of green walls and roofs, it would be first necessary to demonstrate their efficacy, identify the optimal species, to make comparisons and to generate design recommendations. This approach should be utilized to other NBSs too. Ultimately, even if Nature-Based Solutions reveals to be inefficient to tackle important global environmental, social and economic challenges, they raise important sustainability-related questions, and can be considered a possible pathway towards a sustainable way of living. In the best case, they are everything they are claimed to be, their utilization can be increased, and they may deliver a beneficial global impact. One thing is sure, the right way to proceed is to increase the amount of studies related to NBSs; the potential of NBSs is just too tremendous to leave them neglected in decision-making.

CONCLUSIONS

Nature-Based Solutions (NBSs) are nature-inspired ways or approaches on issues related to environmental, social and economic problems, such as unsustainable living and climate change. In practice, NBSs refer to methods such as restoration or creation of waterbodies, green areas, green walls and roofs that aim, for example, at climate change mitigation, air purification, water flow control and water treatment. Currently, the concept itself is still at its development stage as it is relatively novel and loosely defined; there is no unambiguous explanation about its meaning, only similar, slightly different perspectives. For instance, the term "nature-based" can include almost anything. In this study, the meaning of the concept was sharpened by reviewing case studies in which the methods used were tagged as NBS, and the common aims were the main factor in this further classification. A refinement towards an unambiguous definition could increase the possibilities of NBS implementation by reducing confusion among researchers and decision-makers, enabling creation of a better legal framework and, ultimately, resulting in a more sustainable way of living. Despite of this, what matters is the ultimate goal towards a more sustainable future. Using the term "NBS" as an umbrella concept including all the various current concepts that describe the same process (e.g. green-blue infrastructure, ecological engineering) is reasonable, as long as decision-makers understand its purpose and ultimate goal, and as long as there is robust evidence about the beneficial impact.

This study identifies the main NBS-related flaws, problems and knowledge gaps, because as Fernandes et al. (2018) reports, "information about NBS approaches, especially on implementation practices, effectiveness and monitoring remains scarce". Evaluation of efficiency, lack of information about time dependency, spatial impact scale, cost-efficiency, effect of substrate, unknown effects and legal instruments, among other aspects, were identified as the most important issues hindering the improvement of NBSs. Furthermore, specific dynamic interactions (e.g. the ability of vegetation to remove air pollutants and the effect of air pollutants on vegetation's ability to remove air pollutants effectively) was revealed as a field where much research is still needed. This research provides a starting point for further studies by highlighting the most important factors that impact NBS efficacy and by suggesting several ways to advance the knowledge on NBSs. Further emphasis should be placed on future research, because at its current state, the various flaws and possible insignificance of the reported results raises too many questions to consider efficacy of NBSs as a "truth". Despite of this, the potential of NBSs is overwhelming enough, so that further development cannot be neglected. Although NBS is not a silver bullet, and trade-offs should be considered, is has potential to help solve part of our pressing global issues. Enabling scalability of NBSs can trigger the advance of sustainability in some form.

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