

SYSTEMATIC MAP

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How are nature-based solutions contributing to priority societal challenges surrounding human well-being in the United Kingdom: a systematic map

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Abstract

Background: The concept of nature-based solutions (NBS) has evolved as an umbrella concept to describe approaches to learning from and using nature to create sustainable socio-ecological systems. Furthermore, NBS often address multiple societal challenges that humans are facing in the medium to long-term and as such can enhance human well-being (HWB). This study was commissioned to fulfil the need for a targeted systematic evidence map on the linkage between NBS and HWB to support focused research going forward that addresses the key knowledge needs of policy makers in the UK and beyond.

Methods: A consultation with policy makers and government agency staff ($n = 46$), in the four component parts of the UK (England, Wales, Scotland, Northern Ireland) was conducted in spring 2019. This identified four key societal challenges of operational experience lacking a scientific evidence base. Three of these challenges related to management issues: NBS cost-efficacy, governance in planning, environmental justice. The fourth challenge related to the acoustic environment (soundscape). Using systematic methods, this study searched for and identified studies that assessed NBS on HWB with regard to these four selected societal challenges.

Review findings: A total of 7287 articles were returned from the systematic search and screened for suitability at the level of title and abstract. A total of 610 articles passed screening criteria to warrant full text screening. Of these, 115 studies met the full text criteria for eligibility in the final systematic map database. Included studies were coded for twelve NBS interventions and ten HWB related outcome categories. Most of the evidence reviewed referred to natural, blue or green infrastructure in the urban environment and focused on economic, material and health aspects of HWB. Less than 2% of studies identified in the searches robustly reported the role of NBS actions or interventions on HWB compared with non-NBS actions or interventions

Conclusion: This systematic map found the evidence base is growing on NBS-HWB linkages, but significant biases persist in the existing literature. There was a bias in favour of the urban environment and restoration studies focused on conservation aspects, with only a few studies investigating the full suite of advantages to HWB that can be delivered from NBS actions and interventions. The soundscape was the least studied of the societal challenges identified as being of key importance by policy makers, with cost-efficiency the most reported. There was a lack of robust long-term studies to clearly test the potential of NBS regarding the HWB outcomes compared with non-NBS alternatives.

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This lack of robust primary knowledge, covering all four key societal challenges identified, confirms that the knowledge gaps identified by the policy makers persist, and highlights a clear research need for long-term, transdisciplinary studies that focus on comparisons between NBS and non-NBS alternatives

Keywords: Cost-efficacy, Governance in planning, Environmental justice, Acoustic environment, Soundscape

Background

Over the past 30 years, an increasing number of individuals and organisations have started to promote a human-centric view of the management of natural resources [1]. Whilst much debated [2], this human-centric approach to conservation emphasises the interrelationship between humans and nature and continues to resonate with policy makers and researchers [3]. Research and policy have, for over a decade been dominated by the benefits that nature may provide for humans and as a result many theoretical and practical approaches have been developed [4–6]. The concept of nature-based solutions (NBS) evolved out of this paradigm as an umbrella concept embracing concepts such as green/blue/nature infrastructure, ecosystem approach, ecosystem services, natural capital, ecosystem-based adaptation/mitigation, ecological engineering and catchment systems engineering [1, 7].

At their core, all the definitions of NBS cluster into the general theme of learning from and using nature to create sustainable socio-ecological systems, which enhance HWB locally, regionally or globally. NBS interventions are multifaceted and highlight the fundamental influences that preservation and diversification of ecosystems can have on HWB. These range from climate regulation [8] and limiting the impacts of natural disasters such as flooding [9, 10] and epidemic disease outbreaks, to promoting improved human physical health (food, water, shelter etc.), and mental health by reconnecting citizens with nature [11, 12]. At the same time, NBS address and respond to the challenges of nature conservation in the face of ongoing environmental degradation. However, there may be trade-offs between the co-benefits of NBS interventions and co-harms [13], e.g. where exposure to infectious diseases linked to wildlife or arthropod vectors is increased (Fig. 1). In summary, NBS interventions are place-based modifications of the biophysical environment inherently involving human management of landscapes, seascapes and cityscapes. Furthermore, they aim to encourage stakeholders and all societal actors to act sustainably. For the purposes of this systematic evidence mapping study, we adopted the internationally recognised IUCN definition of NBS as it was the most widely agreed and inclusive. The IUCN defines NBS as “actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously

providing human well-being and biodiversity benefits” [1]. An intervention is termed as non-NBS in this study when no aspect of working with and/or enhancing nature is found e.g. grey engineered interventions. The integration of solutions based on nature for robust policy-making has been highlighted in many sectors including transport, housing, energy and health policies, climate regulation strategies and territorial planning [14]. Policy makers need to understand the evidence for the effectiveness of NBS co-benefits, co-harms and trade-offs across multiple policy domains. There have been several reviews looking at evidence about associations between HWB and natural environments. To date they have tended to focus on either physical health [12], or social perspectives [11] and are often centred on the urban environment [15]. McKinnon et al. (2016) broadened the focus from nature-health relations to encompass 10 domains of HWB when they conducted a systematic evidence map examining the link between nature conservation and HWB [16].

Compared with these previous systematic maps, this current systematic evidence mapping study took a novel approach to identifying the focus for the systematic search. The focus was identified by participatory consultation with policy makers and implementers at the operational level within key organisations across the UK. This

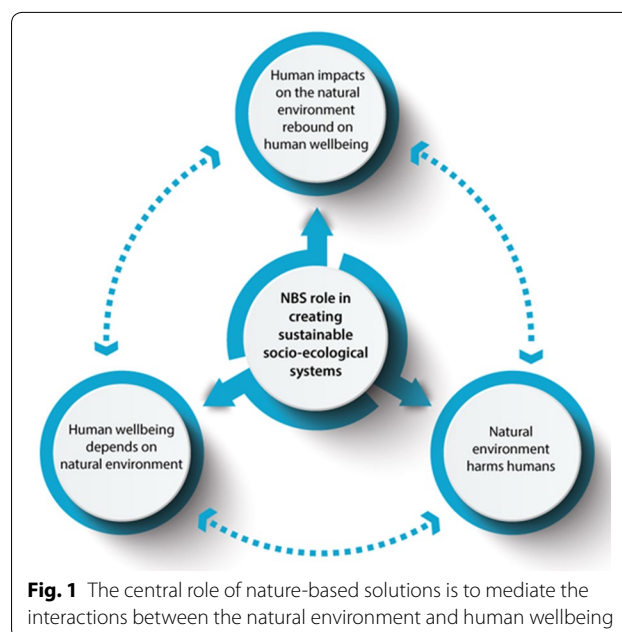


Fig. 1 The central role of nature-based solutions is to mediate the interactions between the natural environment and human well-being

process highlighted the priority areas where evidence for specific benefits and disadvantages of NBS interventions across key societal challenges and policy domains was required.

Stakeholder engagement: participatory co-design of systematic mapping priorities

Stakeholder engagement is an important element in defining the questions and scope for a systematic map and is widely encouraged [17]. The selection of societal challenges and policy domains to be included in this systematic evidence mapping study were identified following consultation with policy makers and government agency staff in the four component parts of the UK [18]. This approach ensured that the focus of the systematic evidence mapping review responded to the needs of those decision makers and operational staff working on a day-to-day basis with the primary environmental challenges facing the UK. Policy champions (n=7) were selected to lead this consultation in the four component parts of the United Kingdom (Scotland, England, Wales and N. Ireland) on the basis of their experience at the interface between science, policy and practice. These policy champions identified and interviewed key decision makers and operational staff across the four regions of the UK. In total 46 individuals agreed to be interviewed over a 5 week period from 8th February to 14th March 2019. The interviewees worked for 21 different UK government departments or government agencies. The majority were in the environmental sector (63%) including the agencies responsible for the protection and enhancement of the environment and nature in the landscape, cityscapes and seascapes in each of the four countries of the UK. Just under a fifth (17%) worked in one of the devolved governments, 13% of interviewees worked in local authorities or national parks and 7% of interviewees worked directly in the health sector (NHS and Public Health England). The final selection of focal societal challenges was made based on this consultation phase and finalised during a Steering Group meeting (comprised of policy champions and all members of the review team). Each policy champion reported the priority societal challenge identified from their interviews and discussed the background to these priorities in relation to their level of perceived importance as well as the need for a systematic evidence review. This process of discussion with policy champions considered all the priority topics together with the secondary topics mentioned by the interviewees. During the meeting it was discussed how the top priority from each region compared to the findings from the other component parts of the UK and a final representative selection of topics was agreed to be taken to the next stage of the process.

The priority societal challenges identified as requiring evidence linking NBS and HWB outcomes primarily addressed management issues and infrastructure creation (Fig. 2).

The management issues for which policy-makers requested additional knowledge were primarily:

(i) *Cost-efficacy*: they recognised the importance of both monetary and non-monetary factors but reported that ultimately it was financial factors which drove decisions as whether to enact an NBS intervention;

(ii) *Governance in planning*: this was recognised as a major challenge, especially relating to evidence on how to create management practices which would foster cross-department decision-taking and encourage wide stakeholder engagement;

(iii) *Environmental justice*: a key evidence gap identified was how NBS interventions can deliver benefits to urban and rural communities in ways that could reduce societal inequalities;

(iv) *Soundscape*: interviewees also highlighted the acoustic environment as an often unconsidered but important aspect impacting on human wellbeing in the natural environment. They noted that the soundscape is also under threat, experiencing rapid change in a similar way to the landscape and seascape, but often ignored in policy considerations.

Objective of the review

The primary question of this systematic map was

What evidence is there for nature-based solutions and their impacts on human wellbeing for societal challenges related to cost-efficacy, governance in planning, environmental justice, and the acoustic environment?

This question has the following components:

Population: Human populations in OECD countries.

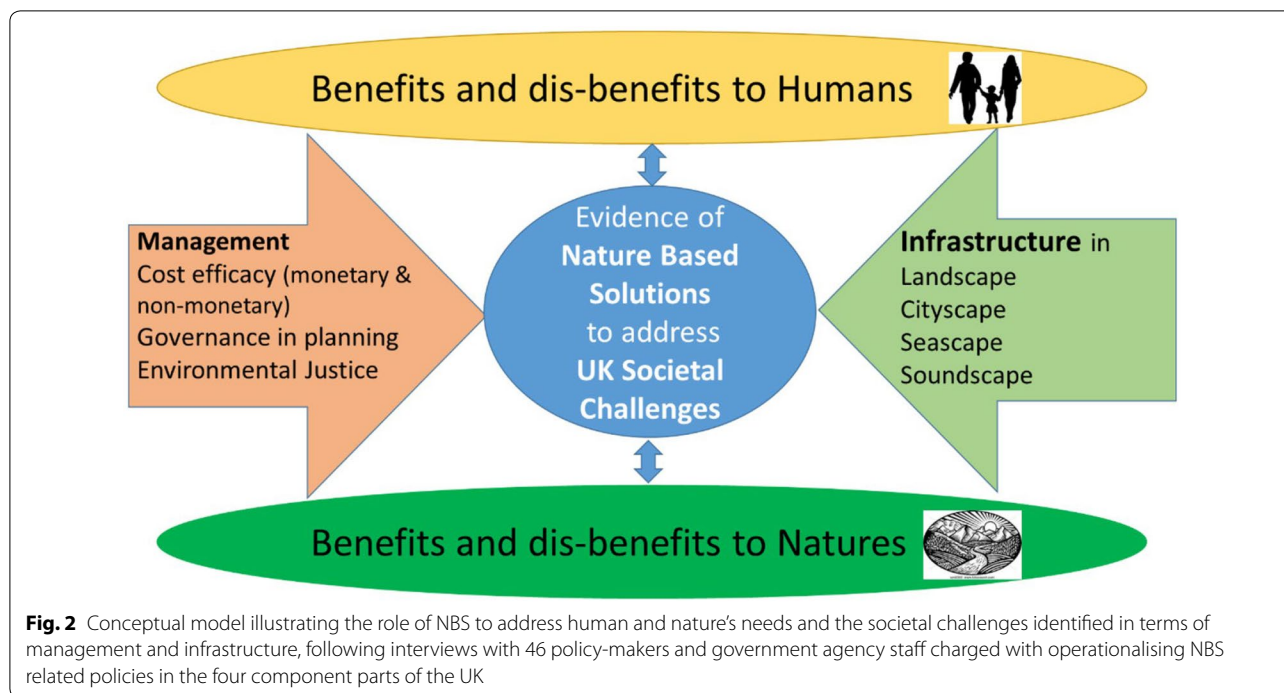
Intervention: Adoption or implementation of NBS to address a specific challenge related to cost-efficacy of NBS, governance in planning, environmental justice, and the acoustic environment in cityscapes, landscapes, seascapes and soundscapes.

Comparator: With/without NBS actions, before/after adoption or implementation of NBS interventions or high/low access to NBS interventions.

Outcomes: Positive or negative effect on domains of HWB as defined by McKinnon et al. [16].

Secondary questions of this systematic map were:

- *What evidence is there for specific economic cost-benefit analyses of individual NBS actions?*
- *What evidence is there concerning the role of NBS actions in addressing environmental justice and societal socio-economic inequalities?*



- *What evidence is there that governance issues are being highlighted with regard to implementing NBS actions or management of NBS interventions?*
- *What is the evidence for NBS actions focused on the acoustic environment (soundscape)?*

Methods

Our systematic map protocol has been published in Environmental Evidence [18]. This section includes updates since that publication including the use of the software CADIMA, details of consistency checks at title/abstract and full screening and alterations to the number of reviewers and data coding.

Search for articles

Multiple online information sources, relating to published and unpublished reports, were searched up and until August 2019 in order to capture a comprehensive and unbiased sample of literature. We found that other databases identified in the protocol would not provide further evidence and given resource constraints, limited the publication searches to Web of Science (wok.mimas.co.uk), BASE (base-search.net), and Google Scholar (scholar.google.co.uk). In total, one publication database, two search engines, 18 English and 6 French institutional and organizational websites, were searched between June and August 2019 (Additional file 1).

Search of the English organisational websites was conducted using the phrase “nature based solutions and human well-being” with Boolean operators appropriate for the site (Additional file 1). All items found at sites which returned less than 50 items were scanned against the eligibility criteria [18] using title and if in doubt the full document was viewed. The first 250 items sorted by relevance were similarly scanned for the other sites. The exceptions were (i) the website NORA, the archive database for research publications of NERC Research Staff in its four wholly owned Research Centres (CEH, BAS, BGS and NOC). This website offered a facility to download all items found in a format suitable to upload into CADIMA and as many of the items were published articles this strategy was adopted because it enabled electronic identification of duplicates with articles found via the other searches. (ii) The web site Natural Health Service (<https://naturalhealthservice.org.uk>) was not included, as the site did not have a search function.

A search of the French literature sources was conducted using the phrase “solutions fondées sur la nature” which is recognised by the IUCN as the official translation of nature-based solutions [18]. We note there were two web systems which would not allow a standard key phrase search, so the website gatekeepers were contacted directly to search their local database (Additional file 1). These results were then included and extracted in Endnote for use in CADIMA.

Search terms and languages

Given the multiplicity of disciplines at the intersection of NBS and HWB research, substantial terminological diversity regarding actions and outcomes exists. In order to maximize comprehensiveness of our search to capture the breadth of ontologies, the search string was co-designed and tested by the review team, which is interdisciplinary including expertise in social and natural sciences. Comprehensiveness was checked by how many articles were recovered from the test library (21 out of 24). The three articles that were not returned were found to be in journals/sources not covered in the Web of Science database, although a related article to one of the test papers was found (Additional file 1).

Search terms of the bibliographic database were limited to English language and Web of Science due to project resource restrictions and initial investigations that revealed no additional studies from the other databases outlined in the protocol. French language websites were scanned as expertise in this language was present in the review team. The following search string was used to query on Web of Science. It was inserted in the database as written here.

TS=(“nature based” OR “nature-based” OR “nature based solution*” OR “nature-based solution*” OR NBS OR “green infrastructure*” OR “natural infrastructure” OR “blue infrastructure” OR “ecosystem approach*” OR “natural capital” OR “ecosystem service*” OR “ecological restoration” OR “landscape restoration” OR “ecological engineering” OR “ecosystem-based” OR “green solution*” OR “green space*” OR “urban green space*” OR urban NEAR “national park” OR “blue space” OR “sustainable management” OR “sustainably manage” OR “grey-engineering” OR “eco-technology” OR “nature-engineering” OR “green roof*” OR “sustainable urban drainage” OR “local indigenous knowledge” OR “renaturalisation” OR “agri-environment scheme*” OR “managed realignment” OR “habitat restoration” OR “multiple benefits” OR “best management practice” OR “BMP” OR “greening” OR “working with nature” OR “environmental stewardship” OR “biophilic*” OR “urban agriculture” OR “community garden” OR “rewilding” OR “wildness” OR “wilderness”).

AND TS=(wellbeing OR well-being OR “well being” OR “ecosystem service*” OR skill* OR empower* OR livelihood OR “human capital” OR “human health” OR “physical health” OR “public health” OR “human welfare” OR “urban health” OR “mental health” OR nutrition OR longevity OR “life expectancy” OR “maternal health” OR “child health” OR “health care” OR “food security” OR “physical security” OR “human rights” OR “progress indicator*” OR happiness OR freedom OR “happy planet index” OR “thriving places” OR “globally responsible” OR “ecosystem resilience” OR “urban ecosystem*” OR

co-benefit* OR “living standard*” OR “living standards” OR wealth NEAR human OR poverty NEAR human OR justice OR transparency OR governance OR security OR right* NEAR human OR “cultur* value” OR “adaptive capacity” OR “personal safety” OR “societal value*” OR green NEAR value OR “social relation*” OR “spirituality” OR “traditional values” OR “sense of home” OR spiritual OR “religious beliefs” OR “religious values”).

AND (TS=(“environment* justice” OR “environmental challenge*” OR “green justice” OR “societal challenge*” OR “cohesive communit*” OR “social cohesion” OR “social relations” OR stewardship) OR TS=(govern* NEAR planning OR urban NEAR planning OR urban NEAR polic* OR land-use NEAR planning OR environment* NEAR govern* OR “decision making” NEAR environment OR “policy challenges” NEAR environment) OR TS=(cost-efficacy OR cost-effectiveness OR “cost efficiency” OR “economic living standards” OR “material living standards” OR “green GDP” OR “circular economy” OR “green economy” OR bioeconomy OR natur* NEAR value OR “quality of life” OR “non-material benefits” OR green NEAR development* OR green NEAR “mental health”) OR TS=(acoustic* OR noise* OR sound* OR sensory))).

For the online search engines a more limited search term was used “nature-based solutions” AND “human well-being” For Google scholar the search term was inserted in the ‘With all the words’ box under ‘Advanced Search’.

Article screening and study eligibility criteria

Articles were screened in three stages: title, abstract, then full-text. When screening articles for relevance, a series of eligibility and exclusion decisions were consistently applied (Table 1). At each stage, each article was assessed against these five criteria and were passed on to the next stage if: (i) all criteria were met, or (ii) there was uncertainty or lack of information to be assessed. In the case where articles authored by members of the review team were encountered, we ensured that authors did not screen nor code their own work. During our discussions about definitions, the comparator criteria was revised from the protocol [18] to include low and high access to the NBS e.g. access to parks. This was deemed necessary, as many studies relevant to the societal challenge of ‘environmental justice’ did not compare either \pm NBS or before and after an NBS intervention; but rather report either binary or gradations of social inequality in access to NBS and consequential influence on HWB.

CADIMA was used for title/abstract and full-text screening. Four reviewers independently participated in title/abstract screening. At the outset to ensure a

Table 1 Article eligibility criteria detailing inclusion and exclusion criteria, summarised from the protocol [18]

Eligibility criteria	Included	Excluded
Intervention (exposure)	Study deals with one of the four key societal challenges: cost efficiency, governance in planning, environmental planning, acoustic environment—and involves implementation of NBS action linked to the four challenges	Study makes no explicit assessment of the four challenge and does not have any primary implementation of NBS action
Comparator	Study uses a comparator such as with/without, or before/after, or low/high access, to assess effectiveness of NBS action. This can be primary or secondary where source study and data is used	No comparator is provided in study of NBS action
Outcome	Study undertakes direct assessment of NBS action on positive or negative effects on domains of human wellbeing	Study does not undertake any assessment of NBS action on human wellbeing
Population (subject)	Study assesses impacts on human wellbeing of human populations in OECD countries	Study does not have an OECD country human population focus

consistent review process the four reviewers determined the relevance of papers for eligibility in the review by scoring four questions (Table 1) using a random selection of 100/7287 articles/books/reports (randomised by CADIMA). Initial agreement was poor (Cohen's kappa coefficient 0.3). A series of emails and Skype meeting explored where there was disagreement and allowed the review team to reach agreement on detailed interpretation of the selection criteria for a wide range of sample studies. For example, one reviewer scored all four questions as NO if the title of the paper indicated the study was conducted in a non-OECD country. This reviewer used the rationale that the paper would not be selected for full review (i.e. data extraction) and consequently there was no point in reviewing all questions. While another reviewer scored each question independently. While both approaches were understandable, it was interpretation of the details like this that resulted in the initial poor kappa value. Following another round of consistency checking focusing on the details of what constituted a comparator, as well as the subtleties and different methodological approach of papers dealing with questions of environmental justice, an appropriate level of agreement was reached between reviewers for the main phase of the systematic mapping (Cohen's kappa coefficient of 0.8).

Full-text screening

Full-text files were downloaded or accessed in hard copy through the UKCEH Library (33). Two reviewers, initially started full-text screening and met 4 times for consistency checks (discussing 12 articles—2%) on a problem solving basis (i.e. when one was unsure of an article). In practise one reviewer completed the majority of the full-text screening (AD 10% & JD 90%). Reviewers included articles focusing on those with relevant subject,

intervention, outcomes, and comparator (Table 1). Articles were included only when all criteria were relevant.

Study validity assessment

Given the broad scope and size of this systematic map and available resources, we did not assess individual articles for quality (e.g. reliability and relevance based on study design).

Data coding strategy

For the purposes of this study, we distinguish between articles and studies, with articles reporting multi-case studies treated as separate studies. All were single study articles.

Each included article was coded using a standardized codebook implemented either in CADIMA, or when working offline in an excel file downloaded from CADIMA, (Additional file 2). This coding tool was piloted by three researchers (JCJ, JM and JD) for 10/115 studies to ensure consistency in extraction. Initial disagreement averaged around ~13% of extracted fields in the testing stage. These disagreements were discussed, and additional, more detailed guidance was added to the data extraction questionnaire (Additional file 2) to ensure consistency between reviewers. The coding questionnaire was designed and deployed in CADIMA to aid in consistency in recording data between researchers and studies. The code book was expanded from the protocol to better enable the mapping of evidence to the primary and secondary questions. During the review process it was not considered necessary to contact authors.

The following categories of data were extracted from each article:

- Unique article ID information.

- Bibliographic information.
- Information on NBS action/intervention.
- Information on HWB categories studied.
- Information on design, and location of study.
- Information on primary or secondary data published on each of the four societal questions.
- Information on result of NBS action/interventions on HWB.

NBS actions/interventions were coded following criterion adapted from Cohen-Shacham et al. [1]; HWB outcomes followed McKinnon et al. [16]. For these criteria each article was coded in the systematic map as reporting:

- Primary data i.e. data collected in the study or data calculated resulting in a new variable using data from either primary and/or secondary sources to produce new data which did not previously exist or
- Secondary data defined as data harvested or filtered from another source e.g. national statistical offices, land cover map and used without further calculation or
- No data presented

If both primary and secondary sources of data were reported, the article was scored as reporting primary data.

Habitat categories followed Brown et al. [19] and study design followed Margoluis et al. [20] (Additional file 2).

Data mapping method

Extracted data were exported from CADIMA and analysed in Excel. The frequency of general characteristics of the studies (e.g. geographic location, year of publication etc.) were examined in table or histogram form. A structured ‘heatmap’ matrix of the distribution and frequencies of studies documenting specific relationships, or linkages, between a range of NBS actions/interventions and HWB outcomes was compiled. Categories for describing intervention and outcome type were identified a priori (Tables 2 and 3) and form the basis of a structural matrix, the major output of the mapping process. Evidence on different outcomes (in rows) is mapped on to different categories of interventions (in columns). Each cell represents a linkage. The matrix represents the primary output of the systematic mapping process and allows an intuitive visual format for synthesizing data on specific studies and linkages and identifying evidence gaps. Knowledge gaps are identified using colours linked to study count numbers. This highlights sub-topics that are underrepresented as having low or zero counts and weak colouring, while knowledge clusters are identified by sub-topics that are strongly coloured and have a high study count.

Results

Number, temporal and geographic spread of articles

In total, 7291 results were retrieved (Fig. 3). Database and bibliographic searching yielded 6917 unique results (see all search results in Additional file 3). Searches of institutional websites in both France and UK identified in Additional File 1 yielded 374 relevant articles. Four

Table 2 Categories, descriptions and codes of NBS actions or interventions, utilised to code evidence, based on Cohen-Shacham et al. [1]

NBS action or intervention type	Description	Code
Ecosystem restoration approaches, focus on nature	Ecological restoration involving minimal intervention other than planting	NBS01
	Ecological engineering involving significant human intervention e.g. plant trees to stabilise river banks	NBS02
Issue-specific ecosystem-related approaches, focus on humans	Ecosystem-based adaptation to any issue	NBS03
	Ecosystem-based mitigation to any issue	NBS04
Infrastructure-related approaches	Natural infrastructure e.g. river, natural forest (minimal human intervention)	NBS05
	Green engineered infrastructure e.g. green rooms, green walls, green roofs, parks	NBS06
	Blue engineered infrastructure e.g. ponds or wetlands for flood mitigation	NBS07
	Mixed natural/green/blue infrastructure	NBS08
Ecosystem-based management approaches	Integrated man-modified and natural landscape management e.g. agricultural and semi-wild lands	NBS09
	Integrated coastal zone management e.g. coast and estuaries	NBS10
	Integrated water resources management e.g. plant trees or place to reduce flow from source to sea	NBS11
Ecosystem protection approaches	Area-based conservation approaches including protected area management	NBS12

Table 3 Categories, descriptions and codes of HWB utilised to code evidence [16]

Category	Definition	Code
Economic living standards	Income, employment, employment opportunities, wealth, poverty, savings, payments, loans	HWB1
Material living standards	Assets owned, access and availability of food, fiber and fuel basic infrastructure (electricity, water, telecommunications and transportation), shelter	HWB2
Health	Physical health, nutrition, longevity/life expectancy, maternal health, child health, access to health care, occurrence of diseases, mental health	HWB3
Education	Education infrastructure (access to school, access to training, quality of education); informal education (transfer of knowledge and skills includes livelihood skills, traditional knowledge and skills); formal education (degrees awarded, students enrolled)	HWB4
Social relations	Interactions between individuals, within and/or between groups (communities, stakeholders, ethnic groups, gender); conflict, relationships, connectedness, ability to work together, ability to help others, and trust	HWB5
Security and safety	Physical security (personal safety and security), resource security; tenure security; human rights; vulnerability, resilience and adaptive capacity	HWB6
Governance (and empowerment)	Structures and processes for decision making including both formal and informal rules; includes participation and control in decision making, accountability, justice, transparency and governance skills	HWB7
Subjective well-being	Measures of happiness, quality of life, satisfactions supported by some value of ecosystem(s) and/or resources	HWB8
Culture and spirituality	Cultural, societal and traditional values of natural resources and nature to the community; sense of home; cultural identity and heritage; spiritual or religious beliefs and/or values	HWB9
Freedom of choice and action	Ability to pursue what you value doing and being	HWB10

duplicates were identified by Endnote and another 17 by manual searching at full text screening. Most articles were excluded at the first stage due to thematic irrelevance (e.g. NBS as a medical term), no primary data or no comparator (6677 articles) (Fig. 3). All articles which claimed to be a review were passed to full text screening. At the full-text screening stage, (n = 610) most articles were excluded due to being classed as reviews rather than providing primary data (~ 30%). Two primary types of reviews were recognised either (i) a review that serves as background for an empirical study, or (ii) a standalone piece of research. All articles of type (i) which provided a background review used to justify decisions made in research design, to provide theoretical context or identify a gap in the literature that the study intends to bridge and also provided primary data were included in the following systematic map. Standalone reviews that aimed to make sense of a body of existing literature through the aggregation, interpretation, explanation, or integration of existing knowledge were excluded (n = 202).

Ultimately, 115 single study articles were included in the final systematic map. Output from the CADIMA software of excluded articles with exclusion criteria is listed in Additional file 4 and coded data for all studies included in the systematic map database in Additional file 5. A ROSES reporting form is included in Additional file 6.

The earliest study recorded was published in 2002 and there was a general trend of increased number of studies found year by year up to the present day (Fig. 4). The

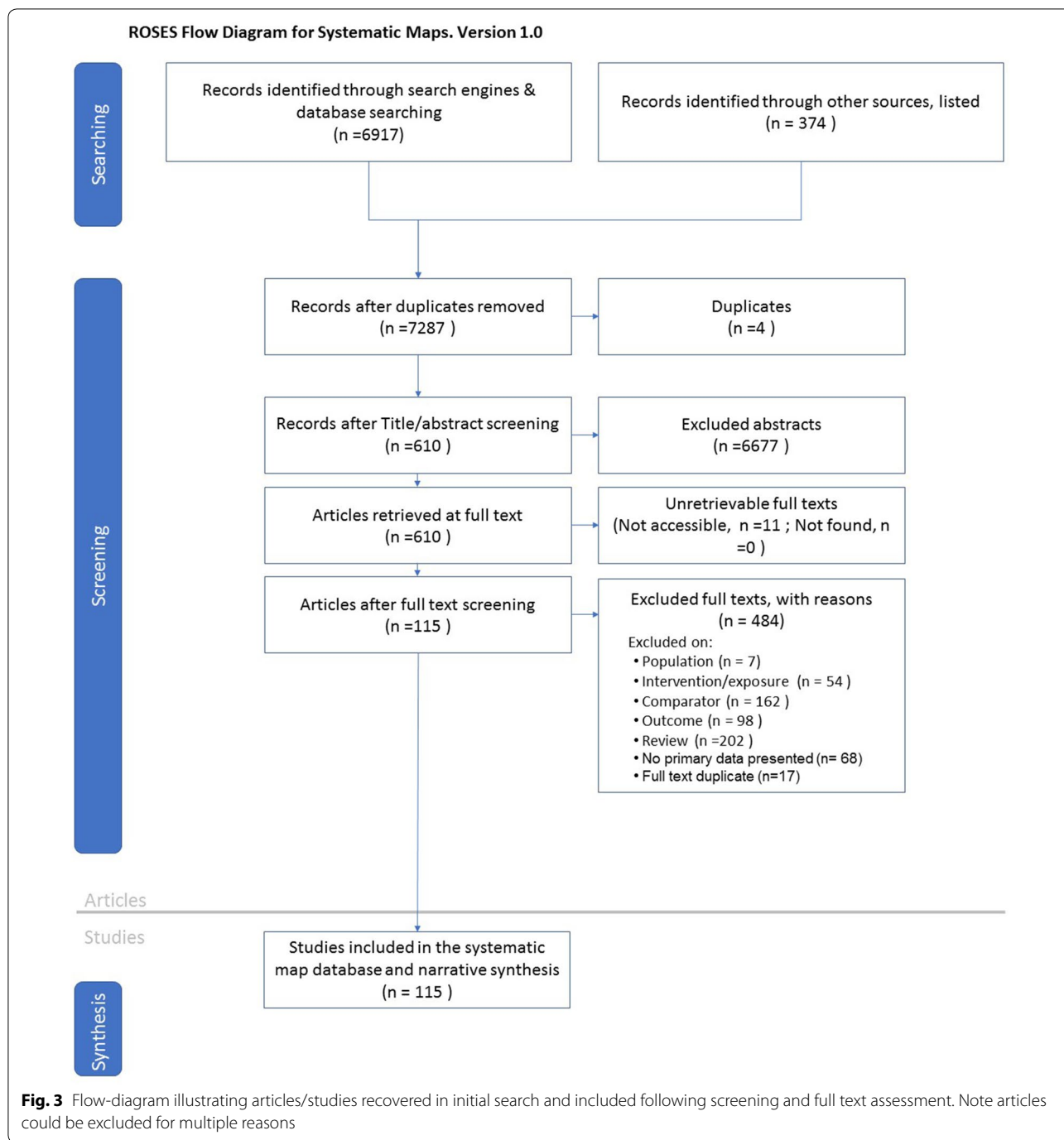
early work (2002–2011) focus on the urban environment and on the linkage between human health and access to green infrastructure. Later work was also dominated by studies conducted in the urban environment (77% of studies published 2012–2019).

Studies from a total of 21 countries (Fig. 5) were found with most studies originating in North America (e.g. USA-28%) and Europe (e.g. UK-15%) and few from Latin America (e.g. Colombia one study) in some respects reflecting the geographic spread of OECD countries around the globe.

The urban habitat was the most studied (75%) with few studies focused on other habitats (Fig. 6). Greece was the only country in the systematic evidence map not reporting a study exclusively in the urban environment, (Fig. 6). This study was located in a small urban setting of Mytilene on the island of Lesbos (North Aegean, Greece) and was coded as multiple habitats as the study also included the peri-urban environment. A greater number of urban studies were located in USA.

Focus and design of the studies

Studies were coded to study design definitions outlined by Margoluis et al. [20] and detailed in Additional file 2. The majority of the studies (60%) utilised a non-experimental study design i.e. drew inferences about the effect of a treatment on subjects (e.g. human perception score before or after NBS created), where assignment of subjects into a treated versus control group was outside the researcher's control. Only 11 studies employed a



standard quantitative experimental design using randomly assigned subjects in multiple groups [20] (Fig. 7).

Included studies used a range of different comparators to examine the contribution of NBS actions/interventions on HWB over time, space, and populations. The majority of studies included in the systematic map used a spatial comparator (38%) or high/low access to

a NBS intervention/action (30%). Technological comparators were also considered, e.g. studies looking at cooling benefits of green infrastructure such as shade trees, green roofs, and vertical greening systems (green walls and facades) compared with non-NBS alternatives. Nine studies (8%) used a technological comparator (Fig. 8).

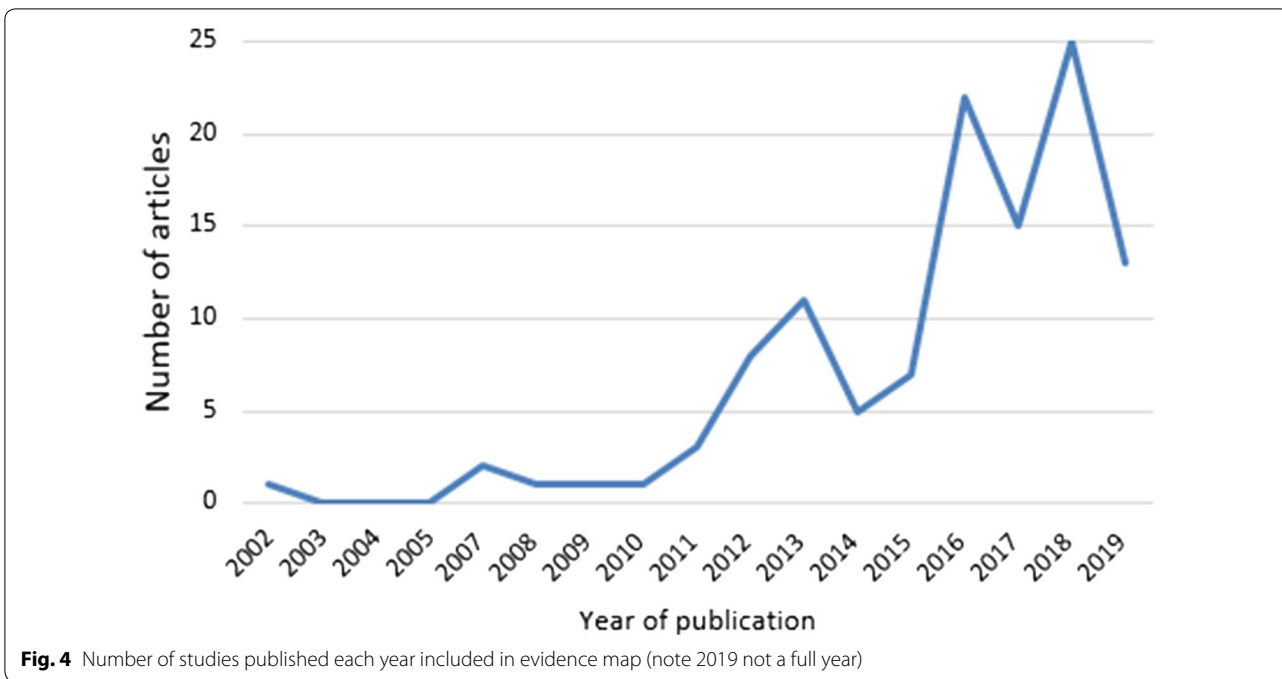


Fig. 4 Number of studies published each year included in evidence map (note 2019 not a full year)

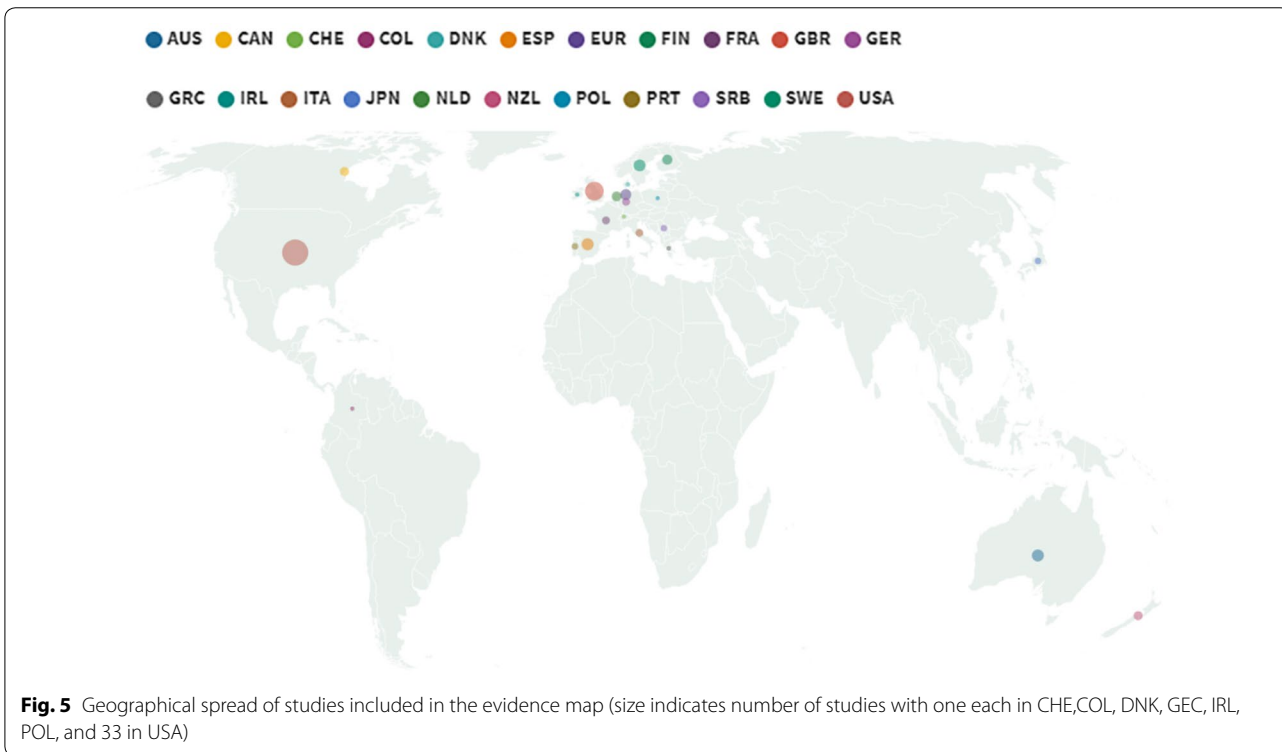
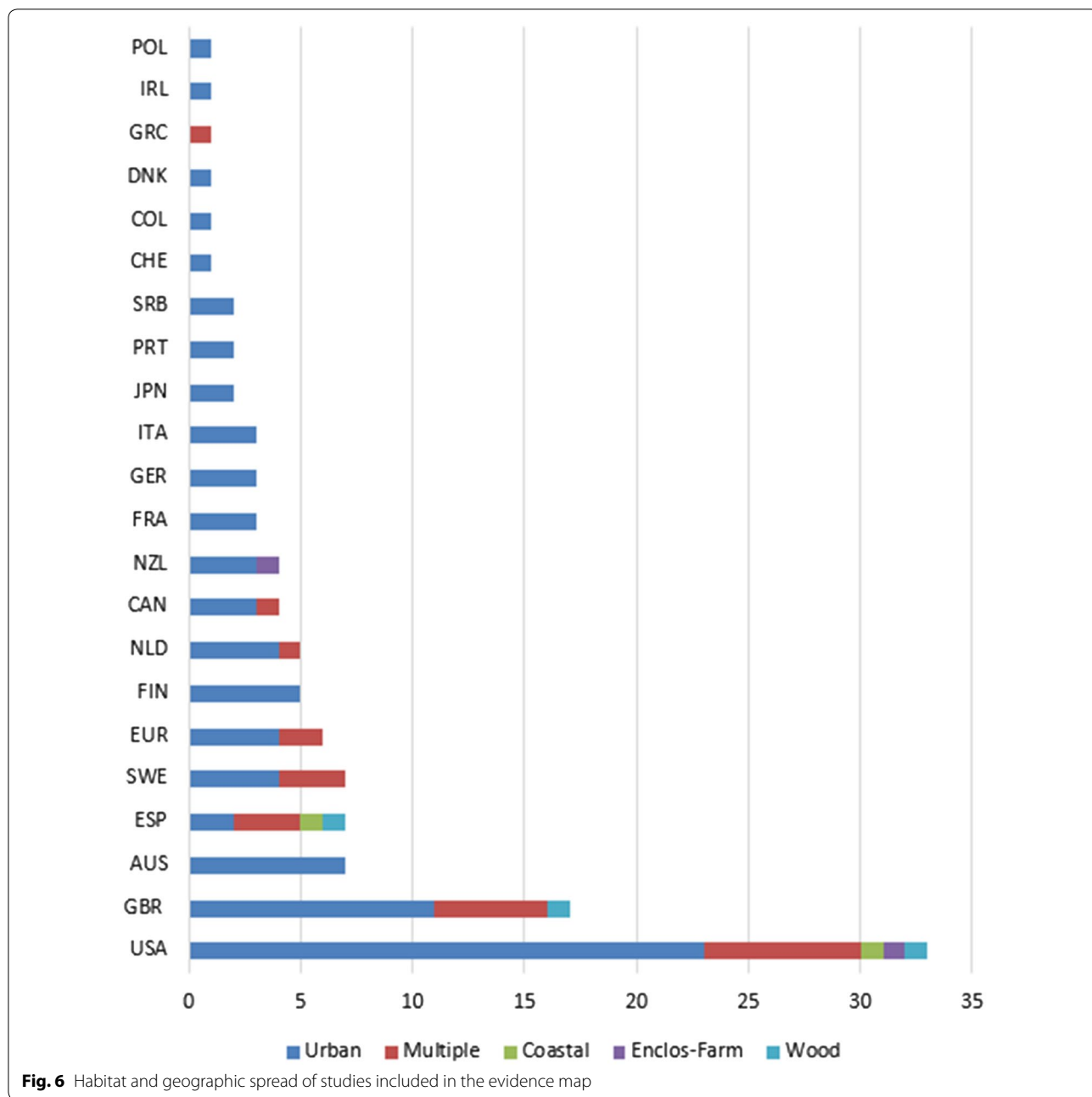


Fig. 5 Geographical spread of studies included in the evidence map (size indicates number of studies with one each in CHE, COL, DNK, GEC, IRL, POL, and 33 in USA)

Population involved

Over 81% of the studies included in the systematic evidence map involved civil society in general with a few studies targeting occupation groups (n=9) and youths

less than 20 years old (n=6). Interestingly only three studies were coded as not involving stakeholders. These dealt with regulating ecosystem services (CO₂

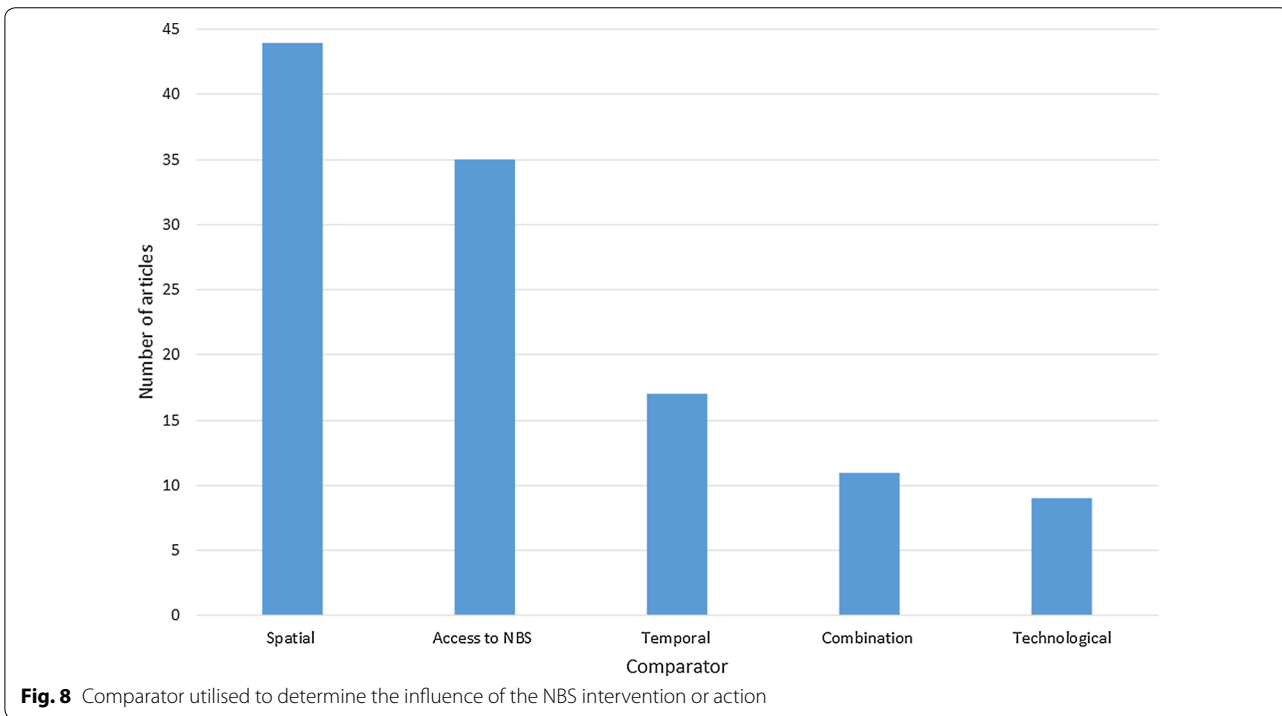
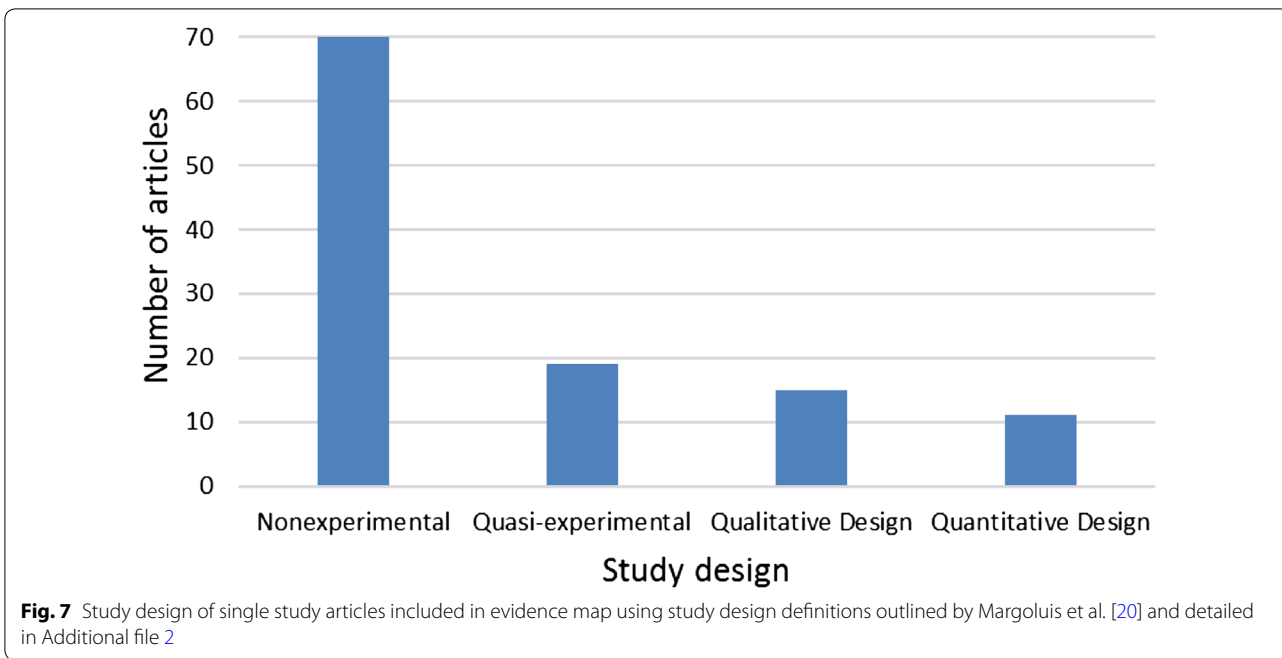


sequestration) and provisioning ecosystem services related to technological NBS in urban agriculture.

Types of NBS reported and longevity of intervention and monitoring of NBS

Figure 9 presents the distribution and extent of studies included according to 5 broad NBS intervention categories and 12 subcategories (Table 2). All the subcategories of the NBS type “Infrastructure-related approaches” were comparatively well represented in the systematic

evidence map. Green engineered infrastructure e.g. green roofs, green walls, parks, gardens were the most frequently studied NBS reported in the studies included in the systematic evidence map (n=86). The subcategory focused on the terrestrial environment (n=8) was the most studied of the “Ecosystem-based management approaches”; with only one study coded as “Integrated water resources management” and none focused on coastal zone management. Less than 12% of the studies considered “Ecosystem restoration approaches-focus

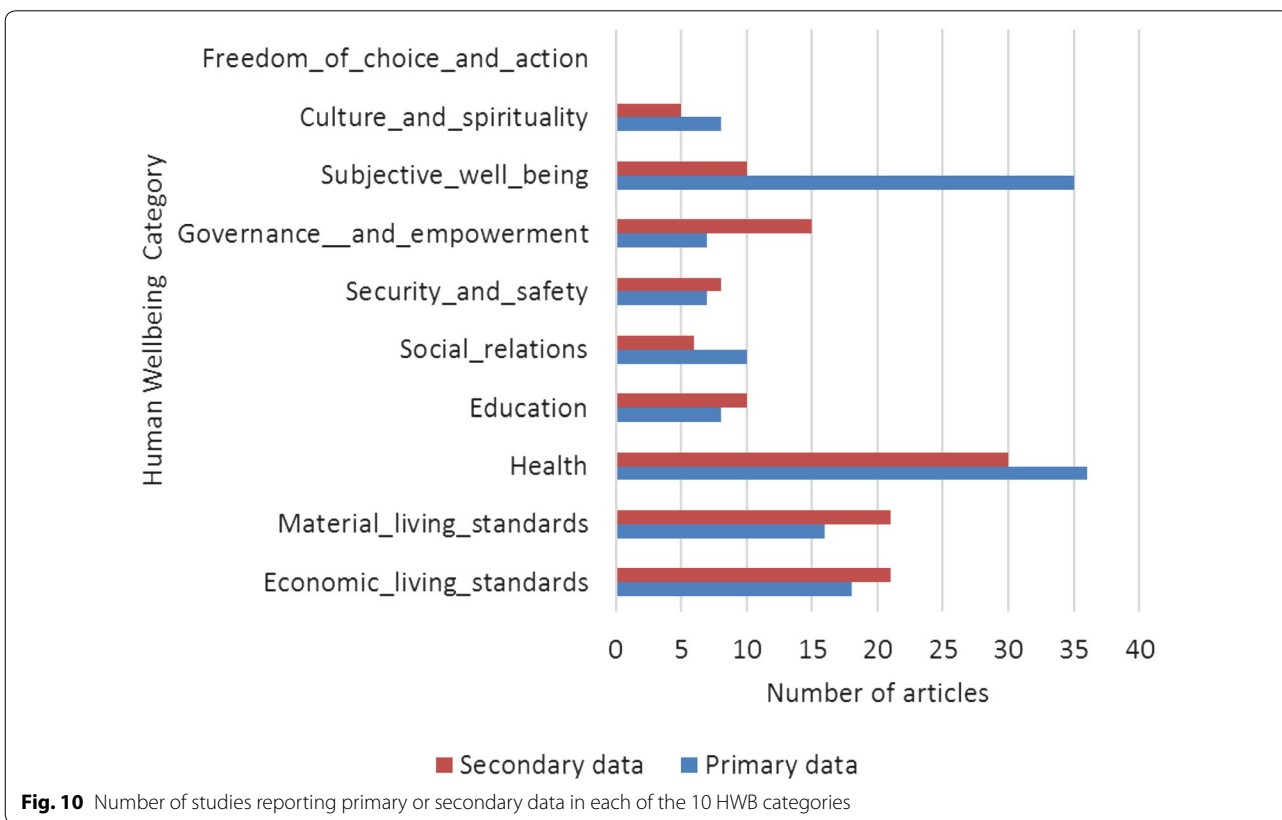
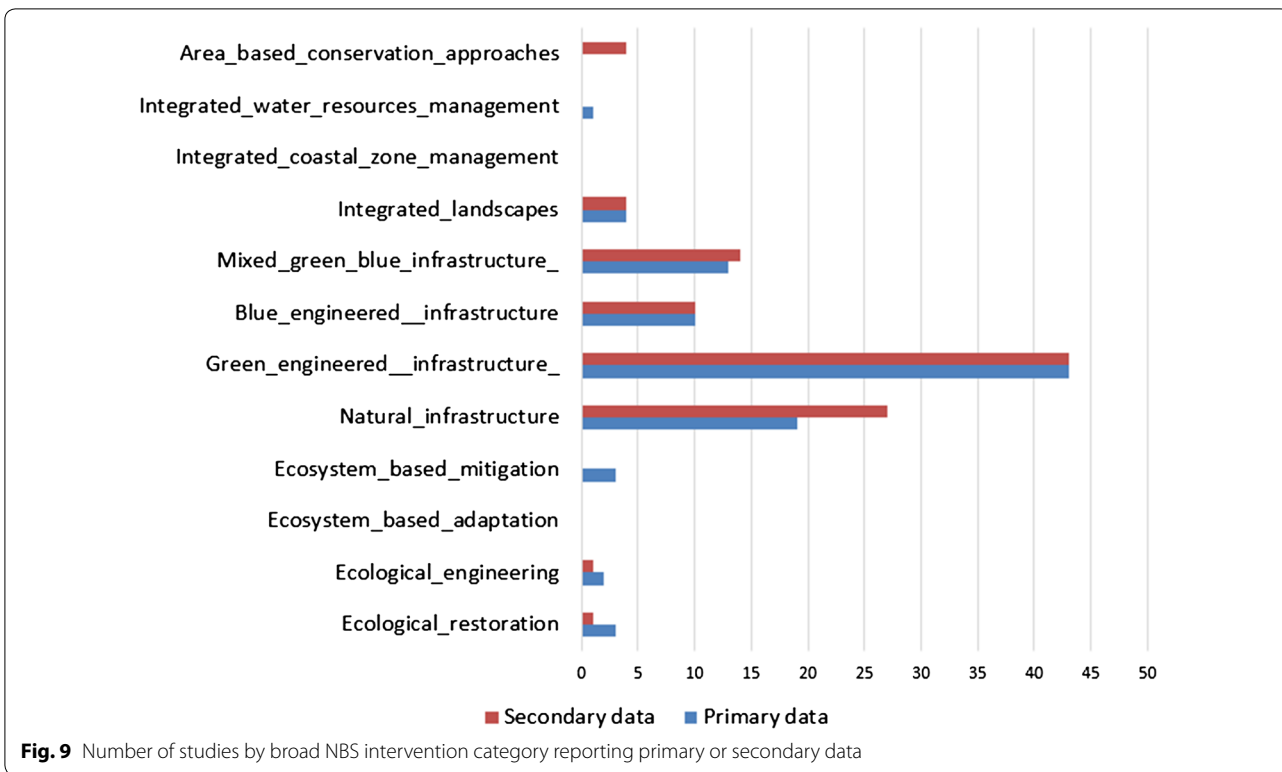


on nature” (n=7) or “Ecosystem related approaches focus on humans” (n=3) or “Ecosystem protection approaches” n=4).

Both primary and secondary data were extensively used by researchers (Fig. 9) with secondary data more

prominent in studies coded as “Infrastructure-related approaches” and “Ecosystem protection approaches”.

The majority of the studies did not define the length of time the NBS intervention had been enacted (84%), or a monitoring time frame (85%) and 75% of the studies did



not provide the funding mechanism of the NBS interventions reported.

Figure 10 presents the distribution of studies identified by outcome category, i.e. 10 HWB categories (Table 3). Most studies measured more than one outcome with the average number of outcomes measured by study = 2.3. Nine out of the ten HWB categories are represented in the systematic evidence map with the final category ‘Freedom of choice’ not studied in any of the studies included in this study (Fig. 10). Health (physical, mental health, nutrition, longevity/life expectancy etc.) was the most frequently documented outcome with over 60 studies including this as a measure. Subjective wellbeing (measures of happiness, quality of life, satisfactions supported by some value of ecosystem(s) and/or resources) was the second most measured outcome (n = 45 studies). Over a third of the studies included in the systematic map measured an aspect of living standards (economic = 39 and material = 37) while the other aspects of HWB were studied in 10–20% of the studies.

Health and subjective well-being were the two categories, which reported the most primary data (32% and 31% of 115 studies respectively) but both primary and secondary data were utilised to measure HWB outcomes in all categories.

The use of both primary and secondary data highlights that many studies researching the linkages between NBS actions and HWB were focused at the interface of social and natural science disciplines. For example, several studies reported using existing medical records of residents (social science secondary data) in conjunction with normalized difference vegetation index (NDVI) data from remote sensing (natural science secondary data). The researchers then calculated the influence of surrounding greenness (based on NDVI) on various aspects of HWB (based on medical records). On occasions when secondary data was combined with primary data, for example primary survey on cognitive development reported along with other health data linked to the residential address of the individual (obtained as secondary data) the paper was coded as reporting primary data. A greater proportion of studies utilised both primary and secondary HWB data compared with NBS data. Almost a fifth (18%) of the 115 studies in this systematic evidence base reported primary and secondary HWB data compared to less than 4% of studies reporting both primary and secondary NBS data (Table 4).

Synthesis of NBS and HWB systematic map findings

A structural ‘heatmap’ matrix of the linkages between the 12 NBS actions or intervention subcategories, and the 10 HWB outcomes, highlights unequal research effort across NBS-HWB linkages (Fig. 11). Empty cells indicate

Table 4 Number of studies and proportion reporting either only primary (PD) or secondary data (SD) or both primary and secondary data

	NBS data reported		HWB reported data	
	No. studies	%	No. studies	%
Only PD	56	49	57	50
Only SD	54	47	37	32
SD + PD	5	4	21	18
Total	115		115	

no studies in the database coded for these linkages. The majority of studies focus on the influence of Infrastructure-related NBS approaches (i.e. natural, green, blue infrastructure, or a mixture of all three) and all aspects of HWB (except the HWB category 10 Freedom of choice). HWB10 was not considered in any of the 115 studies included in this systematic evidence map. Although evidence was found for all nine of the other HWB categories coded, there was a bias in favour of the HWB categories of health either directly (HWB3) or subjective human wellbeing (HWB8).

The terrestrial subcategory of Ecosystem-based management approaches, which are focused on management of agricultural and semi-wild lands, had much less total evidence than Infrastructure-related approaches, however evidence for eight of the 10 HWB categories were reported (Fig. 11). No evidence was found for the linkage between this NBS category and HWB category of Security and safety. Only one study reported the NBS-HWB linkage of integrated water resource management. This article reported primary data on both the economic and material living standards of people in Melbourne, Australia [21].

The heatmap matrix (Fig. 11) highlights the lack of evidence of the NBS-HWB linkages of the other NBS subcategories.

Synthesis of systematic map findings for the four societal challenges

What evidence is there for specific economic cost–benefit analyses of individual NBS actions?

Although 86 studies provided evidence related to key societal challenge of the cost-efficacy of NBS, the majority related to non-monetary valuation aspects of NBS actions on HWB (monetary n = 22 and/or non-monetary n = 77). The most common NBS-HWB linkages found (Fig. 12) were green Infrastructure-related approaches (either green engineered or natural features) and health (either directly and/or subjective well-being). Papers which present primary data (PD) or secondary

	Ecosystem restoration approaches-focus on nature		Ecosystem-related approaches focus on humans		Infrastructure-related approaches				Ecosystem-based management approaches			Ecosystem protection approaches	
	Ecological restoration	Ecological engineering	Adaptation	Mitigation	Natural	Green engineered	Blue engineered	Mixed	Integrated landscapes	Integrated coastal zone	Integrated water resources	Area based conservation	
Economic living standards		2		1	12	29	12	12	4		1	1	HWB1
Material living standards		2		1	7	29	1	12	3		1	2	HWB2
Health	1	1		2	28	53	13	19	3			1	HWB3
Education					6	16	8	7	1				HWB4
Social relations					5	12	5	4	1				HWB5
Security and safety	1				5	1	5	4					HWB6
Governance and empowerment		1			1	19	4	7	2				HWB7
Subjective well being	2				22	36	7	7	3			2	HWB8
Culture and spirituality		1			9	7	3	8	5			2	HWB9
Freedom of choice and action													HWB10
	NBS01	NBS02	NBS03	NBS04	NBS05	NBS06	NBS07	NBS08	NBS09	NBS10	NBS11	NBS12	

Fig. 11 Heatmap highlighting linkages between NBS actions or interventions and HWB outcomes associated with the four focal societal challenges illustrated as a structural matrix of the distribution and frequency of occurrences of either primary or secondary data. (Darker-shaded cells indicate higher occurrence of evidence with lower occurrence indicate by lighter cells, number of studies reported on each cell with blank cells indicating no studies found)

	Ecosystem restoration approaches-focus on nature		Ecosystem-related approaches focus on humans		Infrastructure-related approaches				Ecosystem-based management approaches			Ecosystem protection approaches	
	Ecological restoration	Ecological engineering	Adaptation	Mitigation	Natural	Green engineered	Blue engineered	Mixed	Integrated landscapes	Integrated coastal zone	Integrated water resources	Area based conservation	
Economic living standards		2		1	10	21	9	9	4		1	1	HWB1
Material living standards		2		1	5	22	8	10	3		1	2	HWB2
Health	1	1		2	28	45	12	16	3			1	HWB3
Education					6	12	6	6	1				HWB4
Social relations					4	10	4	4	1				HWB5
Security and safety	1				3	5	4	2					HWB6
Governance and empowerment		1			6	12	3	5	1				HWB7
Subjective well being	2				19	29	6	5	2			1	HWB8
Culture and spirituality		1			9	7	3	7	5			2	HWB9
Freedom of choice and action													HWB10
	NBS01	NBS02	NBS03	NBS04	NBS05	NBS06	NBS07	NBS08	NBS09	NBS10	NBS11	NBS12	

Fig. 12 Heatmap illustrating the distribution and frequency of occurrences of evidence from studies reporting on monetary and/or non-monetary aspects of NBS actions or interventions on HWB (Darker-shaded cells indicate higher occurrence of evidence with lower occurrence indicated by lighter cells, number of studies reported on each cell with blank cells indicating no studies found)

data (SD) for a given combination of nature-based solution and human well-being can be identified using the relevant column code for Nature-based solution (e.g. NBS06=NBS_Cat_6_Green_engineered_infrastructure) and human wellbeing (e.g. HWB3=HWB_Domain_3_Health) in Additional file 7.

What evidence is there concerning the role of NBS actions in addressing environmental justice and societal socio-economic inequalities?

The evidence related to the key societal challenge ‘environmental justice’ were confined to the NBS actions related to natural, green, blue or mixed infrastructure in the urban environment (Fig. 13). Many studies considered distance from the residence to natural, blue or green infrastructure relating the study to economic (HWB1) and material living standards (HWB2), health (directly HWB3) or subjective well-being (HWB8) governance and empowerment

(HWB7). Fewer studies considered other aspects of HWB e.g. social relations, education, security and safety with no studies focused on freedom of choice and action (Additional file 7).

What evidence is there that governance issues are being highlighted with regard to implementing NBS actions or management of NBS interventions?

The urban environment was also the focus of studies related to governance in planning; either focused on the planning process (n=26) and/or policy related to planning (n=20). Research on governance related to green engineered infrastructure in the urban environment was well represented in the evidence map compared to Area-based conservation approaches (NBS12). Ecosystem restoration approaches, Ecosystem-related approaches focused on humans and Ecosystem-based management approaches were poorly studied (Fig. 14). No studies investigated the HWB aspect of security and safety (HWB6) in relation to NBS actions (Additional file 7).

	Ecosystem restoration approaches-focus on nature		Ecosystem-related approaches focus on humans		Infrastructure-related approaches				Ecosystem-based management approaches			Ecosystem protection approaches	
	Ecological restoration	Ecological engineering	Adaptation	Mitigation	Natural	Green engineered	Blue engineered	Mixed	Integrated landscapes	Integrated coastal zone	Integrated water resources	Area based conservation	
													NBS01
Economic living standards					4	14	5	5					HWB1
Material living standards					2	12	3	4					HWB2
Health					4	15	4	7					HWB3
Education						5	3	2					HWB4
Social relations					1	6	3	2					HWB5
Security and safety						3	1	1					HWB6
Governance and empowerment					6	13	3	4					HWB7
Subjective well being					2	8	3	1					HWB8
Culture and spirituality					1	2	1	2					HWB9
Freedom of choice and action													HWB10

Fig. 13 Heatmap illustrating the distribution and frequency of occurrences of evidence from studies reporting on environmental justice related to aspects of NBS infrastructure on HWB (Darker-shaded green cells indicated higher occurrence of evidence with lower occurrence indicate by lighter cells, number of studies reported on each cell with blank cells indicating no studies found)

	Ecosystem restoration approaches-focus on nature		Ecosystem-related approaches focus on humans		Infrastructure-related approaches				Ecosystem-based management approaches			Ecosystem protection approaches	
	Ecological restoration	Ecological engineering	Adaptation	Mitigation	Natural	Green engineered	Blue engineered	Mixed	Integrated landscapes	Integrated coastal zone	Integrated water resources	Area based conservation	
													NBS01
Economic living standards					4	10	3	4	3		1	1	HWB1
Material living standards		1			3	10	4	6	2		1	1	HWB2
Health					4	10	6	8	1			1	HWB3
Education						1	1	1	1				HWB4
Social relations					2	6	2	2	2	1			HWB5
Security and safety					2	3	2	2					HWB6
Governance and empowerment		1			8	15	2	5	2				HWB7
Subjective well being					4	5	3	3	3			1	HWB8
Culture and spirituality					3	4	2	3	2			2	HWB9
Freedom of choice and action													HWB10

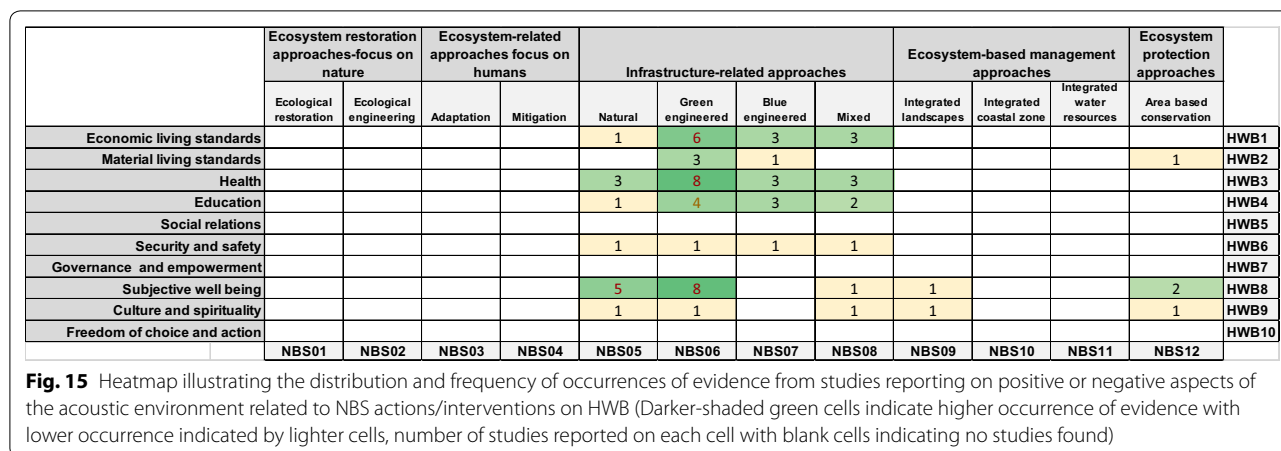
Fig. 14 Heatmap illustrating the distribution and frequency of occurrences of evidence from studies reporting governance in planning related to aspects of NBS actions or interventions on HWB. (Darker-shaded green cells indicate higher occurrence of evidence with lower occurrence indicated by lighter cells, number of studies reported on each cell with blank cells indicating no studies found)

What is the evidence for NBS actions focused on the acoustic environment (soundscape)?

The acoustic environment was the least studied of the four societal challenges identified by the consultation phase as requiring evidence. In total only 20 studies (17%) were identified as addressing the soundscape and NBS-HWB linkage. As was true for the other societal challenges, most of studies were related to infrastructure-related NBS approaches in the urban environment and addressed HWB of human health either directly or subjective health (Fig. 15). Both positive and negative impacts of the acoustic environment were studied. For example, the role of nearby green spaces or the role of green roofs to alleviate noise pollution has been studied in urban environments but few studies reported the positive or negative aspects of the soundscape in rural settings (Additional file 7).

Limitations of the map

Our stakeholder consultation and the resources available for the study dictated the scope of this systematic evidence map and the focus on the four key challenges. We recognise it is a snapshot in time and understand that if the stakeholder consultation was repeated a different set of priority challenges may emerge. In addition, this study focused on only OECD countries. The decision to restrict the geographic scope was informed by our consultation with the stakeholders who reported that the evidence they needed for operationalising decisions relating to NBS actions should be provided in situations as socio-economically and culturally similar as possible to the UK. This may have resulted in no studies reporting on the NBS-HWB10 linkage (Freedom of Choice) as the fundamental rights and freedoms of civil society in OECD



countries is often protected in law e.g. the Human Rights Act 1998 in UK.

The most frequently used exclusion criteria as commented previously was ‘no comparator’. While useful studies may have been excluded with this strict interpretation, our stakeholders were very clear that to operationalise decision making in relation to NBS actions they were very often faced by a lack of hard evidence of the claimed advantages of NBS over cheaper single focus technological solutions. To meet this need, robust studies which included a clear comparator condition were an absolute necessity.

The systematic evidence map was for the same reason also limited to studies reporting primary data and empirical models (e.g. regression and economic models). However, other models were excluded for example explanatory/conceptual models which explored theoretical hypotheses, models focused on anticipatory predictions to guide short-term tactical decision making, or longer-term projections to inform strategic direction setting. Whilst we recognise these types of models continue a long tradition of synthesising knowledge in generalisable and useful forms, in line with the overall approach, they were not considered relevant to the stated operational needs of our stakeholders and therefore beyond the scope of this systematic evidence map. In addition, the final search strategy did not find all the test articles which is a limitation. Similar studies were included but we acknowledge we may have missed some relevant articles.

In addition to limitations to the scope of the search strategy, several limitations related to how data were synthesized and presented should be considered when interpreting results and using the systematic map. First, data extraction was intended to capture general characteristics for each study so for example each study was

restricted to a single habitat or a single ‘multiple’ habitat category. Most of the studies were allocated to the urban habitat although it was recognised that not all studies fit clearly into a single category such as ‘urban environments’ and that landscape gradients are often present within study areas. In a study conducted within the city limits of Los Angeles for example, McPherson et al. (2011) commented that the elevation ranged from sea level to 1543 m at Mount Lukens in the northeast corner of the city [22]. Studies were coded under the dominant landscape character type and all data synthesising protocols used in this study were designed to strike a balance between representing data as accurately as possible and extracting wider patterns in the data.

Conclusion

Implications for policy

Lack of robust evidence to support decision-making

This systematic map was driven from the outset by the key challenges identified during the stakeholder consultation phase [18]. These stakeholders were deliberately chosen because of their operational roles and their clear need for robust evidence to support decision making on the implementation of policy objectives. The stakeholders consulted highlighted a need for knowledge and evidence to support decision making on the implementations of NBS actions or interventions compared with non-NBS alternatives. Ninety seven percent of the papers included in the initial word search were rejected at the title/abstract selection stage as they were either irrelevant or failed the eligibility criteria for the comparator i.e. with/without NBS actions, before/after or high/low access to NBS. As previously stated, in the eyes of the stakeholders consulted, the lack of a comparator in a study constitutes insufficient evidence upon which to base operational decisions. One Scottish stakeholder who worked in the

operationalising of NBS actions for over 10 years, initially within a health service setting and latterly with a forestry focus, commented that he was committed to joined-up planning to promote use of nature for the benefit of human wellbeing. He was of the opinion that there is a great deal of knowledge on the potential benefits of NBS but there remained nevertheless a lack of will to deliver. In his experience, this was driven by the lack of evidence to support a clear cost benefit analysis (comparing NBS to technical/engineered alternative using monetary and non-monetary benefits). This systematic map found that there were a large number of papers, for example, which highlighted the advantages of wooded landscapes in rural and urban settings for recreation and either by inference or through primary data linked recreational activities conducted in nature with human health [23–25]. However, most of the articles failed to compare the benefits of woodland recreation with recreational activities conducted in non-nature environments e.g. a gym or artificial football pitch. Our results highlight the lack of studies which provide sufficient evidence to support clear informed policy and decision-making.

Lack of studies on the multiple HWB benefits of NBS to support decision-making

Stakeholders consulted in all four component parts of the UK commented on the need for evidence related to the cost-efficacy of NBS over non-NBS alternatives, as well as the importance of the multiple benefits resulting from NBS interventions spanning several policy domains. The systematic evidence map (Fig. 12) highlights the lack of studies that address these broader policy needs as there was a predominance of evidence on health (HWB3) i.e. 58% of studies included in this systematic evidence map. Exceptions included a holistic approach to calculating the cost-benefits of NBS actions or interventions, advocated by Monge et al. [26]. They reported on the role of environmental policies on the decision-making processes of farmers when considering the costs and benefits of integrating forestry on dairy farming businesses in the Central North Island of New Zealand. They considered how payments for ecosystem services could assist plantation forestry's integration into pastoral dairy farming in order to (i) improve environmental outcomes (improve water quality and reduce greenhouse gas emissions) and (ii) increase business resilience (HWB1) to both price uncertainty and production limits imposed by environmental policies (reducing mental stress HWB8). They concluded that this type of holistic analysis presents farmers with the financial advantage to undertake afforestation projects which simple cost–benefit analysis did not [26]. It is argued that this knowledge would be welcomed by policy makers, clearly defining the additional cost-benefits

of integrating NBS actions and management interventions (i.e. all HWB1 to HWB10). In addition the study by Morandin et al. [27], which showed that over time, small-scale field edge habitat restoration could benefit nature and be profitable, on farms in the USA when pest control and pollination cost–benefit analysis is considered. Morandin and co-workers also considered economic costs related to human health and demonstrated habitat restoration intended to protect endangered and rare species could also reduce the disease risk to humans in the form of reduction in the risk of the tick-borne Lyme Disease which significantly altered the cost–benefit analysis [27].

The importance to policy makers of studies taking a broader perspective is highlighted for example in Wales where NBS are a key policy priority of the Welsh Government as set out in their Natural Resources Policy. Stakeholders highlighted that delivering on these policy priorities requires a cross policy commitment to working together in order to escape the silo mentality prevalent in public service provision. The problem of single-issue thinking was highlighted by several researchers included in the systematic evidence map. For example, Rigolon and Nemeth [28] studied governance and environmental justice in the urban planning environment. They reported one interviewee as saying “...working across boundaries and combatting this fragmentation is exceedingly difficult in a growth-oriented paradigm” because “elected officials are trying to pit park advocates against affordable housing advocates so that we're fighting each other for scarce resources.” She added that “because funders aren't giving enough money to work together, funders are asking us to come with very narrow views of what we're doing” [28]. This systematic evidence map highlights the lack of research into processes and procedures to tackle this issue.

Lack of studies to support policy decisions outside urban areas

The systematic evidence heat map (Fig. 14) highlights the lack of research effort to date coded to the environmental justice and societal socio-economic inequalities challenges. All articles linked to this societal challenge were conducted in the urban or peri-urban environment. The complete lack of research in all other habitats included in the systematic evidence map for this societal challenge highlights a large evidence gap in OEDC countries which is problematic for the implementation of policy goals. It could be argued that the urban environment and infrastructure approaches (NBS 5–8) have become the focus of research in the UK following publication of the Marmot review (<https://www.local.gov.uk/marmot-review-report-fair-society-healthy-lives>

), a landmark study of health inequalities in England. Interestingly this trend was also highlighted by one of the stakeholders who identified a need for a summary of evidence post-2010. It is of note that only one paper included in the systematic evidence map for this societal challenge was published prior to 2010, which suggests that the need for evidence of this societal challenge was recognised a decade ago—it is the area with the most evidence in this study (51 articles were included in this systematic evidence map). As indicated earlier the strict eligibility/exclusion criteria used in this systematic map resulted in those studies, which exclusively addressed green space, without a comparator, being excluded. For example, Ferrara et al. [29] conducted a pilot study aimed at better understanding how citizens interact with urban green areas and purposely excluded the non-green built environment, as they did not consider it relevant for their study.

Lack of studies to inform policy makers on trade-offs when implementing NBS

Only one study in the systematic evidence map was coded as reporting a negative HWB outcome associated with an NBS action or intervention and it was coded to the inequality societal challenge. The study by Rigolon and Németh [28] reported on the displacement of long-term low-income residents following investment in a large green infrastructure project such as New York's High Line that turned disused urban infrastructure into green space. The study highlighted that the infrastructure project was successful in its intent to improve living conditions and increase the value of land and property in surrounding neighbourhoods but this was at the expense of a section of the community. This study highlights that decisions made to improve quality of life can have unforeseen consequences of which gentrification appears to be a well-documented example [30, 31].

Lack of studies providing evidence to manage acoustic environments

The lack for evidence on the acoustic environment (soundscape) to support the implementation of policy objectives amongst stakeholders is corroborated by the lack of suitable evidence found in our systematic evidence map (14 studies). Most of these studies reported on the environmental burden associated with the soundscape related to anthropogenic influences e.g. road or air traffic noise (negative aspects) and with NBS interventions e.g. green roofs or access to green space to alleviate the burden. A stakeholder in the consultation phase, who works to support delivery of greener urban regeneration,

commented that he had been asked about the benefits of a green wall to mitigate noise and air pollution from dock activities. While he was aware of the literature related to improved air quality, he knew of no studies focused on the ability of green walls to reduce noise pollution. Unfortunately, limited robust evidence meeting the eligibility criteria was found in this study, highlighting a significant knowledge gap for policy makers. A few studies did consider the positive aspects of the soundscape e.g. role of bird song was often highlighted in the urban environment e.g. in Sweden by Hedblom et al. [32].

Implications for research

Need for robust long-term research on highlighted societal challenges

This review sought to highlight the knowledge gaps related to the linkages between nature-based solutions and human wellbeing (NBS-HWB) for four key societal challenges. The use of these four key challenges as a focus for the review was based on an extensive period of consultation with policy makers in the four component parts of the UK [18]. The resultant systematic evidence maps from this study contain only 115 studies reporting primary research (~2% of relevant articles found through the systematic search). This systematic evidence map strongly supports the assertion of the stakeholders consulted that research evidence is lacking on the NBS-HWB linkages necessary for operational decision-making related to the four societal challenges of cost efficiency, governance in planning, environmental justice and the acoustic environment. As highlighted above, few studies reported experimental/quasi-experimental design which may offer an opportunity for increased systematic study comparing NBS and non-NBS alternatives and their implications for HWB.

Paradigm shift in research commissioning and science reward mechanisms required

The transdisciplinary stakeholder consultation undertaken prior to creating the systematic map highlighted the need for interdisciplinary NBS-HWB research. It is recognised by many in the research sector that the transaction costs for interdisciplinary research are very high due to different vocabularies and cultures of the communities of scientists engaged in one tradition or another. The role of the research donor community and the often-linked academic disciplinary preferences of researchers are both implicated in the lack of knowledge available to decision makers.

Some researchers of studies excluded from this systematic evidence map explicitly commented on the role of research donors in determining the scope of

their study. For example, O'Brien et al. working at the Westonbirt Arboretum in England, commented “*The research was limited to a single site with no control or comparison. It would have been useful to explore and compare some of the other non-nature activities participants undertook in their residential settings in order to explore the role and inclusion of nature as part of their rehabilitation or treatment process. However, the funding did not allow for this scale of research to be undertaken*” [33]. Similarly, the short-term nature of the research funding agenda, driven by the donor community, and leading to a lack of studies with a longer time-frame was also highlighted by one of the stakeholders in the participatory consultation phase. A major finding of this systematic evidence mapping study is that the kind of long-term robust evidence base sought by policy makers and those who operationalise NBS is not prioritised by research donors or indeed by academics, under the existing research funding schemes and scientific reward systems.

The rationale of academics in determining study priorities has been investigated recently. Santos et al. [34] suggest that ‘thinking styles’ of academics, at least in the social sciences, can have significant relevance for the knowledge available to policy makers. They concluded, following a participatory survey of 529 academics, that “*current performativity, indicators craze, research assessments and research projects’ limited duration and expected deliverables may be driving for publications en masse with short-term focuses, rather than fomenting research programmes that are longer term, stable and focused on innovative and transformative research*” [34]. While there is evidence that the research donor community is changing, becoming more interdisciplinary and even requiring transdisciplinary studies, there is little evidence of changing attitudes within the academic community where the pressure to publish in high impact single discipline journals is primary, despite increasing attention on the detrimental effect this approach has on knowledge generation [35].

This systematic evidence map highlights that future research on the linkages between NBS and HWB should focus on a broader range of NBS interventions and target habitats, especially outside of the urban space. The need for the research donor community to collaborate and commission research as cross sectoral clusters was also highlighted by stakeholders in the consultation phase [18]. This would require a visionary approach from funding bodies that support long-term, quantitatively designed research studies for a range of NBS and hybrid approaches across multiple habitats

that can be analysed and compared with non-NBS control sites.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s13750-020-00208-6>.

Additional file 1. List of peer-reviewed and grey literature sources searched.

Additional file 2. Codebook and data extraction questionnaire.

Additional file 3. All Search Results.

Additional file 4. Output from CADIMA software of excluded articles.

Additional file 5. Systematic map database.

Additional file 6. ROSES reporting form.

Additional file 7. Heatmap references.

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Authors’ contributions

This study was led by JD. JM advised throughout the project particularly on the scope of the systematic map, design of search strategy, and coding, with input from all authors. Title and abstract screening was conducted by JD, AD, JCJ and SC, and full-text screening by JD and AD. Full-text coding was conducted by JD and JCJ. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analysed during this study are included in this published article and its additional files.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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