

# Assessment of biophysical and ecological services provided by urban nature-based solutions: a review

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## **1** Introduction

Globally, cities are experiencing challenges imposed by for example climate change, water security issues and deteriorating public health and wellbeing (Cohen-Shacham 2016, Raymond 2017). Traditionally, grey (built) infrastructure have been used to handle such challenges, generally focused towards one specific challenge. However, in the last years, nature-based solutions (NBS), generally defined as solutions that are inspired or supported by nature, have been brought forward as alternatives to 'grey' solutions, with the potential to simultaneously solve societal challenges and deliver environmental, social and economic co-benefits (Madureira and Andresen 2014, EC 2015). NBS can be seen as an umbrella concept for other related conceptual frameworks such as ecological engineering, ecosystem services, ecosystem-based adaptation and green infrastructure (EC 2015, Cohen-Shacham 2016). Here we consider urban NBS as ecosystem services delivered by urban green or blue infrastructure, whereby the notion of ecosystem services (as opposed to ecosystem functions) implies that the value/contribution to human well-being is explicitly recognized. However the ecosystem services only become nature-based solutions once they are recognized as having the potential to address a particular societal challenge, such as those imposed by climate change.

Research concerning assessment and evaluation of NBS (i.e. ecosystem services) in cities is developing at an increasing rate (TEEB 2011, Haase et al. 2014), and a large spectrum of indicators and modelling tools are currently being used. However, the focus is often restricted to one or a few ecosystem services or indicators or a single type of green or blue infrastructure (Haase et al. 2014). Thus, there is a need for mapping the evidence base from a diverse suit of NBS in different urban contexts. This evidence base can be used for further development of assessment models of NBS in urban contexts that quantify ecosystem services delivered by current and future urban green and blue infrastructure.

The aim of this review was to synthesize current literature that assess ecosystem services provided by urban green and blue infrastructure, with a focus on services that are of particular importance to societal challenges in the urban context. To that end, we reviewed peer-reviewed published literature on assessment of ecosystem services provided by urban green and blue infrastructure. We analysed the presence of assessment of services such as climate regulation, storm water management, water purification and soil remediation (hereafter waste treatment), air quality regulation, recreation and aesthetic appreciation, in order to cover services that are particularly relevant in an urban context. These ecosystem services are related to societal challenges such as climate change, maintaining water quality and safeguarding human health and wellbeing. We also included pollination to cover an aspect of biodiversity Targets). We identified the most frequently



assessed services and the extent to which these were associated to different types of green-blue infrastructure (hereafter referred to as 'ecological domains'). Based on the results obtained, we identify possible bias and knowledge gaps in the types of ecosystem services studied and their geographical distribution.

The mapping of the literature included the following analyses:

- 1) The proportion of studies reporting on quantitative and qualitative data on NBS (i.e., the amount of ecosystem service delivered by a particular ecological domain).
- 2) The geographical distribution of these studies.
- 3) The identification of indicators used for the assessment of ecosystem services.
- 4) The types of ecological domains that ecosystem services are generally assessed within.
- 5) The extent to which the studies relate the ecosystem services to particular challenge(s) and the type of innovation(s) targeted.

## 2 Methods

The methodological approach involved a literature review covering urban ecosystem services and NBS. A prioritisation was made between the urban ecosystem services listed by TEEB (2011) based on the ecosystem services' relevance to provide benefits to societal challenges in the urban context and a modified set of seven ecosystem services were included in the study. Local climate regulation, storm water management, water purification and soil remediation (hereafter aggregated into waste treatments, following Gomez-Baggethun and Barton (2013)), air quality regulation, pollination (including biodiversity of pollinators), recreation and aesthetic appreciation. We used the database Web of Science and created search strings combining the selected ecosystem services (and synonyms for those terms) with the term 'urban' and overarching terms to cover the different ecological domains (i.e., 'green space', 'green infrastructure' or 'nature'). For ecosystem services that are largely related to blue infrastructure, like storm water management and waste treatment, we included additional search terms such as 'lake', 'pond', 'wetland', 'canal', 'river' and 'floodplain '. The searches were made in February to May 2017 and resulted in 2,629 articles in total (including duplicates). An overview of all search strings used in the literature review is provided in Appendix A.

All titles and abstracts of the 2,629 articles were used for selection of publications meeting the following criteria: 1) presence of the ecosystem service searched for in terms of ecological indicators, 2) studying green or blue infrastructure, 3) being specific to the urban context, and 4) being either a review, empirical (field experimental study) or modelling study (incl. mapping studies). Full texts were searched for at Web of Science and Google Scholar. Articles that lacked full texts or could not be accessed on-line were not included in the



analysis. Literature that was not fully published in English or in non-Academic journals was also not included the review. In the full text screening, criteria 1 to 4 were applied and studies were excluded from the database. An analytical framework was adopted for the categorization. All publications were categorized according to: (i) the *ecosystem services* measured (as denoted by the author(s)) and (ii) *study type* (review, empirical (i.e. measuring) or modelling study). Publications describing empirical, modelling or empirical/modelling studies were further categorized according to the : (iii) *research method* (quantitative or qualitative) (iv) *year of publication*, (v) the *indicator(s)* used to measure the effect, (vi) *the geographical location* (region and country) where the study was performed, (vii) *type of urban green or blue infrastructure* (*'ecological domain'*; Table 1), (viii) *'intervention domain'*; (see Table 2) and (ix) *'NBS goal'*; (see Table 3).

Analysis about the year of publication and the geographical distribution of ecosystem service studies, excluded duplicates (i.e. publications recorded in several ecosystem service groups). For analysis about the research method, the geographical distribution of the different ecosystem service studies, ecosystem service indicators, the ecological domain, NBS goal and interventions, duplicates were included. For each publication all ecological domains, geographical locations, indicators, NBS goals and the interventions were recorded. Studies that occurred in the database with more than one services were identified as addressing multiple ecosystem services together with those that in the title had the words multiple or multifunctional.

Ecological domains	Examples				
Buildings facades and roofs	Balcony green, ground based green wall, living walls, facade-bound green wall, extensive green roof, intensive green roof, indoor vertical greeneries (walls and ceilings), potted plants, atrium				
Urban green space connected to grey infrastructure	Tree alley and street tree/hedges, street green, house garden, railroad bank and tracks, green playground/ school grounds, revitalised/green industrial areas, riverbank greens, greened parking lots, city squares, bare soil (considering a wider area than compared to 'Building facades and roofs')				
Parks and urban forests	Large urban park, historical park/garden, pocket park, arboreta, neighbourhood green space, green corridors, botanical gardens, golf courses				
Allotments and community gardens	Allotments, community gardens, horticulture				
Blue spaces (also including green- blue spaces)	Lake/pond, river/stream, dry riverbed, canal, estuary, delta, sea coast, floodplains, vegetated swales, rain gardens, permeable surfaces, bioswale				
Derelict and industrial areas	Abandoned and derelict spaces with growth of wilderness or green features, mine, sand pit/quarry/open cast, brownfield				
Natural and semi-natural green and blue spaces (not "man-made")	Shrubland, rocks, sand dunes, wetland, bog, fen, marsh, wilderness patches in peri-urban areas, wilderness reserves				
Urban green space	Unspecified vegetation in urban environments.				

**Table 1.** The different ecological domains and examples of structures included in each domain.

 Table 2. The ecological/physical, social and technological NBS interventions with categories.

Intervention	Category
Ecological/Physical	Creation of new green and blue spaces



	Maintenance and management
	Restoration
Social	Policy
	Governance
	Knowledge
	Economic
	Cultural
Technological	Product
	Process
	System/infrastructure

**Table 3.** Categorisation of NBS goals with a short description of each goal.

NBS goal	Description
1	Climate action for adaptation, resilience and mitigation
2	Water management
3	Coastal resilience and marine protection
4	Green space, habitats and biodiversity
5	Environmental quality, including air quality and waste management
6	Regeneration, land-use and urban development
7	Inclusive and effective governance
8	Social justice, inequality and social cohesion
9	Health and well-being
10	Economic development and decent employment
11	Cultural heritage and cultural diversity
12	Sustainable consumption and production

## **3** Results

A total of 526 peer-reviewed publications on urban NBS and assessment of ecosystem services were identified that matched our criteria and hence were used in the review (Appendix B). As some studies considered more than one of the selected ecosystem services, the sum of the services studied across the different ecosystem services were 548. When excluding reviews (71 publications), 477 publications reported data from empirical (56%) or modelling studies (22%) or in combination (10%) (Table 4). Excluding the duplicates, gave 463 unique publications. The majority of the publications (88%) assessed relationship between urban ecosystem services and ecological domains by a range of quantitative research methods, while the rest used a qualitative method (4%) or a combination of qualitative and quantitative methods (8%).

**Table 4.** The distribution of publications reporting data from review, empirical, modelling or a combination of empiricaland modelling studies across the different ecosystem services



	Review	Empirical	Modelling	Combinationofempirical&modelling studies	Sum of studies
Pollination	3 (12%)	17 (68%)	1 (4%)	4 (16%)	25
Air quality regulation	13 (24%)	17 (31%)	9 (16%)	16 (29%)	55
Waste treatment	13 (20%)	43 (66%)	3 (5%)	6 (9%)	65
Water management	7 (15%)	13 (28%)	25 (53%)	2 (4%)	47
Local-climate regulation	16 (8%)	112 (55%)	58 (28%)	19 (9%)	205
Recreation	13 (12%)	73 (67%)	23 (21%)	/	109
Aesthetic benefits	6 (14%)	33 (79%)	3 (7%)	/	42
ΤΟΤΑΙ	71 (13%)	308 (56%)	122 (22%)	47 (10%)	548

## 3.1 Frequency of publications

The earliest publication on urban ecosystem services identified in the study is from 1991 and reports on macrophytic ponds that can be used for cleaning effluents of urban origin (Basseres and Pietrasanta 1991). Since 2010, research on urban ecosystem services and NBS have increased exponentially, and 110 of the empirical and modelling publications included in this review were published in 2016 (Fig. 1).



Figure 1. Year of publication of empirical and modelling publications, covering urban ecosystem services (N=462)



## 3.2 Frequency of assessed ecosystem services

The majority of the studies represented evidence on local climate regulation (40%) and recreation (20%), followed by waste treatment (11%). A low proportion of the publications covered urban pollination (5%) (Fig. 2). Only 13 publications addressed more than one ecosystem services at the same time. Among those studies, recreation and aesthetic benefits was the most common combination. Additionally a low number of studies (8) included multifunctional or multiple services in the title.



Figure 2. The frequency of the different ecosystem services among the included publications (N=477)

## 3.3 Geographical distribution of studies

The geographical distribution of urban ecosystem service studies was focussed towards some regions, and depended on the ecosystem services that were the focus of the study (Fig. 3a-h). USA had the highest number of studies (88), followed by China (84) (Fig. 3a). European countries had 177 studies in total. Only a few studies have been conducted in South America and Africa. Aesthetic appreciation has mainly been studied in European countries and North America (Fig. 3b). Most studies about air quality regulation came from Europe, USA and China. (Fig. 3c). Local climate regulation was the service that had been studied in the highest number of countries across the world (Fig. 3d). Studies concerning pollination have almost exclusively been done in Europe and USA (Fig. 3e). Recreation has mainly been studied in Europe, USA, China and Australia. About one third of the studies about waste treatments came from China (Fig. 3g) while nearly half of the studies about water management came from the USA (Fig. 3h).



a) total



#### b) aesthetic



#### c) air quality regulation





#### d) local climate reg.



#### e) pollination



#### f) recreation





#### g) waste treatment



**Figure 3.** The geographical distribution of NBS studies on country level. Figure (a) the total number of NBS studies (N=462 publications) and (b-h) the number of studies per ecosystem service (N=477 publications). The left hand figures shows the distribution at a global level and the right hand figures the distribution on a European level.

#### 3.4 Ecosystem service indicators

Ecosystem services can be assessed by a number of indicators and Table 5 provides an overview of the identified indicators in the review. There was a wide diversity of indicators used and some publications reported the indicators in detail, while other used more general indicators for the same service. For example, water management includes a number of different processes such as water losses from evaporation by trees to storm-water runoff retention by ponds and wetlands. The waste treatment includes remediation activities for e.g. soil of previous industrial land that is restored for housing, but also waste water treatment activities, thus also here a high variety of indicators were used. Recreation and aesthetic appreciation had the most diverse set of indicators used in the different studies, ranging from more quantitative indicators as the total surface and accessibility of green space to more qualitative indicators as perception of green space.



 Table 5. Examples of indicators used to assess the different ecosystem services.

Ecosystem services	Service indicators	Example References			
Local climate regulation	Surface temperature (°C)	(Larondelle et al. 2014, Weber et al. 2014)			
	Air temperature (°C)	(Klemm et al. 2015, Vaz Monteiro et al. 2016)			
	Thermal comfort/Physiological equivalent temperature (°C)	(Ketterer and Matzarakis 2014, Stocco et al. 2015)			
	Tree shade area (%)	(Baró et al. 2015)			
	Heat absorption (kJ)	(Zhang et al. 2014, Wang et al. 2016b)			
	Solar radiation (reflexion)	(Bale et al. 2002, Wang et al. 2015b)			
	Cooling distance from larger green space (m)	(Doick et al. 2014, Lin et al. 2015)			
	Heat island intensity (°C)	(Melaas et al. 2016)			
	Wind velocity (m/s)	(Radhi et al. 2015)			
	Humidity (%)	(Yao et al. 2015b)			
	Indoor temperature (°C)	(Jim 2015)			
Air quality regulation	Surface emissivity, f-Evapotranspiration (absorption of insulation and thermal emissivity) (f-value)	(Kain et al. 2016)			
	Pollutant contents in plant (mg/kg, SIRM = saturation isothermal remnant magnetisation))	(Li et al. 2013, Hofman et al. 2014)			
	Dust sequestration ability (g/m2)	Li et al. (2013)			
	Pollutant emission by plants (e.g. VOC, allergies)	(Upmanis et al. 2001, Pataki et al. 2011, Saumel et al. 2016)			
	Dispersion and deposition velocity of pollutants	(Tong et al. 2016)			
	Air quality index	(Zhao et al. 2012, Cohen et al. 2014)			
	Concentration negative ions (lons/cm <sup>3</sup> )	(Li et al. 2013, Liang et al. 2014)			
Water management	Estimated and measured actual evapotranspiration (mm/day)	(DiGiovanni et al. 2013, Feng and Burian 2016)			
	Perceived benefits associated with greenways	(Larson et al. 2016)			
	Runoff volume reduction (m <sup>3</sup> ) or (m <sup>3</sup> ha) or (ml)	(Borris et al. 2013, Yao et al. 2015a, Liu et al. 2016)			
	Peak runoff reduction (%)	(Palanisamy and Chui 2015)			
	Stormwater runoff (mm)	(Tratalos et al. 2007)			
	Precipitation infiltrated by green infrastructure (%)	(Zeller et al. 2012)			
	Peak discharge (m <sup>3</sup> s <sup>-1</sup> ) or (l/s)	(Versini et al. 2015, Yang et al. 2016)			
	Flood magnitude (m3/s) and duration (days)	(Mogollon et al. 2016)			
	Peak event flow rate (I/s)	(Khin et al. 2016)			
	Drainage discharge (cm3/min) or (l/s-1)	(Alfredo et al. 2010, Shuster and Rhea 2013)			
	Base flow and total flow magnitude (mm/hour <sup>2</sup> )	(Bhaskar et al. 2016)			
	Discharge (mm)	(Carpenter et al. 2016)			
	Rainwater retention (%)	(Alfredo et al. 2010, Carpenter et al. 2016, Karteris et al. 2016)			
	Runoff coefficient	(Sjoman and Gill 2014)			



	Peak flow reduction (%)	(Palla et al. 2010)		
Waste treatment	Reduction contaminant load (%)	(Andersson and Barthel 2016, Li et al. 2016)		
	Removal rate/efficiency/reduction of pollutants (e.g. organic matter, solids, nutrients, suspended sediments, metals) pharmaceuticals and pathogens (%)	(Walters et al. 2014, Avila et al. 2016, Zhang et al. 2017)		
	Concentration of pollutants influent and effluent (mg $l^{-1}$ ),	(Avila et al. 2016, Leroy et al. 2016)		
	Water quality (concentration pollutant, pH, T )	(Wang et al. 2015c, Spromberg et al. 2016)		
	Toxicity testing (to e.g. amphipods, midges, fish) (gene expression, survival rate, mortality rate)	(McIntyre et al. 2016, Spromberg et al. 2016)		
	pollution accumulation in plant (mg plant <sup>-1</sup> , mg/kg)	(Wang et al. 2015c, Karbassi et al. 2016)		
	Soil quality (concentration pollutant, physical soil properties)	(Grover et al. 2013)		
	Time to remediate heavy metals	(Wilschut et al. 2013)		
Pollination	Pollinator abundance (# pollinators)	(Sattler et al. 2010, Baldock et al. 2015)		
	Pollinator richness (# species)	(Gunnarsson and Federsel 2014, Threlfall et al. 2015)		
	Pollinator diversity (Berger–Parker and Simpson indices, Shannon diversity Index)	(Gunnarsson and Federsel 2014, Verboven et al. 2014)		
	Pollination success (fruit set, seed set, flower: fruit ratio, pollen limitation)	(Ksiazek et al. 2012, Pellissier et al. 2012, Hausmann et al. 2016)		
	Pollinator occupancy (presence/absence pollinators from nest boxes)	(Maclvor and Packer 2016)		
	Bee hive performance (hive biomass, # workers, # pollen collected)	(Parmentier et al. 2014)		
	Pollination potential (floral abundance, flowering plant richness, diversity of flowering plants)	(Matteson et al. 2013, Radford and James 2013, Baldock et al. 2015)		
Recreation	Green space cover (%)	(Richards et al. 2017)		
	Annual change of green space (%)	(Kabisch and Haase 2013)		
	Area (ha/per capita	(Larondelle and Haase 2013)		
	Accessibility of green space (proximity (distance, walking time), walking experience)	(Schipperijn et al. 2010, Willemse 2013, Wang et al. 2015a)		
	Number of visitors	(King et al. 2015, Lin et al. 2017)		
	Use of (activity) green space	(Özgüner 2011, Campbell et al. 2016, Rupprecht et al. 2016)		
	Preference, attitudes to green space	(Bertram and Rehdanz 2015, Japelj et al. 2016)		
	Perception, satisfaction of green space	(Heyman 2012, Verlič et al. 2015, Roe et al. 2016)		
	Reasons for visitation	(Breuste and Artmann 2014)		
	Place attachment	(Arnberger and Eder 2012, Sharp et al. 2015)		
Aesthetic appreciation	Visual aesthetic quality	(Du et al. 2016, Wang et al. 2016a)v		



## 3.5 Ecological domains

'Parks and urban forest' was the most frequently studied ecological domain, covered by 27% of the reviewed publications (

**Table** 6). Other commonly studied domains were 'green space' (22%) and 'urban green space connected to grey infrastructure' (20%). The least studied domains were 'natural and semi-natural green and blue space' (1%), 'derelicts and industrial land' (2%) and 'allotment and community gardens' (3%). The frequency of ecological domains differed depending on the ecosystem services. For some services the major part of the assessments came from one ecological domain, e.g. recreation in 'parks and urban forest' (58 %) and waste treatment in 'blue space' (87%). For other studies the assessments were more diverse, e.g. local climate regulation was studied in 'urban green space connected to grey infrastructure', but also in 'parks and urban forest', 'green space' and 'blue space'. Water management was assessed for 'building facades and roofs', 'blue space' and 'green space'. Only 17% of the studies focused at more than one ecological domain in their studies (excluding studies with the domain 'green space').

Ecosystem services	Building facades & roofs	Urban green space at grey infrastructure	Parks /urban forest	Allotments /community garden	Blue space	Derelict /industrial areas	Natural /semi- natural green / blue space	Green space
Pollination	3 (10%)	3 (10%)	8 (28%)	6 (21%)	1	1 (3%)		8 (28%)
Air quality	6	17	14	2	1	1	/	11
regulation	(12%)	(33%)	(27%)	(4%)	(2%)	(2%)		(21%)
Waste treatment	3 (6%)	2 (4%)	1 (2%)	/	47 (87%)	1 (2%)	/	/
Water management	7 (17%)	/	2 (5%)	/	20 (49%)	/	/	12 (29%)
Local-climate	22	77	64	2	36	4	2	57
regulation	(8%)	(29%)	(24%)	(1%)	(14%)	(2%)	(1%)	(22%)
Recreation	1	7	60	4	4	5	2	19
	(1%)	(7%)	(59%)	(4%)	(4%)	(5%)	(2%)	(19%)
Aesthetic	2	10	9	3	2	1	2	7
appreciation	(6%)	(28%)	(25%)	(8%)	(6%)	(3%)	(6%)	(19%)
TOTAL	44	116	158	17	110	13	6	114
	(8%)	(20%)	(27%)	(3%)	(19%)	(2%)	(1%)	(22%)

**Table 6.** Distribution of ecosystem services studies over the different ecological domains.



## 3.6 NBS Goals

A wide range of goals was addressed by the publications (Table 7). 'Climate action for adaptation, resilience and mitigation' (NBS Goal #1) was the most frequently mentioned goal (32%), especially linked to the service local climate regulation. Improving 'health and well-being' (NBS Goal #9) was also a common goal of the research publications (24%), and was identified in all groups of ecosystem services. Research publications on regulating services such as air quality, waste treatment and water management addressed primarily improving 'environmental quality' (NBS goal # 5) challenges, while publications on pollination addressed 'biodiversity conservation' (NBS goal #4). The goal for improving 'coastal resilience' is not included in Table 6 as no study was found in the literature search that targeted that goal.

	Climate action for adaptation, resilience and mitigation (#1)	Water management (#2)	Green space, habitats and biodiversity (#4)	Environmental quality, including air quality and waste management (#5)	Regeneration, land-use and urban development (#6)	Inclusive and effective governance (#7)	Social justice, inequality and social cohesion (#8)	Health and well-being (#9)	Economic development and decent employment (#10)	Cultural heritage and cultural Diversity (#11)	Sustainable consumption and Production (#12)	No goal
Pollination	/	/	11 (46%)	1 (4%)	/	/	2 (8%)	1 (4%)	/	/	4 (17%)	5 (21%)
Air quality regulation	3 (5%)	/	3 (5%)	20 (34%)	10 (17%)	/	1 (2%)	14 (24%)	/	/	/	8 (14%)
Waste treatment	1 (1%)	2 (3%)	8 (12%)	44 (65%)	4 (6%)	2 (3%)	/	6 (9%	/	/	/	1 (1%)
Water manageme nt	9 (10%)	40 (44% )	9 (10%)	23 (26%)	1 (1%)	/	1 (1%)	3 (3%)	1 (1%)	2 (2%)	1 (1%)	/
Local- climate regulation	165 (85%)	1 (1%)	1 (1%)	1 (1%)	2 (1%)	/	/	16 (8%)	/	/	/	7 (4%)
Recreation	2 (2%)	1 (1%)	/	1 (1%)	1 (1%)	/	3 (3%)	68 (69%)	/	1	/	22 (22%)
Aesthetic benefits	1 (2%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)	1 (2%)	/	27 (64%)	2 (5%)	1 (2%)	/	6 (14%)
TOTAL	181 (32%)	45 (8%)	33 (6%)	91 (16%)	19 (3%)	3 (1%)	7 (1%)	135 (24%)	3 (1%)	3 (1%)	5 (1%)	49 (9%)

 Table 7. NBS goals mentioned in relation to the different ecosystem services.



## 3.7 NBS interventions

The majority of the publications in the database generate 'knowledge' by monitoring, evaluating, mapping or modelling urban ecosystem services (88%) (Table 8). Only few publications concerned each one of the other types of interventions.

	Creation of new green or blue space	Mainten ance & manage ment	Restorati on	Policy	Govern ance	Know- ledge	Economic	System/infras tructure
Pollination	/	1 (5%)	/	/	1 (5%)	20 (91%)	/	
Air quality regulation	/	/	/	2 (4%)	/	50 (94%)	1 (2%)	
Waste treatment	9 (16%)	/	4 (7%)	1 (2%)	/	40 (71%)	/	2 (4%)
Water management	2 (5%)	/	1 (2%)	2 (5%)		38 (86%)	1 (2%)	
Local-climate regulation	9 (5%)	1 (1%)	/	1 (1%)	/	178 (94%)	/	
Recreation	2 (2%)	8 (8%)	3 (3%)	4 (4%)	/	79 (82%)	/	
Aesthetic benefits	2 (6%)	1 (3%)	1 (3%)	1 (3%)	0	31 (86%)	/	
TOTAL	24 (5%)	11 (2%)	9 (2%)	11 (2%)	1 (0%)	435 (88%)	2 (0%)	2 (0%)

 Table 8. NBS intervention focus of the publications

## 4 Discussion

## 4.1 Knowledge base and gaps

The knowledge base of ecosystem services delivered by urban green and blue infrastructure is increasing at an exponential rate and the great majority of the articles included in this review have been published in 2010 or later. Given that we used general terms in the search strings like 'urban' and 'green' (see Appendix A), we expect that this increase in the number of publications reflect an increase in interest rather than the introduction of a particular term (like 'ecosystem service' or 'NBS').

Our review revealed that the knowledge base is mainly focussed towards two ecosystem services, local climate regulation and recreation, which were studied in 60 % of the included publications. However, as we restricted



our search to seven ecosystem services, we have excluded certain services upfront such as coastal protection or carbon sequestration, which are yet to be analysed. Only a few of the reviewed studies considered more than one urban ecosystem service at a time, for example Baró et al. (2015) and Kremer et al. (2016), indicating a general lack of knowledge about the multi-functionality delivered by urban green and blue infrastructure, which confirms previous publications of urban ecosystem services (Haase et al. 2014). However, as we neither included multi-functionality as an explicit search term, nor explicitly searched for additional ecosystem services in the publications, the proportion of studies assessing multiple ecosystem services may be higher than reported here.

The mapping of the publications illustrated a geographical distribution where the main part of the ecosystem service studies have been conducted in Europe, North America and China and only a few in Africa and South America. Within Europe there is bias towards Western European cities, and much less is published about NBS in Eastern European cities. The review results further shows that a diverse set of indicators are being used for quantifying the different ecosystem services. The benefit of such diversity is that many different aspects are being assessed. However, the diversity may also be problematic as it reduces the comparability between studies and make generalisations difficult. Many indicators, especially those concerning cultural ecosystem services such as recreation and aesthetic appreciation, are also influenced by context-dependent factors, such as socio-demographic factors, which makes it even more difficult to generalise the results. The knowledge base regarding the delivery of ecosystem services is greater for some ecological domains than for others. 'Parks and urban forest' have been much more thoroughly studied than 'derelict and industrial land', 'allotment and community gardens' or 'natural and semi-natural green and blue spaces', both in terms of the total number of studies and the cover of different ecosystem services. In addition, 20 % of the studies did not specify the type of green-blue infrastructure studied. This was especially common in studies looking at air quality and local climate regulation. What needs to be considered is that the search terms used in the review is rather general which potentially may cause bias towards some ecological domains as compared to others.

Climate change mitigation/adaptation and improving health and wellbeing were the goals (challenges) that were most commonly addressed in the literature reviewed. Publications covering local climate regulation and water regulation generally mentioned climate change and those addressing recreation and aesthetic related it to health and wellbeing. However, the different goals are overlapping and several goals may fit for some studies. For example, health and wellbeing can be related to 'social justice, inequality and social cohesion' and the number of studies mentioning the latter goal may therefore be higher than recorded in this review. To provide a more complete picture about the relationship between the goal(s) and the research questions, a much more thorough text analysis would be needed.



There is a general lack of knowledge about interventions looking at other aspects than just generating knowledge. Cities are generally creating, restoring or exploring different management strategies for urban green and blue infrastructure and the possibility therefore exist for studying ecological and biophysical interventions. However, there may be obstacles that hinder such research projects. For example, the time scale for interventions as creation and restoration may be to long for a typical research project. Additionally, researchers may be unaware of many interventions due to a general lack of interactions between municipal stakeholders and researchers and also due to a low uptake of grey literature among researchers.

## 4.2 Summary

The review of the evidence base in this study provides insights into the needs and focus of future studies on urban NBS. In particular, we found that:

- Few studies look at more than one ecosystem services (multi-functionality, ES-bundles), among researchers and users.
- Few studies assess services from derelicts and industrial areas, allotment and community gardens or natural and semi-natural green and blue spaces.
- Few studies has been done in South America and Africa
- Few studies look at other NBS interventions than generating knowledge.

Based on the above, possible directions for future research include the following:

- Include a larger set of ecosystem services and geographical areas to cover the geographical bias and the context-dependency of ecosystem services.
- Quantify the relationship between the provision of NBS and the general or typical characteristics of green and blue infrastructure, including the effects of modifying factors to account for context-dependency.
- Increase the evidence of NBS for urban planning and management, by including potential synergies and trade-offs (multi-functionality) among NBS in multi criteria analysis.
- Bridge between researchers and municipalities to increase the opportunities for studying NBS from ecological and biophysical interventions and thus close the corresponding knowledge gaps.



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## 6 Appendix

## 6.1 Appendix A.

The different search strings that were used in the study.

#### **Pollination:**

- 1. Urban AND green AND space AND pollination
- 2. Urban AND green AND space AND bee AND abundance
- 3. Urban AND green AND space AND pollinator AND abundance
- 4. Urban AND green AND infrastructure AND pollination
- 5. Urban AND nature AND pollination
- 6. Urban AND nature AND bee AND abundance
- 7. Urban AND nature AND pollinator AND abundance

#### Air quality regulation

- 1. (Urban AND green AND space AND air) AND (regulation OR filtration OR quality OR purification)
- 2. (Urban AND nature AND air) AND (regulation OR filtration OR quality OR purification)
- **3.** (urban AND green AND infrastructure AND air) AND (regulation OR filtration OR quality OR purification)
- 4. Urban AND nature AND pollution AND removal

#### Waste treatment

- 1. (Urban AND green AND space AND water) AND (purification OR filter)
- 2. Urban AND nature AND water AND purification
- 3. Urban AND nature AND waste AND treatment
- 4. Urban AND green AND space AND waste AND treatment
- 5. urban AND (lake OR pond OR wetland OR canal OR river OR floodplain) AND water AND purification
- 6. Urban AND green AND space And soil AND (remediation OR quality)
- 7. Urban AND green AND space AND phytoremediation
- 8. Urban AND nature AND soil AND (remediation OR quality)
- 9. Urban AND nature AND phytoremediation
- 10. Urban AND green AND infrastructure AND soil AND (remediation OR quality)
- 11. Urban AND green AND infrastructure AND phytoremediation



#### Local climate regulation

- 1. Urban AND green AND space AND temperature
- 2. Urban AND nature AND temperature
- 3. Urban AND green AND infrastructure AND temperature

#### Recreation

- 1. Urban AND green AND space AND recreation
- 2. Urban AND nature AND recreation
- 3. Urban AND green AND infrastructure AND recreation

#### Storm water management

- 1. Urban AND green AND space AND water AND (regulation OR management)
- 2. Urban AND green AND space AND storm AND water AND retention
- 3. Urban AND green AND infrastructure AND storm AND water AND management
- 4. Urban AND nature AND storm AND water AND management
- 5. Urban AND (lake OR pond OR wetland Or canal OR river OR floodplain) AND storm AND water AND management

#### Aesthetic appreciation

- 1. Urban AND green AND space AND aesthetic
- 2. Urban AND nature AND aesthetic
- 3. Urban AND green AND infrastructure AND aesthetic



#### 6.2 Appendix B

The following publications were used in the review.

#### Pollination

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