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Urban natural environments as nature-based solutions for improved public health – A systematic review of reviews

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ABSTRACT

Increasing urbanisation, changing disease scenarios, and current predictions of climate change impacts require innovative strategies for providing healthy and sustainable cities, now and in the future. The recently coined concept, Nature-based solutions (NBS), is one such strategy referring to *actions that are inspired by, supported by, or copied from nature*, designed to address a range of environmental challenges. The objective with this article is to evaluate the evidence on public health benefits of exposure to natural environments and explore how this knowledge could be framed within the NBS concept. We conducted a systematic review of reviews following established methodology, including keyword search in several databases, predefined inclusion criteria, and a data extraction in accordance with the PICOS structure. We reviewed literature on associations between public health and natural environments in relation to pathways – sociobehavioural/cultural ecosystem services (e.g. stress and physical activity) and regulating ecosystem services (e.g. heat reduction) – or defined health outcomes (e.g. cardiovascular mortality). The results show that there is strong evidence for improved affect as well as on heat reduction from urban natural environments. These conditions may mediate the effect seen on cardiovascular disease (CVD)-related mortality by exposure to natural environments. By also reviewing existing literature on NBS and health, we phrase the results within the NBS context, providing guidelines on how public health and well-being could be integrated into implementation of NBS for resilient and liveable urban landscapes and health in a changing climate.

1. Introduction

1.1. Urbanisation and health

Urban populations are expanding rapidly across the world, putting pressure on cities' resources and the equal distribution of those. In combination with the current predictions of climate change impacts, suggesting, for example, increase in urban temperatures, storms, extreme drought/precipitation, and other environmental hazards, this puts urban areas under a lot of stress to provide environments that support human health and well-being.

Another challenge, related to urban environments and lifestyles, is the epidemic of non-communicable diseases (NCDs). NCDs, such as diabetes, obesity, chronic respiratory diseases, cancer, mental and cardiovascular disorders, are dominating the current global disease burden and are expected to increase in prevalence also in low- and middle income countries (Vos et al., 2015). These conditions are best prevented by societal and environmental interventions (WHO, 2012).

Finally, urban environments are also characterised by an excessive load of toxic exposures, such as air pollution and noise, from, for example, motorised traffic and industries. Air pollution alone accounts for around 600,000 deaths annually in the pan-European region (van den Bosch, et al., 2016) and noise is a major health problem, causally linked to, for example, mental and cardiovascular disorders (WHO, 2011).

Mitigating impacts and adapting to actual or expected effects of changes in the climate involve a range of potential actions to help reduce risks and vulnerability and improve resilience capacity. Equally, sustainable prevention of NCDs and reduction of harmful exposures require multisector approaches and actions (McMichael, 2015). These actions could be effective on different spatial and temporal scales, proactively planned, or results of socio-political drivers such as e.g. new planning regulations, market demand, or even social pressure (IPCC, 2014). They may work in isolation or in synergies, and can include co-benefits or trade-offs.

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1.2. Nature-based solutions and health

"Nature-based solutions (NBS) are actions which are inspired by, supported by, or copied from nature", and that are designed to address a range of environmental challenges in an efficient and adaptable manner, while at the same time providing economic, social, and environmental benefits (ECDG, 2015). Types of NBS that have been identified by the European Commission Directorate-General (ECDG, 2015) as relevant to cities include: ecosystem restoration, greening of grey surfaces (e.g., green rooftops, green walls or greened brownfields), and integrated broad scale climate change mitigation and adaptation measures, e.g., afforestation, natural flood control, and constructed wetlands. In a review carried out by Pauleit et al. (forthcoming) a broader view of the term NBS is taken, proposing NBS as an umbrella term, incorporating terms such as Green Infrastructure (GI), Ecosystem-based adaption, and ecosystem services (ESS). How the concept of NBS is presented in scientific literature and to what extent it is related to public health protection have been unclear. We therefore conducted a review of existing literature on (i) NBS and on (ii) NBS and health. The search terms were correspondingly (i) "Nature based solution*" and (ii) "nature based solution*" AND health (search carried out in April 2016 using 4 databases; Scopus, Web of Science, CAB and PubMed) and resulted in 27 papers covering NBS and only 3 of those were retrieved if including health in the search terms. The papers were categorised with regards to (i) type of paper (empirical, review, conceptual), (ii) focus of the paper, and (iii) environmental adaptation and health (see Appendix A). The results showed that most of the current articles are conceptual, with their discourse mainly being 1) NBS in relation to Green Infrastructure (e.g. H. Chen et al., 2016; Clabby, 2016; Derkzen et al., 2017; Kazmierczak, 2016); 2) NBS for mitigating and or adapting to climate change (e.g. Bennett et al., 2016; Brink et al., 2016; Kabisch et al., 2016); and 3) NBS in relation to ESS (e.g. J. Chen et al., 2016; Fink, 2016; Haase, 2016; Lafortezza and Chen, 2016). The three papers explicitly relating NBS to human health and well-being, were all in a conceptual form and presented different perspectives (Annerstedt van den Bosch and Depledge, 2015; Beatley, 2016; Richardson et al., 2016). Beatley (2016) discusses urban nature from a perspective of city planning, through the discourse of biophilic cities, where health is the main motivating factor. Richardson et al. (2016) provides a summary of the evidence of the value of the natural environment to well-being followed by how this could inform the wider practice and epistemology in ergonomics. The paper by Annerstedt van den Bosch and Depledge (2015) draws on earlier research on the effect nature has of evoking psychological and physiological reactions and suggest that NBS could be used to automatically foster pro-environmental behaviour and indirectly improve public health by reducing climate change impact. The relative lack of literature on the possible relation between NBS and public health indicates that the intimate relation between environmental conditions and human health is insufficiently explored within the NBS-context. NBS are often considered as mainly related to environmental/ecological issues. However, as human health is, to a large extent, depending on surrounding social and physical environments, the public health realm should be as relevant for NBS considerations and trans-sectoral and trans-disciplinary efforts are required for improved human health.

2. Natural environments and health

Current literature on hypotheses, theories, and studies on associations between contact with natural environments and health refers to either pathways – sociobehavioural/cultural ESS (e.g. stress reduction and physical activity) and regulating ESS (e.g. heat reduction) – or defined health outcomes (e.g. cardiovascular mortality) (Hartig et al., 2014) (see Table 1).

The ecological model of health, originally developed by (Dahlgren and Whitehead, 1991) and further developed by (Barton and Grant, 2006) and (Coutts and Hahn, 2015), identifies the importance of the natural environment for our health and well-being. Several frameworks have been put forward and also been frequently cited, theoretically further outlining the link between human health and well-being and the natural environment (Bedimo-Rung et al., 2005; Calogiuri and Chroni, 2014; Hartig et al., 2014; Lachowycz and Jones, 2011; Shanahan et al., 2015; Tzoulas et al., 2007).

The focus of these frameworks have mostly been on socio-behavioural pathways such as physical activity (e.g. Bedimo-Rung et al., 2005, Lachowycz and Jones, 2011) stressing the impact of user as well as green space characteristics for explaining activity. Other frameworks, such as the one proposed by (Calogiuri and Chroni, 2014), stress only the motivational processes underlying the relationship between natural environments and physical activity, leaving out the characteristics of the environment as a moderating factor. Frameworks taking an ESS approach – looking at human health as a service provided by ecosystems – consider the function and health of the ecosystem as determinants of potential health outcomes (Shanahan et al., 2015; Tzoulas et al., 2007). Within this context, sometimes the so called "Old Friends hypothesis" is considered, where a dysfunctional immune system is suggested to be due to minimised contact with biodiverse natural environments and consequentially a non-sustained human microbiome (Rook, 2013; Rook et al., 2014). This means that by increased exposure to natural environments, and thereby biodiverse microbiota, a protective effect against infectious and autoimmune disorders may be achieved (Rook et al., 2015, 2014).

In a recent meta-review of the evidence on associations between human health and natural environments (Hartig et al., 2014) a framework of the various pathways, including both cultural and regulating ESS, was provided. While this article was published no later than 2014, the literature search was conducted in the first half of 2013, and the evidence between pathways and respective health outcomes was not considered. The study design was not firmly aligned to a systematic review method and, for example, the direct health effects of the regulating heat reduction service were not considered in terms of reduced heat related morbidity and mortality. The research area has increased exponentially the latest three to four years, and a plethora of reviews, systematic or not, has emerged since 2013 around health effects of exposure to urban natural environments. These reviews have considered sociobehavioural pathways, regulating ESS, or direct health outcomes respectively. A few have evaluated any health related outcome, i.e. including two or three of the categories (pathways, ESS, or direct health outcomes).

To our knowledge, no previous systematic review of reviews on natural environments and health has been conducted, following a systematic review design. Considering that several reviews, reports, and systematic reviews are now available, some with overlapping themes, it is of value to synthesise the results from those to conclude in which areas evidence is already at hand and for what topics additional systematic reviews are required. In this article, we will approach the topic from an NBS-perspective and will thus focus on the physical, natural environment, rather than the social environment, although those are often related. We aim to establish a specific level of evidence for suggested pathways between any urban natural environment and any pathway or health outcome by conducting a systematic review of systematic reviews, restricting our inclusion criteria to only studies with defined search terms, inclusion criteria, and quality assessments, providing a more precise assessment of what evidence is actually available. By using strict inclusion criteria we aim for as high quality appraisal as possible. The above mentioned criteria – defined search terms, inclusion criteria, quality assessment – are fundamental in any systematic review and without predetermined inclusion/exclusion criteria the review is of lower quality and the interpretation of results is less reliable. Equally, defining search terms and conducting a quality assessments are crucial for the quality of the review. These endpoints are also outlined in the AMSTAR tool for assessing quality in systematic reviews (Shea,

Table 1
Theories around associations between health and nature discuss, for example, the restorative and stress reducing potential, which can be conceptualised as sociobehavioural pathways or cultural ecosystem services. Regulating ecosystem services can also contribute to improved health by, for example, reducing the urban heat island and related morbidity and mortality. Recent studies have demonstrated impact on various defined diagnoses and health outcomes, such as all-cause mortality and birth weight.

Sociobehavioural pathways/cultural ecosystem services	Stress reduction, improved mood/happiness, increased physical activity, reduced overweight, improved social cohesion, reduced health inequalities, strengthened immunocapacity
Regulating ecosystem services	Heat reduction, reduced levels of air pollution, improved water management, noise reduction
Health outcomes and functions	Mortality, birth weight, mental health, autoimmune diseases, respiratory diseases, cancer, perceived general health/ morbidity, neurocognitive development and function

2009). The purpose of our review, is also to critically scrutinize the probability for each respective defined health outcome that has been studied and associated with nature, by addressing the level of evidence between pathway and outcome, for example between stress and cardiovascular diseases. This would meet the call for a summary of currently available evidence, which is needed for establishing evidence-based decision tools for policy makers and urban planners, aiming at improving health through green planning and possibly NBS. Equally, the aim is to highlight which areas remain to be explored and reviewed. Finally, following the policy and implementation line, we aim to synthesise the outcome of the review into a framework of NBS, considering mainly the physical, natural environment, for improved urban public health. This paper will hereby provide an updated evidence base for implementation of NBS, including the interaction point between public health and urban green planning. This interaction point is currently not defined or formalised in the concept of NBS and this review could potentially create a new starting point, not only for further and extended research, but also by providing new input to a prioritised policy area in Europe and other urbanising areas.

3. Method

3.1. Systematic review of systematic reviews

3.1.1. Literature search

We conducted a structured review of reviews in accordance with the methodology described in Smith et al. (2011). We followed the PICOS structure for defining the scope of the review and data extraction. This means that we considered (i) **P**articipants (any); (ii) **I**nterventions (urban natural environments); (iii) **C**omparators (any); (iv) **O**utcomes (pathways, regulating and provisioning ESS); and (v) **S**tudy design (systematic reviews). An electronic literature search was conducted and finalised in August 2016, using the databases Scopus, PubMed, PsyINFO, and Web of Science. We limited the search to peer-reviewed articles written in English and also filtered the results by study type to include only reviews. No other filters were applied. Search terms relating to (i) outdoor green or blue spaces; (ii) pathways; and (iii) health were combined and searched for in keywords, topic, title and abstract, or MeSH-terms (PubMed), (Table 2). The search terms for green and blue spaces and either pathways or health terms were combined with the Boolean AND and within each group the Boolean OR was used. Aiming for as complete coverage as possible, we widened the search beyond the protocol, using "snowballing" and scanning of identified articles' bibliographies. The selection of search terms was based on existing theories and research on relations between natural environments and health (see Table 2).

Titles and abstracts of articles, identified by the searches, were reviewed by the authors independently. For all the studies described in this review at least the abstract was retrieved, and if fulfilling the inclusion criteria, the entire article. We based our inclusion criteria on the AMSTAR tool (Shea, 2009), in order to incorporate only high quality systematic reviews. While the AMSTAR tool is initially designed for evaluating the quality of review-articles in a review of reviews, we used the AMSTAR domains as indicators of eligibility for our study. Thus we aimed to achieve as strong evidence as possible in our results, based on high quality studies. The domains included in the tool for evaluating the quality of a systematic review refer to, for example, (i) establishing the research question and inclusion criteria before the conduct of the review, (ii) data extraction by at least two independent researchers, (iii) comprehensive literature review using at least two databases, (iv) key word identification, and (v) quality assessment of included studies.

We applied the following inclusion criteria:

- Systematic reviews and meta-analyses
- Including a structured quality evaluation of included studies
- Published in peer-reviewed, scientific journal
- Written in English
- Reporting on pathways and/or health outcomes related to accessibility or exposure to urban outdoor natural spaces, including green infrastructure

Table 2
Search terms used.

Green and blue outdoor natural environments	Pathways/ESS and defined health outcomes
"Green infrastructure"	"Physical activity*"
"Green space*"	walkability
"Urban park*"	Stress
"urban forest*"	Restoration
"urban tree*"	Affect*
Biodiversity (AND urban)	"social cohesion"
"blue space*"	"social capital"
Water (AND urban)	"air pollution"
	"air quality"
	Cooling
	Heat
	Noise
	"water management"
	Flooding
	food
	Inequalit*
	Overweight
	Obesity
	immun*
	"Public health"
	"Human health"
	Well-being
	Health
	"quality of life"
	attention
	Development (AND child*)
	"birth weight"
	Morbidity
	Mortality
	Illness*
	Disease*
	Disorder*
	cardiovascular
	Cancer
	Asthma
	Depression
	anxiety

* Indicates wild card, i.e. any ending is possible.

Table 3
Included review articles and how natural environments and health outcomes have been described.

Article	Number of studies	Meta-analysis	Definition of natural environment	Definition of health outcome or pathway	Evidence for impact on health outcome
Gascon et al. (2016)	28	No	Both green and blue spaces, percentage in a specific buffer or at census area level. Land cover maps and NDVI[a]	*Mental health*, measured by either GHQ12[b], MHI[c], or SF−36[d]. Or specific diagnoses, such as depression, anxiety and mood disorders assessed with various tools	Limited evidence
Gascon et al. (2016)	12	Yes (for all-cause, CVD[e]- and lung cancer related mortality)	Percentage of greenness in buffers at census level, distance to nearest green, measured with land cover maps or NDVI	*Mortality*. All cause, heat related, CVD, stroke and post-stroke, lung cancer, self-harm, respiratory disease, diabetes, traffic accident,	Moderate evidence for all-cause and CVD mortality. No evidence for lung cancer mortality.
McGrath et al. (2015)	23	Yes	Neighbourhood (both built and green environments), defined with GIS[f], street audits or GPS[g]	*Physical activity* among children and adolescents, measured by accelerometers	No evidence
van den Berg et al. (2015)	34	No	Open spaces with natural elements such as parks, playgrounds and recreation areas, as measure by GIS, NDVI, combinations of detailed maps and/or land classification databases. Mostly proximity measures/ buffers or geographically defined small areas, such as census tracts. Tree canopy cover. Quality of green space was included in a couple of studies	*Perceived general and mental health, all-cause mortality*	Strong evidence for an association between quantity of green space and perceived mental health and mortality. Moderate evidence for perceived general health and quantity of green
Dzambov and Dimitrova (2014)	5	No	Unclear from the review, but included both green spaces in neighbourhood and photos of nature	*Psychological buffer of noise*, defined as noise annoyance, noise responses such as irritation, anger	Moderate evidence, but only 5 studies included why evidence is considered weak.
Dzambov et al. (2014)	8	Yes	Residential greenness, measured by NDVI	*Birth weight*	Strong evidence for a weak effect
Lovell et al. (2014)	17	No	Biodiversity, as measured in various ways – audits, visual assessments, self-reports of diverse features, national park, bird species richness	*Any health outcome*, e.g. life expectancy, self-perceived health, infant mortality, psychological wellbeing, community level of wellness, physical activity, BMI[h], mental health deprivation	Positive tendency in general, but inconclusive evidence
McMahan and Estes (2015)	32	Yes	Real nature or simulated. Wild versus non-wild. No further details on how green was assessed in the studies.	*Emotional state* as measured by PANAS[i], ZIPERS[j], SVS[k] or other scales that were used less frequently.	Strong evidence for moderate effect
Lachowycz and Jones (2011)	60	No	Distance and amount of nature, measured by GIS or professional audits	*Physical activity* (self-reported or accelerometer), weight status (BMI) or health outcomes shown to be related to obesity (e.g. diabetes, CVD, metabolic syndrome).	Mixed evidence for relation to physical activity, some evidence for relation to BMI and obesity related health outcomes
Lee and Maheswaran (2011)	35	No	Green space, public open space, open space, park	*All health outcomes*. Physical activity. Stroke mortality. Mental health, obesity, ADHD[l], all-cause mortality, social isolation, stress	Weak evidence for the links between physical, mental health and well-being
Bowler et al. (2010a)	25	Yes	Park, reserve/wildlife preserve, wilderness, 'forest, or a garden. Not clear how those were defined in each respective study.	*Emotions* (self-reported based on various questionnaires), *Attention* (various tests), ADD/ADHD, *Cardiovascular symptoms* (Blood pressure, pulse), *Endocrine* (hormone concentrations), *Immune function* (IgA[m], NK[n]-cells, T-cells)	Strong evidence for reduction of negative emotions, moderate evidence for improved attention. Other health parameters - less consistent evidence.
Kaczynski and Henderson (2007)	50	No	Includes both parks and indoor recreational facilities, such as swimming pools, sport fields, dance studios. In general, not clear how green space was measured, most likely self-reported	*Physical activity* - not clarified how that has been measured, seemingly most self-reported	Positive trend, but inconclusive evidence for improved physical activity by parks, open spaces, or lake/beach/coast

(continued on next page)

Table 3 *(continued)*

Article	Number of studies	Meta-analysis	Definition of natural environment	Definition of health outcome or pathway	Evidence for impact on health outcome
Bowler et al. (2010b)	47	Yes	Parks, green spaces, green roofs, garden roofs, green ground cover, tree canopy. In general not clarified how greenery was measured	*Air temperature*	Strong evidence

[a] Normalized Difference Vegetation Index.
[b] General Health Questionnaire.
[c] Mental Health Inventory.
[d] Short Form health survey.
[e] Cardiovascular disease.
[f] Geographic Information Systems.
[g] Global Positioning Systems.
[h] Body Mass Index.
[i] The Positive And Negative Affect Schedule.
[j] Zuckerman Inventory of Personal Reactions.
[k] Symptom Validity Scale.
[l] Attention Deficit Hyperactivity Disorder.
[m] Immunoglobulin A.
[n] Natural Killer.

Studies that did not follow a standardised systematic review method, e.g. not identifying search terms used, not providing a transparent report on study selection process, or not describing any evaluation of study quality, were excluded.

As the aim was to use the results for NBS in an urban planning perspective, mainly for health promotion and disease prevention, we did not consider reviews on nature- or animal assisted therapies. We also excluded any reviews on indoor plants. Equally, we excluded reviews on connectedness to nature as a personality trait rather than exposure or accessibility to natural spaces.

3.1.2. *Data extraction*

We used a standardised data extraction sheet to ensure a controlled analysis and data retrieve. The articles were scrutinized by the authors together and disagreements regarding fulfilment of inclusion criteria were resolved by consensus. The extraction sheet included data on, for example, search terms used, number of articles included, definition of natural space and health outcome reviewed, and quality assessment. (A summary of the results from the extraction sheet is provided in Table 3).

We did not conduct a meta-analysis of the included reviews. It is likely that many individual studies were included in more than one review, resulting in incorrect statistical power and a risk for misleading results. As our review considers one type of "intervention" (urban natural environments), though of varying composition (e.g. green infrastructure, biodiversity, or blue environments), and its effect on several different pathways and health outcomes, we considered the challenge of unpicking each included review, extracting the results from each individual study included, and the subsequent combination of the results, to be of less value given the heterogeneity in the outcome measures and the dubious accuracy of a pooled effect estimate (Brok et al., 2008).

4. Results

The initial search resulted in 351 retrievals. A first scan of titles and abstracts was carried out limiting the amount of potentially relevant papers to in total 57. The remaining potentially eligible full papers were reviewed and evaluated as fulfilling inclusion criteria or not, resulting in a final inclusion of 13 articles. See flow chart, Fig. 1.

Following our strict inclusion criteria, in accordance with AMSTAR (Shea et al., 2009), the included reviews were all assessed to be of high scientific quality.

Our presentation follows the model of hypothetical outcomes that would be plausible to appear in systematic reviews on the topic (Table 1). Several reviews included more than one pathway or health outcome associated with natural environments. On the other hand, several possible pathways or health outcomes, such as air pollution reduction and cognitive development, were not analysed in any of the included systematic reviews, and could therefore not be included in our synthesis. We chose to extract results for each respective outcome separately and present those accordingly below. Equally, several reviews considered various urban environments, natural spaces being just one of them. We then extracted only the results related to the natural environment. A summary of the data extraction and results are presented in Table 3.

4.1. *Socio-behavioural pathways/cultural ecosystem services*

4.1.1. *Stress*

One review (Bowler et al., 2010a) addressed stress, among other outcomes (emotion, attention, cardiovascular function). While trends were positive, no significant effect on biomarkers of stress (cortisol, systolic and diastolic blood pressure) was concluded in the meta-analysis (based on four studies).

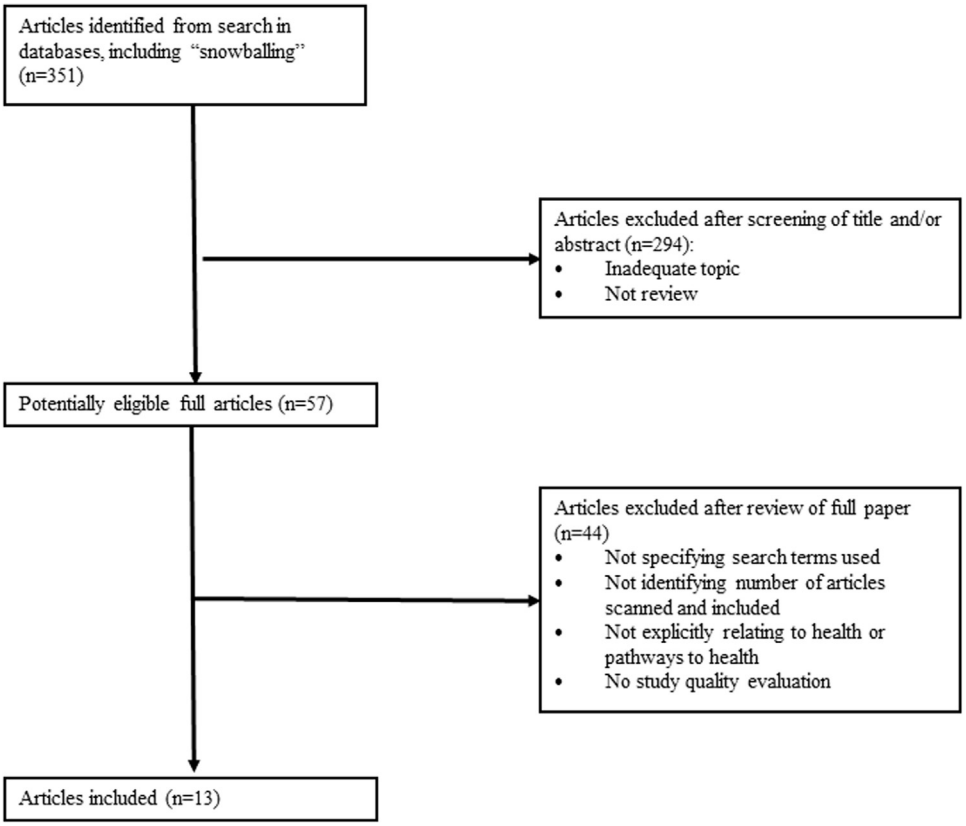

Fig. 1. Process of data evaluation and study selection.

4.1.1.1. Stress and health outcomes. The relation between stress and disease is complex and a multitude of disorders as well as mechanisms have been considered (Juster et al., 2010). Looking at the defined health outcomes that have been associated to natural spaces, and systematically reviewed (all-cause mortality, cardiovascular disease (CVD) mortality, mental health, pregnancy outcomes, and lung cancer), we can conclude that there is strong, consistent evidence for a correlation between stress and CVD-mortality (Ippoliti et al., 2013; Lu et al., 2013). Similarly, there is moderate to strong evidence for stress as a risk factor for all-cause mortality, mental disorders, and reduced birth weight or preterm birth (Staufenbiel et al., 2013; Gallo et al., 2014, McEwen, 2012, Ding et al., 2014). Research on stress and lung cancer mortality is still limited. The evidence suggests a potential relation, but is inconclusive (Schuller, 2014; Rensing and Rippe, 2009).

4.1.2. Physical activity

Five reviews addressed increased physical activity as an outcome of contact with green spaces (McGrath et al., 2015, Lovell et al., 2014, Lachowycz and Jones, 2011, Lee and Maheswaran, 2011, Kaczynski and Henderson, 2007). Results from the meta-analysis (McGrath et al., 2015), addressing physical activity as primary outcome, were inconsistent. However, the exposure factor in this review included built environments in general and therefore the extraction of results primarily related to green space was complicated, as some of the data related to greenery in combination with built environment. The four remaining reviews showed a positive, but weak association with physical activity.

4.1.2.1. Physical activity and defined health outcomes. Physical activity is strongly related to most of the health outcomes systematically reviewed and associated with natural spaces. The strongest evidence indicates that the greatest benefit of physical activity is in the reduction of CVD risk and related mortality as well as all-cause mortality (WHO, 2006; Hupin et al., 2015; Lavie et al., 2015). There is also consistent evidence for the positive impact of physical activity on mental health (Pareja-Galeano et al., 2016; Schuch et al., 2016). Evidence on maternal physical activity and birth weight is inconsistent and is mostly related to preventing overweight new-borns (Mudd et al., 2013; Wiebe et al., 2015). There is an association between lung cancer mortality and physical activity, but the strength of the relation is still to be determined and the evidence is inconclusive (Brenner et al., 2016; Zhong et al., 2016).

4.1.3. Overweight/obesity

Obesity may be considered a diagnosis and direct health outcome. In this review we chose to include it among pathways together with overweight. Two reviews (Lachowycz and Jones, 2011; Lovell et al., 2014) studied overweight/obesity as outcome. While many other outcomes were included in the review by Lovell et al. (2014), BMI-measures were the primary outcome in Lachowsky and Jones (2011). Lovell et al. (2014) studied a particular aspect of the natural environment, namely biodiversity, while Lachowsky and Jones (2011) studied green spaces in general. Both reviews concluded that there seem to be a tendency of a positive association, but the evidence is weak or inconsistent.

4.1.3.1. Overweight and health outcomes. There is firm evidence that overweight and obesity are strongly correlated to CVD- and all-cause mortality (Aune et al., 2016). There is also evidence, though less strong, for a relation between overweight and mental disorders (Becofsky et al., 2015). Overweight during pregnancy increases the risk for excessive weight in offspring (Bello et al., 2016; Paliy et al., 2014). While obesity increases the risk for several cancer forms, any association to lung cancer has yet not been proven (Pan and Desmeules, 2009).

4.1.4. Affects and emotions

Two reviews included affects and emotions as outcome, either as primary outcome (McMahan and Estes, 2015) or one of several (Bowler et al., 2010a). Both studies included meta-analyses and found strong evidence for a positive impact on affect and reduced levels of anger and sadness.

4.1.4.1. Positive affective states and health outcomes. Positive affect is strongly related to CVD- and all-cause mortality (Mroczek et al., 2015; Shirom et al., 2010; Lamers et al., 2012) and mental health. The impact of positive affect on risk for lung cancer mortality risk or poor pregnancy outcomes has not been consistently investigated.

4.1.5. Social cohesion, health inequalities, immunocapacity

None of the included reviews addressed these potential pathways.

4.2. Regulating and provisioning ecosystem services

4.2.1. Heat reduction

Bowler et al., (2010b) reviewed the cooling effect of urban greening and found moderate to strong evidence for reduced temperature. The meta-analysis demonstrated that, on average, a park is 0.94 °C cooler as compared to surrounding built environments.

4.2.1.1. Heat reduction and health outcomes. Excess heat can make people susceptible to disease, due to a limited adaptation capacity of human thermoregulation (Benzinger, 1969; Downey et al., 1971). In addition, there is an augmented risk for exacerbations in existing chronic conditions, making certain groups particularly vulnerable to heat (Jehn et al., 2014; Patz et al., 2014). Increased heat is a strong predictor of a range of diseases (including several which have to date not been addressed in studies on natural environments and health, such as infant mortality and renal disorders) and mortality (Basagaña et al., 2011; Benmarhnia et al., 2015). It also has an impact on mental health (Berry et al., 2010). There seem to be an association between heat and birth weight, but the evidence is inconsistent (Beltran et al., 2014; Poursafa et al., 2015). The relation between heat and lung cancer mortality is not sufficiently investigated.

4.2.2. Noise reduction

Dzhambov and Dimitrova (2014) reviewed the effect of green spaces on negative health impacts of noise. No meta-analysis was conducted and only five studies were included in the final review. They concluded that there is moderate evidence that the presence of vegetation can reduce the negative perception of noise.

4.2.2.1. Noise and health outcomes. Noise is related to hypertension and a substantial disease burden (WHO, 2011), but the evidence for associations with the outcomes that have been studied and reviewed in relation to natural environments is unclear (Skogstad et al., 2016; WHO, 2011). No consistent associations have been found between chronic noise exposure and pregnancy outcomes (Ristovska et al., 2014; Hohmann et al., 2013). Regarding mental disorders there is a positive association with noise, but the evidence is inconclusive (Pirrera et al., 2010).

4.2.3. Air pollution reduction, storm water management, filtering of drinking water, food supply

None of the included reviews addressed these regulating ESS.

4.3. Defined health outcomes

4.3.1. All- cause mortality

Two reviews studied all-cause mortality, together with other health outcomes (Gascon et al., 2016; van den Berg et al., 2015). Gascon et al. (2016) conducted a meta-analysis, while this was considered non-applicable in van den Berg et al. (2015) due to heterogeneity in green space metrics. The results in Gascon et al. (2016) were inconsistent, while van den Berg et al. (2015) concluded that there is moderate to strong evidence for a positive association between green spaces and all-cause mortality.

4.3.2. Mortality related to CVD

Gascon et al. (2016) found moderate to strong evidence for an association between natural environments and CVD-mortality.

4.3.3. Lung cancer mortality

Gascon et al. (2016) found no evidence for a relation between natural environments and lung cancer mortality.

4.3.4. Birth weight

Dzhambov et al. (2014) conducted a meta-analysis and concluded that there is significant, but weak evidence for an association between natural environments and birth weight. Lovell et al. (2014) found no evidence for a relation between biodiversity and birthweight.

4.3.5. Mental health and well-being

The evidence for a positive relation between natural environments and mental health and well-being was concluded as strong by van den Berg et al. (2015). Gascon et al. (2016) found limited evidence for mental health benefits of long-term residential surrounding greenness in adults. For access to green space and for studies in children the evidence was inadequate. In the earlier review by Lee and Maheswaran (2011) the evidence was found to be weak.

4.3.6. Other health outcomes that have been studied in relation to natural environments, such as children's early and cognitive development, attention deficit disorder (ADHD), depression and asthma, were not addressed in any of the included reviews

A model of the evidence for relations between natural environments and pathways and subsequent health outcomes is presented in Fig. 2.

4.4. Greeness/green space/natural environments

The different reviews show variation in how green is classified and collected and how it has been included in the review. The focus on greenness (meaning including all vegetation) or the focus on green space is not a clear distinction – most cover both type of studies in their review. A few of the reviews are just focusing on presence of vegetation (Dzhambov and Dimitrova, 2014; Lachowycz and Jones, 2011) or natural vs synthetic (e.g. Bowler et al., 2010a), though most are able to give some support for a positive relationship between different aspect of health and green space quantity (e.g. Gascon et al. 2016; van den Berg et al., 2015; Dzambov et al., 2014; Lee and Maheswaran 2010; Kaczynski and Henderson, 2007). A common remark in the reviews is that there is a lack of studies that cover qualitative aspects of green space in a more sophisticated way (e.g. Lachowycz and Jones, 2011 p. 187) and that the amount of studies including those aspects were insufficient for an evidence synthesis (van den Berg et al., 2016) and hence often producing mixed associations (as for instance with physical activity (Kaczynski and Henderson, 2007)). However, several of the reviews outline aspects such as features, conditions, perceived quality, accessibility, and safety as likely to be of importance, though without founding a strong evidence base for them (e.g. van den Berg et al., 2016; Lee and Maheswaran, 2010). The link between biodiverse natural (or wild) environments and health is inconclusive (Lovell et al., 2014; McMahan and Estes, 2015).

5. Discussion

This systematic review of high quality systematic reviews shows that there is strong evidence for a positive effect of green spaces on improved affect as well as on heat reduction. Affect state and heat are both strongly related to CVD-mortality and there is also moderate evidence for a relation to mental disorders and all-cause mortality, according to existing reviews. This corresponds to the strong evidence for a relation between CVD-related mortality and natural environments. Thus, it is plausible that natural environments' effect on CVD-related

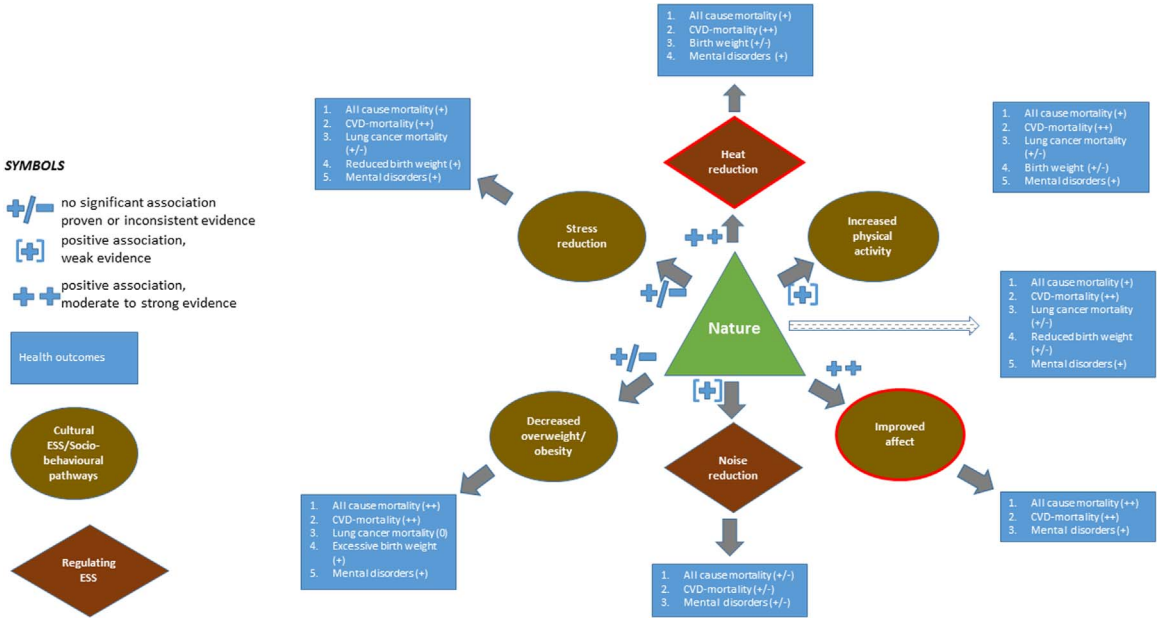

Fig. 2. The relations between natural environments, pathways (sociobehavioural and ecosystem services related), and health outcomes, as those have been treated in existing reviews. We assume that the health outcomes are mediated by pathways. For each pathway the health outcomes for which there is scientific evidence on a relation proven, and which have been studied in relation to natural environments, are listed. The strength of the evidence is indicated behind each outcome.

mortality is mediated by affect regulation and reduced heat, most likely acting independently. Equally, it is possible that the effects on mental disorders and all-cause mortality, for which the evidence on a relation to natural environments is moderate, are mediated by improved affect or heat reduction. There is also a correspondence between the lack of evidence for effects on lung cancer mortality and birth weight and the relative lack of evidence for mediators related to these outcomes – stress and physical activity. While other reviewed mediators or pathways – stress reduction, physical activity, decreased overweight, and noise reduction – are also related to several of the suggested health outcomes, the evidence for these pathways is still not sufficient for drawing any firm conclusions.

The results also demonstrate that, as research on the topic is exponentially increasing, more up-to-date systematic reviews could be conducted for several pathways and outcomes. For example, while stress is one of the most common pathways referred to, only one review, six years ago, addressed this topic (Bowler et al., 2010a). Equally, several other pathways that are referred to in the literature – social cohesion, health inequalities, and immunocapacity – have to date not been scrutinized in any systematic review, nor has related defined health outcomes, such as reduced risk for autoimmune or infectious diseases through improved immune system development. This may also be due to a lack of original studies on these subjects. Regulating ESS that have been studied in relation to natural environments, but yet not systematically reviewed, are air pollution reduction, storm water management, and filtering of drinking water. These kind of services could potentially mediate effects on air pollution related morbidity, such as asthma and other respiratory diseases, drowning, and infections due to contaminated water. While reduced prevalence of asthma has indeed been associated to natural environments (Sbihi et al., 2016, 2015), no studies have, to our knowledge, addressed the topics of water management and related morbidity in association to natural environments in cities. Neither has provisioning services, like food supply, been reviewed. The latter may, at least partly, reflect the general lack of studies from low- and middle income countries.

Another line of inquiry which is not addressed in this review is the studies of therapeutic landscapes within the realm of health geography (Williams, 1998; Gesler, 1992). This concept provides a theoretical understanding of the relevance of places and settings for mental, physical, and social health and well-being in a holistic sense (Classen and Kistemann, 2010) and includes both green and blue spaces. While this concept provides a strong link to geography of health and medicine (Völker and Kistemann, 2011), to date no systematic reviews were identified, which met all inclusion criteria for our study.

5.1. Strengths and weaknesses of the review

The main strength of this review is the rigorous quality control in the inclusion criteria. This implies that the results are reliable and should be possible to rely on in policy and practice contexts. The inclusion of evidence assessments between pathways and related defined health outcomes is novel and provides an even more integrated understanding of how natural environments may influence health and which factors are likely to mediate effects. A limitation of the review is that we did not explore theoretical or mechanistic explanations, though this is thoroughly reviewed elsewhere (see for example Gascon et al., 2016, Hartig et al., 2014). Equally, the strict quality control can also present itself as a limitation, as some evidence may be available although displayed in reviews outside our inclusion criteria. However, we tried to reduce this risk by relying on a previously established tool for evaluating the quality of articles in a review of reviews (Shea et al., 2009).

5.2. Limitations of existing research and scope for future studies

Most reviews commented on the relatively poor specificity in existing studies. This means that, while there is evidence for the effect of natural environments on affect and heat, we still don't know enough about effect sizes, scale, dose-response relationships, size, distance, or specific qualities or amenities of the spaces. Sometimes original studies may have used suboptimal measurement tools, like for example in the case of urban cooling, where most studies are based on air temperature monitoring, while the most adequate method for assessing impact on human health is heat, as defined by air temperature together with absolute and relative humidity (which then optimally is equated into a human-impact estimate, such as Universal Thermal Climate Index, UTCI, or Wet Bulb Globe Temperature, WBGT). There is also insufficient evidence on effects on subpopulations (e.g. children or ethnic

minorities) or about discrepancies depending on cultural or societal context. Equally, interaction effects between individual and environmental factors, such as for example immunocompromised people being more susceptible to harmful environmental exposures like heat stress, are rarely controlled for. This means that a human-environment interaction becomes a moderator, resulting in an adverse health outcome. Another moderating effect on health outcome rarely elaborated on in the systematic reviews is the fact that the quality of an urban environment and green spaces is often determined by socioeconomic status of the neighbourhood, which in turn affects health of the population. By optimising measurements, including moderator effects, and specifying the scope in original studies, the evidence may be strengthened or better tailored for implementation. However, as studies on co-benefits, synergies, and cost-efficiency analyses are beginning to appear (TNC, 2016; Kardan et al., 2015), it seems reasonable to invest in urban natural environments as a general public health intervention, sometimes irrespective of specific size, distance, or qualities (van den Bosch and Nieuwenhuijsen, 2017).

To further strengthen the evidence of potential pathways or mechanisms, it would also be valuable to explore and relate other direct health outcomes which have to date not been studied in relation to natural environments. By studying diagnoses that are specifically related to one of the suggested pathways, for example heat-induced nephropathy (Roncal-Jimenez et al., 2016), it would be possible to better specify which pathways account for the majority of the health benefits. Equally, referring to the "Old Friends hypothesis" and natural environments' potential effect on immune systems (Rook, 2013), autoimmune diseases and exposure to biodiverse natural environments should be explored.

In addition, in order to provide evidence on net-effects and trade-offs, harmful effects of urban green spaces should be quantified and actions to increase positive net-effects should be implied. A common example is the risk for increased allergy prevalence by exposure to airborne pollen from urban trees and vegetation. This risk can be reduced by adequate urban planning using plant species and genotypes with low allergenic potential (Ogren, 2000). Equally, behavioural adaptation can prevent other so called ecosystem "disservices", for example by well managed high-quality natural environments, education, and adequate clothing to avoid e.g. vector-borne diseases in urban vegetation (Vogt et al., 2015). Hitherto, most studies indicate a clear overweight for the benefits of urban natural environments with demonstrated cost-efficiency (Villa et al., 2014, McPherson et al., 2005, Wolf and Robbins, 2015) and to reduce negative health effects of environmental degradation and climate change, functional and healthy ecosystems, also in cities, are a necessity (MA, 2005; Whitmee et al., 2015; WHO, 2016, van den Bosch, 2016).

5.3. The relation to NBS

Considering urban natural environments as a public health tool, would conform well to the concept of NBS. In a changing climate and with a changing disease scenario, efficient solutions for protecting and improving health are urgently required. Using urban natural environments for reduced CVD-related mortality is a conspicuous example of an action that is "supported by nature" and which addresses environmental challenges (e.g. reduced heat), while at the same time providing economic and social benefits (e.g. reduced health care costs). This is of particular importance in an era when CVD and other NCDs are dominating the global disease burden (Vos et al., 2015). Thus, even small effect sizes by interventions like providing access to green spaces can have a large impact on a population level. Although the evidence is still insufficient, several co-benefits are likely, for example improved immune system development and reduced air pollution levels, which would make the link between NBS and "urban nature for health" even more explicit. As our scoping review demonstrated, only three studies are published on the theme of NBS and health and these are of a theoretical or conceptual character (Annerstedt van den Bosch and Depledge, 2015; Beatley, 2016; Richardson et al., 2016). There is therefore a strong need to further explore how NBS can be optimally related to health in an urban nature context. The incorporation of the nature-health evidence in the NBS-agenda can serve several purposes. It may expand the understanding of co-benefits to the environment by greening for health, such as climate change mitigation and adaptation, but also provide estimates of trade-offs. Framing the nature-health relation in an NBS-context, which can improve trans-sectoral communication, can also contribute to reducing the science-policy gap (van den Bosch and Nieuwenhuijsen, 2017), making the evidence more applicable in urban planning and practice.

5.4. Planning, designing, implementing and managing NBS

This review has highlighted the importance of green space for multiple health effects and thereby the potential for the use of NBS as a framework for improving public health in urban areas. While the definition of NBS states that those are actions aimed at "providing environmental, social and economic benefits" (ECDG, 2015), human health is not explicitly mentioned as a benefit. We suggest that human health should be incorporated in the definition as a crucial vision and outcome of NBS implementation. Making this link more visible would facilitate and encourage collaborations across sectors, including health disciplines, much needed for meeting the increasingly complex challenges related to urban living. This would directly meet the goal for the EU Research and Innovation policy agenda (ECDG, 2015), aiming at providing the evidence and knowledge base for NBS and advance the development of innovative NBS. An innate integration of human health in the NBS framework is a unique opportunity for increasing and improving resilience and health in an urbanising world. It would showcase the need for analysing health issues and outcomes in environmentally related projects, both within science, and assessment and policy processes. NBS could contribute to public health both through improving the environmental conditions through regulating and provisioning ESS and through cultural ESS linked to socio-behavioural pathways. As this review has highlighted there is today evidence that most of these services from urban nature contribute towards decreasing all–cause and CVD mortality, adverse birth outcomes, and mental disorders, through various and sometimes interacting pathways. The improvement of environmental living conditions, through provisioning and regulating services are spatially explicit in their impact with zone of influence depending on the specifics of the NBS implemented. The cultural ESS are based on socio-behaviour and require an interaction between individual and the green spaces. While the provision of NBS within easy access for people increases the availability of cultural ESS (van den Bosch et al., 2016) it is sometimes necessary to combine them with targeted programmes and outreach program in order to change behaviour and thereby ensuring the needed interaction to gain the prioritised health benefits (Hunter et al., 2015).

A key component when implementing NBS is the spatial location within the urban fabric, in order to understand it mediating role for desired health outcomes. This includes to ensure general access to green space in order to provide health benefits associated with physical access, as well as targeting specific subgroups or environmental problems (e.g. Urban Heat Island, pollution etc).

While there is a bundle of approaches for quantifying physical access to green space (WHO, 2016), the component of perceived or cultural access is often neglected. This deals with to what extent people feel that they have the right to use the area, and is a key factor in order to determine the quantity that is actually available for people (Koppen et al., 2014). With regards to quality of green space, two of the reviews (Lovell et al., 2014, McMahan and Estes, 2015) focused specifically on biodiversity and its link to health outcomes. These showed no conclusive evidence, but some of the studies reviewed indicated that more natural area could have stronger health impact (Curtin, 2009; Huby

et al., 2006; Luck et al., 2011; Poudyal et al., 2009). This could be explained by them being more appreciated for activities as well as providing diverse, pleasant visual and sound experiences (Ode Sang et al., 2016; Hedblom et al., 2017). Several studies have emphasised the role that engagement with nature (Husk et al., 2016) and place-making (Hausmann et al., 2016) has for gaining positive health benefits from nature. This in all indicates that there might be positive health effects possible to gain also from using site adapted processes of co-designing, co-implementation, and co-management in relation to green spaces. This will further safeguard that green spaces are used and recognised as important spaces in the continued urban development and thereby getting a long term legacy.

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Appendix A

See Table 4

Table 4
Result of the review of NBS paper – categorised with regards to type of article, focus, and obvious climate change framing (e.g. mentioned in the abstract).

Author (Year)	Type of study	Focus	Climate change framing
Derkzen et al., 2017	Empirical - survey	Green infrastructure	Yes
Beatley, 2016	Conceptual	Health	No
Bennett et al., 2016	Empirical - survey	Mitigation/Adaptation	No
Brink et al., 2016	Review	Mitigation/Adaptation	Yes
Chen et al., 2016a	Empirical - experiment	Ecosystem Services	No
Chen et al., 2016b	Empirical - measurement	Green infrastructure	No
Clabby, 2016	Empirical - case study	Green infrastructure	No
Fink, 2016	Conceptual	Ecosystem Services	Yes
Haase, 2016	Conceptual	Ecosystem Services	No
Kabisch et al., 2016	Conceptual	Mitigation/Adaptation	Yes
Kazmierczak, 2016	Empirical - case study	Green infrastructure	No
Kremer et al., 2016	Review	Ecosystem Services	Yes
Lafortezza & Chen, 2016	Conceptual	Ecosystem Services	Yes
Lennon & Scott, 2016	Conceptual	Health	No
Pontee et al., 2016	Conceptual	Mitigation/Adaptation	No
Richardson et al., 2016	Conceptual	Health	No
Wamsler et al., 2016	Empirical - case study	Ecosystem Services	No
Annerstedt van den Bosch and Depledge, 2015	Conceptual	Health	Yes
Camps-Calvet et al., 2015	Empirical - case study	Ecosystem Services	No
Capotorti et al., 2015	Empirical - case study	Green infrastructure	No
Connop et al., 2015	Empirical - case study	Green infrastructure	No
Eggermont et al., 2015	Conceptual	Ecosystem Services	No
Haase, 2015	Conceptual	Ecosystem Services	No
Kronenberg, 2015	Conceptual	Ecosystem Services	No
Maes & Jacobs, 2017	Conceptual	Mitigation/Adaptation	No
Stürck et al., 2015	Empirical - modelling	Ecosystem Services	No

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