



# Nature-based solutions for climate change adaptation: A systematic review of systematic reviews

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## ABSTRACT

More than 90 systematic reviews have been conducted on the topic of nature-based solutions for climate change adaptation (NBS-CCA). These prior reviews, however, are scattered across more than 45 different peer-reviewed journals and gray literature sources, making it difficult to follow all of the knowledge generated and remaining research gaps. In this study, we conducted a systematic review of systematic reviews on the topic of NBS-CCA, with the objective of mapping and analyzing these prior reviews. We found that most of the prior systematic reviews had relatively narrow research focuses, typically focusing on a particular geographic context of NBS-CCA (mainly in urban and coastal areas) or on a particular aspect of NBS-CCA planning/implementation (mainly outcomes assessment and policy/governance issues). Fewer reviews focused on mountainous areas or on social and financial aspects of NBS-CCA planning/implementation. The majority reviews relied solely on peer-reviewed literature for analysis, with only 26% including gray literature, despite the large amount and variety of gray literature on NBS-CCA that exists. Notably, we found that no prior systematic reviews have yet attempted to comprehensively analyze all geographic contexts and all aspects of NBS-CCA, e.g. through a review and meta-analysis of all available peer-reviewed and gray literature on the topic. This would likely require a massive multidisciplinary effort, but could be a worthy endeavor considering the realized need to integrate NBS-CCA into national/subnational policies and various international environmental agreements pertaining to climate change (e.g., Paris Agreement) and biodiversity conservation (e.g., Post-2020 Global Biodiversity Framework).

## 1. Introduction

Global climate change and biodiversity loss are two of the great challenges of the 21st century. They cannot be tackled independently, however, because the Earth's climate, ecosystems and biodiversity, and human society are highly interdependent [1]. For example, deforestation can result in loss of biodiversity as well as the release of greenhouse gasses that cause global climate change [2], while urban expansion can lead to increased exposure of people and physical assets to climate hazards [3] as well as the displacement of animal and plant species. To reduce exposure and vulnerability to climate change, ecological systems adapt autonomously through ecological and evolutionary processes (e.g., through inland migration or increasing salt tolerance to adapt to rising sea levels), while in human-managed systems, climate change adaptation occurs through the implementation of incremental or transformative measures in reaction to or in anticipation of the changing climate conditions [1]. In the context of climate change adaptation, nature-based approaches, commonly referred to as “nature-based

solutions” (NBS) [4] or “ecosystem-based adaptation” (EBA) [5], harness the benefits provided by different types of ecosystems to enhance human well-being (e.g., by reducing exposure to climate change hazards) while also protecting biodiversity [6,7]. Thus, these types of adaptation approaches are helpful for addressing both climate change and biodiversity loss.

Some examples of the benefits from nature in the context of climate change adaptation include the ability of urban green spaces to reduce urban temperatures through evapotranspiration and shading [8], and the ability of mangroves to reduce the impacts of sea level rise and storm surge through soil accretion and wind/wave attenuation, respectively [9–11]. Implementation of NBS/EBA involves conducting activities to protect, sustainably manage, or restore natural or modified ecosystems [6]. Although the term NBS is rather new, it has gained popularity as an “umbrella concept” that incorporates EBA (another fairly recent term) and other nature-based approaches like ecosystem-based disaster risk reduction and ecosystem-based management [12,6]. This is because the challenges that NBS are intended to provide “solutions” for are much

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broadly than just climate change adaptation, and can include any societal challenge for which nature-based interventions simultaneously provide human well-being and biodiversity benefits [6]. The benefits of NBS have now become widely accepted by the scientific community, with the recently approved IPCC (Intergovernmental Panel on Climate Change) Sixth Assessment Report acknowledging that effective NBS/EBA “reduces a range of climate change risks to people, biodiversity and ecosystem services with multiple co-benefits (high confidence)” [1].

There is already a large body of literature focusing on NBS for climate change adaptation/EBA (hereafter, “NBS-CCA”). For example, a comprehensive search of the Web of Science and Scopus databases of peer-reviewed literature, conducted by Chausson et al. [13] in April 2018, found nearly 17,000 papers having titles/keywords/abstracts related to NBS-CCA. There is also much gray literature on the topic, i.e. literature not published in traditional academic journals, which typically has not been peer-reviewed in the conventional manner [14]. Indeed, Giffin et al. [15] found more information on coastal/marine NBS-CCA projects in the Asia-Pacific from gray literature than peer-reviewed journals. As one prominent example from the gray literature, the International Union for Conservation of Nature (IUCN) recently published a report entitled the “Global Standard for NBS”, containing a comprehensive set of criteria for assessing NBS projects (Table 1) [16] to ensure that they align with the internationally accepted principles of NBS [17]. These IUCN criteria are intended to apply to NBS addressing all types of societal challenges, so in this paper we also consider them as core principles for the specific challenge of climate change adaptation (i.e. NBS-CCA).

Due to the large (and continuously increasing) amount of peer-reviewed and gray literature on NBS-CCA, numerous research efforts have also focused on analyzing and extracting information derived from these existing works, i.e., through conducting literature reviews ([13, 15]; Smith et al. [18]). Several types of literature review exist, with the simplest being the “narrative review”. A narrative review involves searching for and analyzing the literature on a topic in a nonsystematic, or opportunistic, manner [19]. Many narrative reviews have been published on the topic of NBS-CCA, focusing mainly on summarizing the key concepts and policy issues of NBS-CCA as a whole (e.g. Munang et al. [7]), or within a specific geographic context like urban areas (e.g. Hobbie and Grimm [20]), coastal/marine areas (e.g. Zari et al. [21]), or forest areas [22]. Although these types of narrative reviews can be very effective for summarizing the published literature to clarify future research and policy needs, they have several limitations. For example, their lack of an objective methodology for the literature search and analysis makes the review process (and thus the results/conclusions drawn from the literature) relatively subjective [23].

Aside from narrative reviews, more systematic types of literature reviews also exist (Table 2). These systematic reviews require the development of explicit protocol for the literature search and/or literature appraisal process [24,19], and should follow established guidelines for reporting, e.g. the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) [25]. The first step of a systematic

**Table 2**

Descriptions of some common types of literature reviews. Based on Leenaars et al., [19] and Grant & Booth [24].

Type of literature review	Description	Level of comprehensiveness of literature search
Narrative review	Non-systematic review contributing an idea or opinion to scientific discourse.	May or may not include comprehensive searching.
Mapping review	Review providing a high level overview of the complete literature, using a (partially) systematic methodology.	Completeness of search determined by time restraints and scope of paper.
Scoping review	Review providing evidence based on an incomplete convenience sample of the literature, using a (partially) systematic methodology.	Completeness of search determined by time restraints and scope of paper.
Full systematic review	Review comprising a full search resulting in a complete literature overview, inclusion of papers following strict criteria, tabulation of extracted data, risk of bias assessment of included studies, and meaningful (qualitative or quantitative) synthesis of the data.	Aims for exhaustive, comprehensive searching.

review is to define the research question that will be addressed. Next, for the literature search process, one or more literature databases are identified (e.g. Scopus: <https://www.scopus.com/>), and a search query (or a set of search queries) is formulated to retrieve potentially relevant papers from the database(s). The retrieved papers are then appraised based on a clear set of exclusion criteria to determine which papers are relevant to the study’s research objective(s). The final set of relevant papers is used as the basis for all subsequent analyses conducted in the systematic review. Systematic reviews are useful in that they are backed by a clear and replicable methodology, which can, among other things, help readers to understand potential sources of bias and uncertainty (i.e., due to missing literature) in the literature review and analysis process [26]. Several systematic reviews have been conducted on the topic of NBS-CCA, and these prior systematic reviews are the focus of remainder of this paper.

In this study, we conducted a *systematic review of systematic reviews* on NBS-CCA. Conducting a reviews of reviews, also referred to as an “umbrella review”, involves compiling information from various individual reviews into a more accessible and usable format [24]. Umbrella reviews are typically beneficial when the existing reviews on a topic have been published in a wide variety of different sources which may not be easily accessible to policymakers and other scientists [27]. This is indeed the case for NBS-CCA systematic reviews, which have been published in at least 45 different journals, as well as in other peer-reviewed and gray literature sources (see Section 3.1. for more information). Systematic umbrella reviews can be particularly useful due to their application of rigorous and transparent methodologies to aggregate the findings of existing systematic reviews [24]. Umbrella reviews are widely conducted in the field of medical science, e.g. to compile evidence on risk factors for different diseases [28,29], or compare the health outcomes of different treatments or interventions [30]. They have rarely been applied, however, for the study of NBS and other related topics. Indeed, the only umbrella review we could find related to NBS dealt specifically with the public health benefits of urban ecosystems [31].

The main objective of our umbrella review in this study was to systematically analyze and summarize the existing systematic reviews on NBS-CCA, because while many systematic reviews have been conducted on this topic, there have been no previous attempts to systematically summarize these reviews. Thus, our primary research question was:

**Table 1**

IUCN Global Standard for NBS, a set of criteria to aid project design and implementation [16].

Criterion 1: “NbS effectively address societal challenges”
Criterion 2: “Design of NbS is informed by scale”
Criterion 3: “NbS result in a net gain to biodiversity and ecosystem integrity”
Criterion 4: “NbS are economically viable”
Criterion 5: “NbS are based on inclusive, transparent and empowering governance processes”
Criterion 6: “NbS equitably balance trade-offs between achievement of their primary goal(s) and the continued provision of multiple benefits”
Criterion 7: “NbS are managed adaptively, based on evidence”
Criterion 8: “NbS are sustainable and mainstreamed within an appropriate jurisdictional context”

“What were the main characteristics of the prior systematic reviews on NBS-CCA?”. To address this question, we conducted an analysis to summarize the following characteristics of the prior reviews:

- Publication years and publication venues of previous systematic reviews;
- Literature databases and types of literature used in the prior reviews;
- Geographic contexts of the prior reviews;
- Research objectives of the prior reviews;

We focused on these characteristics to better understand the publication trends, literature search approaches used, and main topics investigated in prior systematic reviews.

The main contribution of this study to the NBS literature is that it represents the first umbrella review on the topic of NBS-CCA, and only the second umbrella review on NBS in general (the first focused on the public health benefits of urban ecosystems, as previously mentioned). Thus, the results of our analysis of the existing systematic reviews provides a new picture of the current progress and remaining research gaps on NBS-CCA, which may help guide future research (systematic reviews and primary studies) and inform relevant NBS plans/policies. Aside from this main contribution, the database we have compiled containing the characteristics of the prior reviews (Supplementary Table S1) can also help readers identify prior systematic review(s) matching their interests, and the collected data can potentially be added to and/or reanalyzed in subsequent studies.

## 2. Methods

### 2.1. Search of literature databases

As the first step of the review process, we developed a literature search and appraisal protocol. Our intention was to provide a high level overview of the existing systematic reviews on NBS-CCA, so the approach we adopted for literature search and appraisal was similar to that of a “mapping review” (Table 2), i.e. using a systematic methodology and a literature search whose level of completeness is determined by the time restraints and the scope of the paper [24,19]. Mapping reviews, also sometimes referred to as “systematic maps”, are commonly used in social and environmental sciences to collate, describe and catalog the available evidence relating to a topic or question of interest [32]. The main difference between our review and the typical mapping review is that our focus was on systematic reviews rather than primary research papers.

For the literature search, we first conducted primary searches using the “Scopus” and “Web of Science” databases (search date July 19, 2021), two of the largest databases of peer-reviewed literature, using the following title/abstract/keywords search query:

- ("nature-based" OR "nature based" OR "ecosystem-based" OR "ecosystem based") AND "climate change".

We limited these initial primary searches to papers classified as “Reviews”, and excluded other types of papers (e.g. Original Research Articles, Editorials, and Commentaries). These primary searches were intended to retrieve systematic review papers dealing with nature-based/ecosystem-based approaches for adapting to (or building/enhancing resilience to) climate change impacts, i.e. NBS-CCA.

Relying solely on Scopus and Web of Science risks that we could miss relevant studies from growing body of work being published outside of standard scientific publishing. Thus, to supplement our primary search of Scopus/Web of Science, we conducted secondary searches to identify other relevant systematic reviews, including peer-reviewed studies from journals/books not indexed in Scopus/Web of Science, and reviews from

gray literature sources. Firstly, we conducted a search for all systematic reviews indexed in the “Oxford University Nature-based Solutions Initiative” website (<https://www.naturebasedsolutionsinitiative.org/bibliography/>; Last accessed December 08, 2021), which contains peer-reviewed works. Secondly, we conducted full-text searches of Google Scholar (search date December 08, 2021), which contains gray literature in addition to peer-reviewed work. For the Google Scholar search, we appended the term “systematic review” to the previous Scopus/Web of Science search query (because it is not possible to filter by the paper type in Google Scholar), and downloaded the first 100 search results retrieved (i.e. the most relevant papers according to Google’s search algorithm) for further screening. Thirdly, we searched the websites of several international organizations that publish reports related to NBS, including the IUCN (<https://www.iucn.org/resources?rstyle=1124&thm=1145&tpc=All&rgn=All&cntry=All>; Last accessed October 03, 2022), the United Nations Environment Programme (<https://www.unep.org/resources?keywords=nature-based+solutions>; Last accessed October 03, 2022), the Nature Conservancy (<https://www.nature.org/en-us/search/?q=nature%20based%20solutions>; Last accessed October 03, 2022), the World Wildlife Fund (<https://www.worldwildlife.org/search?cx=003443374396369277624%3Av3nraqhmyk&ie=UTF-8&x=nature+based+solutions#gsc.tab=0&gsc.tab=0&gsc=nature%20based%20solutions&gsc.page=1>; Last accessed October 03, 2022), and the European Commission ([https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications\\_en?f%5B0%5D=oe\\_publication\\_title%3Anature-based%20solutions](https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications_en?f%5B0%5D=oe_publication_title%3Anature-based%20solutions); Last accessed November 07, 2022). Relevant organizations for these searches were identified through our previously identified literature, i.e., through our reading of papers that analyzed gray literature from these organizations’ websites. Fourthly, we hand-picked two additional systematic review papers that were not included in our previous searches because they had been classified as “Original Research Articles” by their respective journals rather than “Reviews”. Finally, after our initial submission of this manuscript, we were requested by one of the peer reviewers to conduct an additional search of Scopus for other papers not classified as “Reviews”. This was necessary because some journals do formally classify papers as “Reviews”. To retrieve these papers, we revised our initial Scopus search query as:

- ("nature-based" OR "nature based" OR "ecosystem-based" OR "ecosystem based") AND "climate change" AND “systematic”.

Through all of these initial literature searches, we identified a total of 512 review papers for further screening, including both peer-reviewed and gray literature.

### 2.2. Inclusion/exclusion of papers retrieved by the initial literature searches

To extract the relevant papers from the initial search results for subsequent analysis, we set the following pre-defined exclusion criteria according to our study’s research question:

- (1) Papers that were not systematic literature reviews, i.e., papers that did not use a (partially or fully) systematic approach for identifying and appraising relevant literature. This included purely narrative reviews, as well as non-review papers;
- (2) Papers unrelated to NBS-CCA. This included: review papers focusing on aspects of CCA unrelated to NBS, papers focusing solely on nature-based solutions for other societal issues (e.g. climate change mitigation or ecotourism), papers focusing solely on climate change impact assessments without discussing NBS-CCA measures. [Note: If a review focused on NBS for addressing present-day climate hazards, but the authors stated that climate change could exacerbate the hazard(s), we included the paper in our analysis.]

The full-texts of each of the 512 papers was reviewed by at least two authors to determine which papers to include/exclude from further analysis, with the first author doing the final check of all papers. Fig. 1 shows the workflow of the literature review and appraisal process, which is based on the PRISMA approach [25].

### 2.3. Coding of data extracted from relevant papers

Next, we coded various types of information extracted from the papers included in our analysis, including: the year and venue of publication, the literature databases and types of literature (i.e., peer-reviewed and/or gray literature) searched, the geographic context(s) of the NBS investigated, and research objective(s) of each paper. We then categorized and summarized the extracted information to elucidate when and where prior systematic reviews were published, what types of literature they used as evidence for their analyses, and what types of environments and objectives they focused on.

## 3. Results and discussion

From the initial 512 papers identified through our literature searches, we identified 91 as relevant for subsequent analyses (Fig. 1). Of the excluded papers ( $n = 421$ ), 121 were duplicates, and 300 were out of the scope of the study according to our defined exclusion criteria.

### 3.1. Year and venue of publication of prior systematic reviews

Of the 91 systematic reviews included in our analyses, all were published between 2012 and 2021, and the number of reviews published per year was found to be rapidly increasing since 2017 (Fig. 2). It was unsurprising that there were no systematic reviews prior to 2012, as NBS and EBA were still very new terms at this time. The NBS term was first promoted internationally by the World Bank in 2008 [4] and the IUCN in 2009 [33]. The EBA term also started being used around 2009, after the Secretariat of the Convention on Biological Diversity published a report on the topic [5]. The number of primary research articles published on NBS for addressing climate-related hazards (including those exacerbated by climate change) has reportedly been increasing rapidly in recent years [34,35], so this growing number of primary studies is likely driving the recent increase in systematic reviews on the topic.

We found that 96% of the systematic reviews ( $n = 87$ ) were

published in peer-reviewed journals (Table 3). Reviews were published in 45 different journals, covering a wide range of topics including disaster risk reduction, climate (change), sustainable development, policy, and urban and environmental planning/management. This indicates that NBS-CCA has emerged as a highly multidisciplinary topic, of interest to a wide range of academics. The sheer number of journals in which these reviews have appeared, however, makes it challenging for readers to keep track of all the evidence being generated on the topic. Umbrella reviews like this current study are thus useful for identifying and compiling information on the reviews published in these various sources.

Aside from journal articles, there were two additional peer-reviewed papers included in our analysis: one was a conference paper, and one was a book chapter. We also identified five systematic reviews from gray literature sources, including two preprints (i.e. papers currently undergoing peer review), one report for a European Union funded research project, one independent expert report summarizing the results/outputs European Union Funded NBS projects, and one student thesis. Notably, from the websites of the different international organizations that we searched, we could find only one systematic review (which was on the European Commission publication services website). Thus, unlike primary studies on NBS-CCA, of which many can be found in gray literature sources, nearly all systematic reviews on the topic have been peer-reviewed or are currently undergoing peer review (in the case of the preprints). This may be because the rigorous methodology employed for the systematic review process is more typical of peer-reviewed research, and/or due to a lack of access to the necessary literature databases (Scopus, Web of Science, etc.) in non-academic institutions, as subscriptions to these databases tend to be expensive [36].

### 3.2. Literature databases and types of literature used in prior reviews

Next, we extracted information on the literature databases and types of literature used in the papers included in our analysis (Fig. 3).

Scopus was the most frequently searched literature database in prior reviews, having been used in 67% of the papers ( $n = 61$ ). Web of Science (previously called “Web of Knowledge”) was the second most frequently searched database, having been used in 63% of the papers ( $n = 57$ ). Both Scopus and Web of Science contain peer-reviewed literature, including journal articles, conference papers, and books/book chapters. Google Scholar was the third most frequently searched database, having been

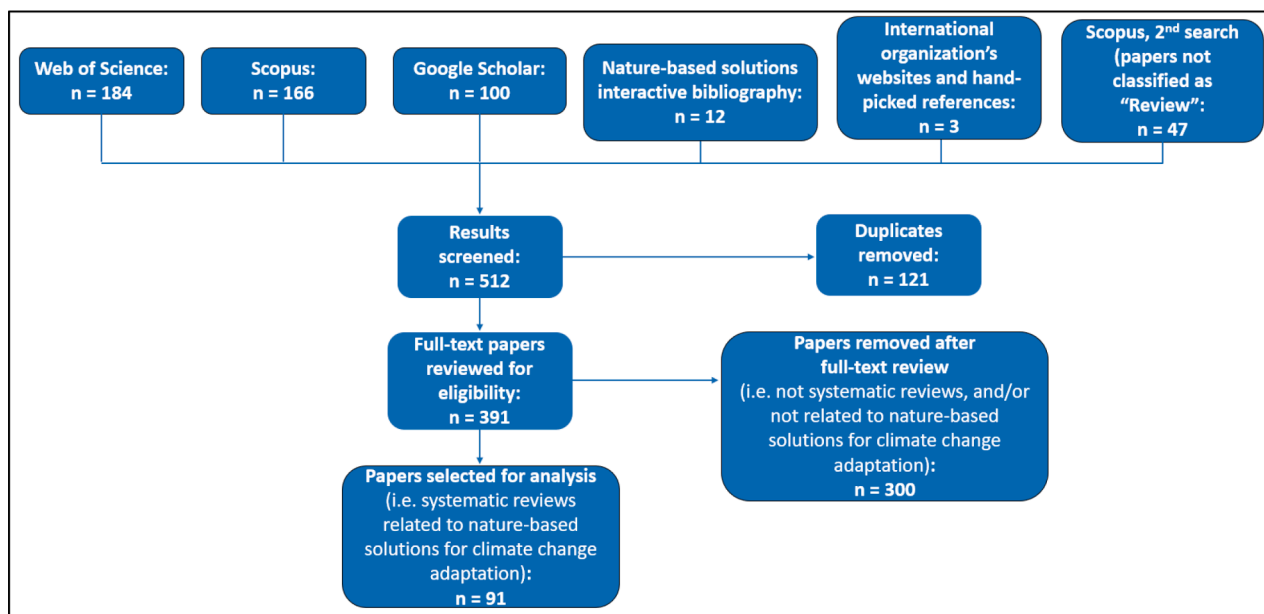


Fig. 1. Workflow of literature search and appraisal process.



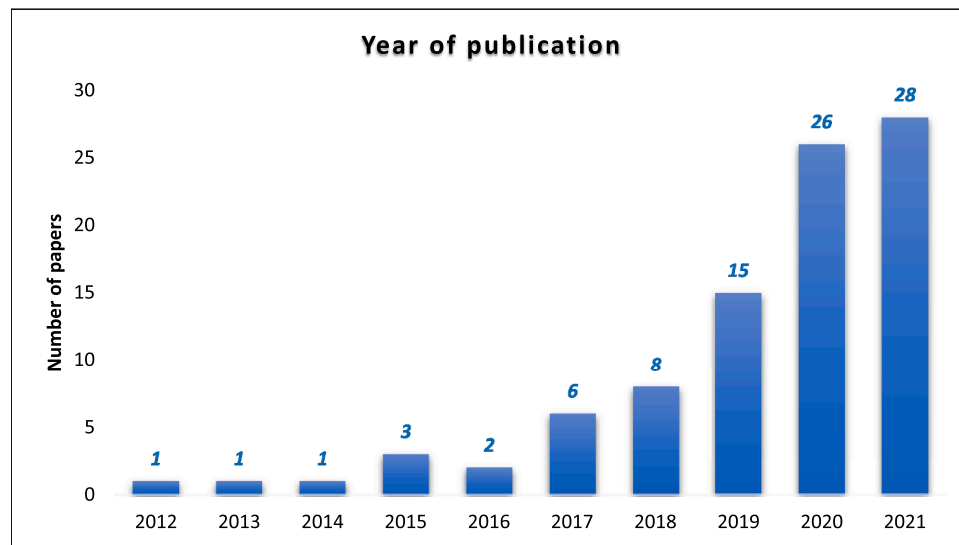


Fig. 2. Publication year of the 91 systematic reviews included in our analysis.

Table 3

Publication venue of the 91 systematic reviews included in our analysis. Italic text indicates journal names, and bold text indicates gray literature sources.

Publication venue	# of reviews	Publication venue	# of reviews
<i>Sustainability</i>	7	<i>Journal of Environmental Planning and Management</i>	1
<i>International Journal of Disaster Risk Reduction</i>	5	<i>Climate Change Economics</i>	1
<i>Environmental Science &amp; Policy</i>	4	<i>Natural Hazards and Earth System Sciences</i>	1
<i>Science of the Total Environment</i>	4	<i>Remote Sensing</i>	1
<i>Ambio</i>	3	<i>Building and Environment</i>	1
<i>Resources</i>	3	<i>Frontiers in Marine Science</i>	1
<i>Landscape and Urban Planning</i>	3	<i>Climate Services</i>	1
<i>Forest Policy and Economics</i>	3	<i>Environmental Research Letters</i>	1
<i>Journal of Environmental Management</i>	3	<i>Climatic Change</i>	1
<i>Land Use Policy</i>	3	<i>Ecology and Society</i>	1
<i>Journal of Cleaner Production</i>	3	<i>South African Journal of Science</i>	1
<i>Sustainable Cities and Society</i>	2	<i>Ecological Economics</i>	1
<i>Environmental Evidence</i>	2	<i>PLOS One</i>	1
<i>Water</i>	2	<i>Forest Policy and Economics</i>	1
<i>Global Environmental Change</i>	2	<i>Global Sustainability</i>	1
<i>Climate and Development</i>	2	<i>Global Change Biology</i>	1
<i>Environmental Research</i>	2	<i>Journal of Environmental Policy &amp; Planning</i>	1
<i>Climate</i>	2	<i>Regional Environmental Change</i>	1
Preprint servers	2	<i>Frontiers in Environmental Science</i>	1
<i>Marine Policy</i>	2	<i>Earth-Science Reviews</i>	1
<i>Pacific Conservation Biology</i>	1	Conference paper	1
<i>Science Communication</i>	1	Water Security	1
<i>Agriculture Ecosystems &amp; Environment</i>	1	Book Chapter	1
<i>Biological Conservation</i>	1	Project report	1
<i>Ocean &amp; Coastal Management</i>	1	Independent expert report	1
<i>Journal of Sustainable Forestry</i>	1	Student thesis	1

used in 31% of the reviews ( $n = 28$ ). Other peer-reviewed databases searched in multiple papers included ScienceDirect, PubMed, ProQuest, and individual university libraries/university databases. Of the reviews that used Google Scholar, about half ( $n = 13$ ) used it for searching only peer-reviewed literature (i.e. excluding gray literature based on the studies' exclusion criteria), and slightly more than half used it for searching both peer-reviewed and gray literature ( $n = 15$ ). In total, 26% of the papers included gray literature in their searches ( $n = 24$ ). Outside of Google Scholar, some of the gray literature sources searched included websites of key organizations involved in NBS-CCA, including the IUCN, Nature Conservancy, World Wildlife Fund, United Nations Convention on Biological Diversity, U.S. Army Corp of Engineers, and U.S. Environmental Protection Agency [15,37,38]. Workshop reports [39] and newspaper articles [40] were other sources of gray literature used in prior reviews.

The number of literature databases (or other literature sources) searched varied by study. 41% of studies ( $n = 37$ ) utilized one literature database/source, 25% of studies ( $n = 23$ ) utilized two literature databases/sources, and 34% of studies ( $n = 31$ ) utilized three or more literature databases/sources. 2% of studies ( $n = 2$ ) did not report which database(s) that they used (Fig. 4).

In general, we interpreted these results encouragingly, as nearly all systematic reviews reported which database(s) were used (a basic requirement for systematic review studies), and the majority of the systematic reviews involved searches of multiple literature databases (which is recommended for most types of systematic reviews). Searching multiple databases can help ensure that a wider range of literature is included in systematic reviews, as articles from a particular academic field may be lacking or underrepresented if only one database is searched [26]. Gray literature, however, seems to be underrepresented in the existing systematic reviews on NBS-CCA, especially considering the large amount of gray literature that reportedly exists on the topic. This may be due in part to the fact that, unlike with peer-reviewed literature, no consolidated database of gray literature on NBS-CCA exists. Google Scholar can successfully retrieve some gray literature, but it does not provide comprehensive coverage [36]. Thus, the process of determining where else to search for gray literature, e.g. which organizations' websites to include in the search, can be difficult to fit into the strict search protocol required for systematic reviews. For example, Munroe et al. [41] noted 26 different organization websites containing gray literature related to NBS-CCA as far back as 2012, and the number of websites containing this literature has likely grown significantly since then. This difficulty of searching for gray literature is not unique to NBS

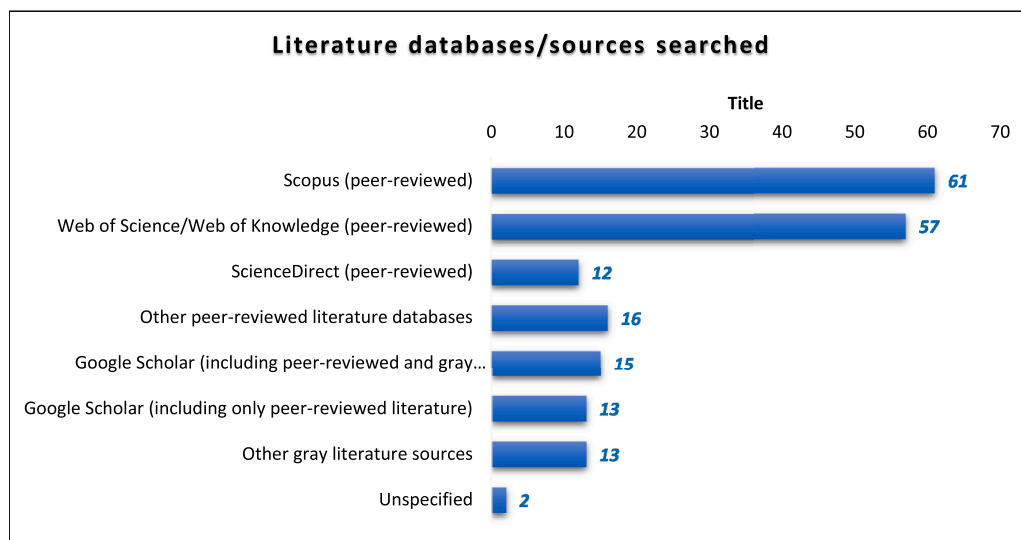


Fig. 3. Number of systematic reviews that searched different literature databases/sources.

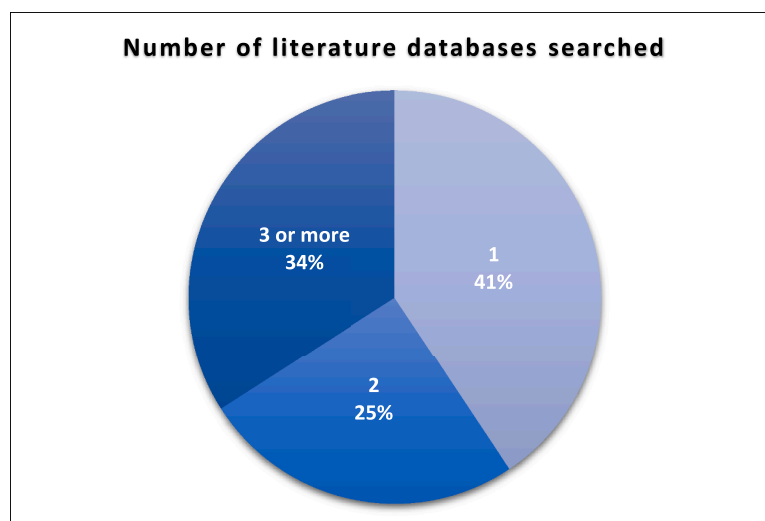


Fig. 4. Number of literature databases searched in prior systematic reviews on NBS-CCA.

research. Indeed, gray literature is also sometimes referred to as “fugitive literature” because of its elusiveness to reviewers [14]! Although some studies reported why gray literature had been excluded from their analyses, many studies did not provide any rationale for this exclusion. Despite the difficulty of retrieving gray literature, we suggest that future studies should strive to include it when at all relevant, e.g. by conducting secondary searches of Google Scholar and/or a few well-targeted organizations’ websites (depending on the scope of the paper), acknowledging that some relevant literature may be missed. Efforts to further consolidate the existing gray literature on NBS-CCA are also warranted to ensure that future systematic reviews are more comprehensive in terms of the gray literature included.

### 3.3. Geographic focus of prior reviews

After an initial screening of the papers included in our analysis, we found that their geographic focuses could be generally categorized according to the topographic conditions, types of land-use/land-cover feature(s), and/or the particular countries or regions that they investigated NBS-CCA within (Table 4).

From this categorization, we found that 38% of the prior reviews ( $n$

**Table 4**

Geographic context of prior systematic reviews on NBS-CCA. Land-use/land-cover features are categorized according to the Level I land-use/land-cover classification system of Anderson et al. [42] with the exception of “Rural areas, in general”, which contains a mixture of multiple types of non urban/built-up land-use/land-cover features.

Topographic focus	Land-use/land-cover features of interest	Other geographic focus
1 Coastal/marine areas (including urban and rural coastal areas)	1 Urban or built-up land, in general	1 Particular country, group of countries, or region of interest
2 Mountainous areas (including urban and rural mountainous areas)	2 Agricultural land, in general	
	3 Forest land, in general	
	4 Rural areas, in general	

$= 35$ ) focused their analysis on NBS located within a specific geographic context, while the remaining 62% of papers ( $n = 56$ ) did not have a specific geographic focus. Of the papers having a specific geographic focus, most dealt with urban/built-up lands ( $n = 15$ ) and coastal/marine

areas ( $n = 10$ ), as shown in Fig. 5. A few papers focused on agricultural lands ( $n = 4$ ) and mountainous areas ( $n = 3$ ), while forest lands, in general (i.e., rather than forests in a more specific geographic context, like coastal or mountainous areas) and rural areas, in general (i.e., rather than more specific types of rural areas, like agricultural or forest land) were focused on by two and one paper, respectively. It should be noted that many additional papers focused on forest and rural lands (alone, or in combination with other types of land-use/land-cover features) in more specific geographic contexts, e.g., studies related to NBS in coastal, mountainous, or agricultural areas. Seven papers focused on NBS-CCA within the context of a particular country, group of countries, or region. Of these, five papers had a focus on developing countries (individual countries, or on a group of developing countries), while the remaining two papers focused on the European Union. This focus on developing countries in prior reviews is significant because developing countries are known to be understudied despite having great potential for NBS [43,13]. Of the papers focusing on developing countries, two focused on Small Island Developing States [44,45], one focused on the Global South in general [46], one focused on the Hindu Kush Himalaya region [43], and one focused on Bangladesh [47].

In the urban/built-up land context, many NBS-CCA reviews focused their analysis on urban green and/or blue spaces, in general (e.g. Dorst et al., [12] and Pineda-Pinto et al., [48]); other reviews focused on a few particular types of urban vegetation and/or water features of interest (e.g., Brink et al., [49]); and four reviews focused on a particular type of urban vegetation, namely green roofs [50], green walls [51], and urban agriculture/urban gardens [52,53] (Fig. 6).

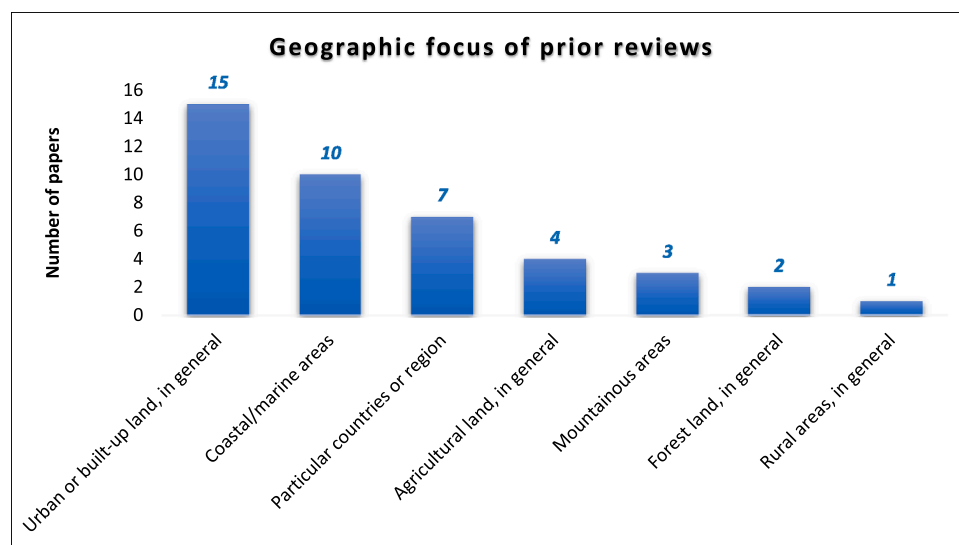
In the coastal/marine area context, several reviews focused on coastal adaptation, in general (i.e. also reviewing hard infrastructure measures), with NBS being included as one adaptation strategy [54,44]. Reviews focusing specifically on NBS-CCA in coastal/marine areas tended to focus on natural ecosystems, including mangrove, coral reef, seagrass, dune, and marine habitats [15,55,56] (Fig. 7). As a notable exception, Smith et al. [18] conducted a systematic review focusing specifically on living shorelines, a type of coastal ecosystem often composed of both natural (e.g. vegetation, shells, and/or rocks) and artificial materials (e.g. concrete), which is designed to protect the shoreline from coastal hazards (see Fig. 7 for an example). Gauthier et al. [57] reviewed various coastal NBS, and also focused on living shorelines (specifically, for protecting avian species from climate change impacts in coastal areas). Further investigations of other types of semi-natural

ecosystems could be one area of focus for future primary studies and reviews targeting coastal/marine areas. It should be noted that the reviews focusing on coastal areas included studies where the coastal ecosystems were located adjacent to/intermixed with many different types of land-use/land-cover features (e.g., urban/built-up, forest, or agricultural lands). However, most reviews did not specify all of the types of land-use/land-cover features present in the coastal studies they investigated. Thus, it was not possible to identify how many of these coastal studies were also focused on urban, rural, or mixed urban/rural areas. For the purpose of our analysis, we have counted all reviews focusing on coastal areas only once, i.e., as focusing on “coastal/marine areas” (rather than as focusing on other land-use/land-cover categories as well). That said, it is clear that the coastal/marine NBS-CCA measures presented in these coastal studies can also potentially benefit cities or rural areas located near the coastline.

Reviews focusing on agricultural lands focused on identifying NBS-CCA measures for smallholder farmers [58], on enhancing food production and livelihoods through the use of trees on farmland (either interspersed with crops or in spatially distinct patches) [59], and on evaluating the potential of urban agriculture/urban gardening as NBS [52,53]. Of the reviews focusing on mountainous areas, two focused specifically on NBS (e.g. protection forests) to help prevent gravity-driven hazards like landslides, avalanches, and rockfalls [60, 61], while one focused on a broader range of NBS in the Hindu Kush Himalaya mountainous region [43].

We also identified one review focusing on rural areas, in general, and two reviews focusing on forest lands, in general. The review focusing on rural areas, in general dealt with assessing the vulnerability-reduction outcomes of different NBS in the rural Global South [46]. Of the reviews that we identified focusing on forest areas, in general, one was related to payment for ecosystem services initiatives (specifically, payments for hydrological services) in the Brazilian Amazon [62], and the other was related to evaluating forest management practices that generate integrated mitigation and adaptation benefits.

Generally, we found it encouraging that prior reviews have focused on NBS in various geographic contexts, and that several different types of NBS were highlighted within many of these geographic contexts. Coastal and urban/built-up areas may have received particular attention in prior reviews due to the high level of climate change hazard in coastal areas and the high level of exposure to climate change hazards in urban areas (i.e., high population and built infrastructure). We also found it



**Fig. 5.** Number of systematic reviews focusing on different types of geographic areas. The number of papers shown is greater than 35 because some papers are counted twice (e.g. papers on Small Island Developing States are counted under both “Coastal/marine areas” and “Particular country or region”). The remaining 55 papers did not have a specific geographic focus.



Fig. 6. Examples of the types of environments investigated in systematic reviews focusing on urban/built-up areas.

encouraging that several reviews focused specifically on developing countries/regions. These countries/regions tend to be underrepresented in systematic reviews that have a global focus (due to fewer published studies on NBS in developing countries), and thus results of (meta-)analyses from global studies may also be biased towards the developed country context. Further reviews may also be warranted on NBS in other understudied regions, e.g., arid/semi-arid regions and inland lowland forested lands.

### 3.4. Research objectives of prior reviews

Next, we reviewed the research objectives of the 91 papers included in our analysis. From this, we found that the objectives of these papers could be generally categorized into eight different groups:

- i Papers that broadly reviewed many types and many aspects of NBS-CCA;
- ii Papers that reviewed a specific aspect of NBS planning/implementation;
- iii Papers that reviewed NBS within a specific geographic context (see Section 3.3.);
- iv Papers that reviewed one specific type of NBS;
- v Papers that reviewed another topic related to adaptation or ecosystems, but included NBS-CCA as one component of the review;
- vi Conceptual papers focusing on defining/framing NBS, EBA, and/or other similar terms;
- vii Papers focusing on reviewing particular models/tools for monitoring and evaluating NBS; and
- viii Papers which described systematic literature review protocol but did not conduct analysis of any literature (i.e. systematic review protocol registries).

Some papers were included in multiple groups, e.g., papers focusing on a specific aspect of NBS planning/implementation within a specific geographic context would fit in both Group ii and Group iii. Fig. 8 shows the number of papers belonging to each group.

From this categorization, we found that most systematic reviews on NBS-CCA had relatively narrow research scopes, with 53% of papers ( $n = 48$ ) focusing on a specific aspect of NBS planning/implementation (see Section 3.5. for a discussion of these reviews), and 5% ( $n = 5$ ) focusing on reviewing a single type of NBS (namely green roofs [50], green walls [51], allotment gardens [53], urban agriculture [52] and deculverting of urban streams [63]). 38% of the papers limited their review to a specific geographic area of focus (as already discussed in Section 3.3.), while 5% ( $n = 5$ ) focused on reviewing specific models/tools for monitoring and evaluating NBS.

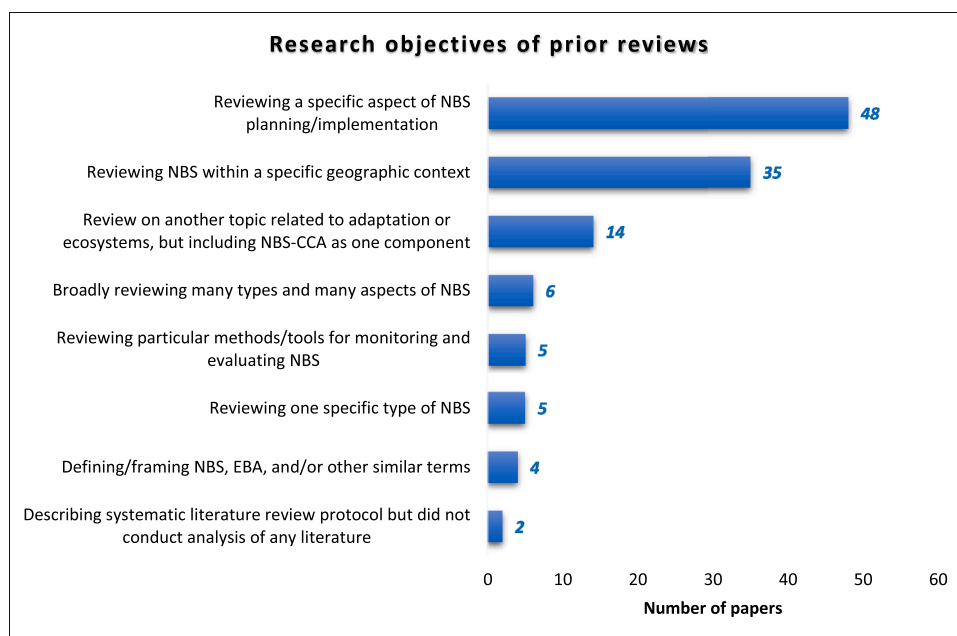
Aside from the studies focusing on specific contexts/aspects of NBS-CCA, 15% of papers ( $n = 14$ ) focused on reviewing another topic related to adaptation or environmental management, through which NBS-CCA was considered as one particular aspect or component (i.e., group v.). Many of these papers related to CCA measures/strategies in general, e.g., coastal CCA measures [54,44], and highlighted NBS as part of their analyses. Other papers related to CCA considered: decision support tools (e.g. cost-benefit analysis [64] or Bayesian Networks [65]), social impacts of adaptation measures (e.g. on gender equality [66]), environmental/social factors affecting the impacts of climate-related hazards [40], and climate change communication/engagement strategies like citizen science [67]. Aside from papers focusing on CCA issues, a few papers focused on ecosystem management issues, e.g. marine [68,55] or forest [69] ecosystem management.

Finally, 7% of papers ( $n = 6$ ) involved broad systematic reviews of many types and many aspects of NBS-CCA. We found that, unlike the systematic reviews having narrower research scopes, these broad systematic reviews tended to involve mainly narrative analysis of the





**Fig. 7.** Examples of the types of environments investigated in systematic reviews focusing on coastal areas. Living shorelines image courtesy of the Center for Coastal Resources Management ([http://ccrm.vims.edu/livingshorelines/photo\\_gallery/index.html](http://ccrm.vims.edu/livingshorelines/photo_gallery/index.html)), Virginia Institute of Marine Science.



**Fig. 8.** Number of systematic reviews focusing on eight different research objectives. Note: Some papers belonged to multiple groups listed in this Figure.

literature rather than quantitative meta-analysis [34,70–72]. Thus, they were quite similar to the traditional narrative literature review (see Table 2), with the principle difference being their use of a systematic (rather than opportunistic) approach for the literature search. Two of the broad systematic reviews that we identified did involve quantitative meta-analysis, but both of these reviews based their analyses on a relatively limited number of primary studies (31 papers in Cobb [73] and 54 papers in Parker et al. [74]), of which none came from gray literature sources. This was mainly due to their adoption of highly specific search queries to identify relevant literature; Cobb [73] searched Scopus and Web of Science using the query “ecosystem-based adaptation” (with or without hyphens), and Parker et al. [74] searched ProQuest Summons using the search query “nature-based solutions”. While all of these broad reviews mentioned are undoubtedly important for summarizing the general state of research on NBS-CCA, they each had some limitations with regards to either the types of analyses conducted (mostly narrative) or the amount and types of literature included (due to the literature search protocol adopted). Our intention here is not to criticize these prior reviews, but to highlight the challenge of conducting broad systematic reviews, e.g. finding a good balance between the type(s) of analysis conducted and the number of primary studies analyzed.

Indeed, the preference for focusing on relatively specific aspects of NBS-CCA in prior reviews, particularly in reviews involving quantitative meta-analysis, is likely due to the fact that the number of primary studies on the topic has grown so large as to make the systematic review process unmanageable for a small team of researchers to tackle broad research topics (e.g. a comprehensive review of all types/all aspects of NBS-CCA). This tendency for systematic reviews to adopt narrower research scopes is also common in other scientific fields, as it is more feasible to conduct a comprehensive search/appraisal of the relevant literature when the research question (and thus the amount of literature that needs to be analyzed) is narrower [23]. Nevertheless, our findings indicate that despite the large number of publications focusing on specific aspects or specific geographic subsets of NBS-CCA, a comprehensive understanding of the topic (i.e. based on an analysis of all of the available peer-reviewed and gray literature) is still lacking. While extremely challenging, it would certainly be possible to conduct such a comprehensive systematic review of NBS-CCA if a sufficiently large and diverse research team could be assembled. This would likely be a major international initiative, however, like a Thematic Assessment Report of the IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) or the IPCC, which can have hundreds of authors. NBS-CCA has received wide attention over the last decade, and is now being highlighted in global environmental agreements related to climate

change (e.g. Paris Agreement) and biodiversity conservation (e.g. Post-2020 Global Biodiversity Framework), so it may be timely to conduct such an initiative.

### 3.5. Aspects of NBS planning/implementation focused on in prior reviews

In this section, we provide more information on the papers belonging to Group ii: “Papers that reviewed a specific aspect of NBS planning/implementation”. After reviewing papers, we found that they focused on six main aspects, namely:

- barriers/enablers of NBS,
- public participation/engagement/education,
- monitoring/evaluation of NBS project outcomes,
- policy and governance issues,
- social issues, and
- private sector involvement

The most common aspect investigated was monitoring/evaluation of NBS project outcomes ( $n = 23$ ) (Fig. 9), and these papers mainly involved conducting analysis to understand the reported benefits/co-benefits/trade-offs of different types of NBS reported in primary studies ([13,75]; A. C. [47,37,76]); or on developing of new protocol for monitoring and evaluation of NBS projects (e.g. indicators or modeling frameworks) [77,35]. The second most common aspect investigated was policy and governance issues ( $n = 9$ ), and these papers focused mainly on the integration of NBS into relevant plans [78,56] and the identification of useful policy instruments to help promote NBS [79]. Papers focusing on public participation/engagement/education ( $n = 7$ ) investigated various topics including participation processes [80,81] and public perception of NBS [82,83]. Of the papers focusing on barriers/enablers of NBS ( $n = 5$ ), three focused the various types of social/physical/financial/knowledge barriers inhibiting greater adoption of NBS [84–86], while one focused on ecological barriers and enablers [87]. Papers focusing on social issues ( $n = 3$ ) were related to social/ecological justice [88,48] and social empowerment [38]. Finally, two papers focused on identifying the needs and willingness to contribute of different private sector agents in the planning and management of NBS [89,90].

We found that many of these reviews focusing on a specific aspect of NBS planning/implementation were related to urban/built-up areas. This is perhaps because urban NBS have particularly complex social and economic co-benefits and trade-offs that need to be carefully considered so-as to avoid adversely impacting a particular group of residents [91,66]. For example, if public urban greening initiatives (for the purpose of

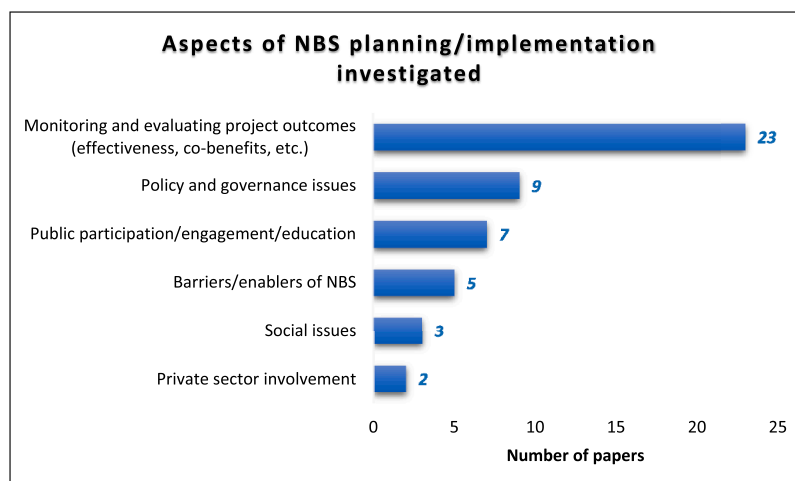


Fig. 9. Number of systematic reviews focusing on different aspects of NBS planning/implementation (limited to papers from Group ii).

NBS-CCA) are conducted favoring areas where residents are already relatively well off (e.g., high income housing areas), it may divert government funds that could be allocated to areas where disadvantaged or minority groups (which may have higher vulnerability to climate change hazards) live. These types of social and economic issues are also very important for the planning and implementation of NBS in rural areas, however, so future primary studies and systematic reviews related to these social/economic/environmental issues of NBS-CCA planning/implementation could also focus on rural areas in general, or in more specific rural contexts (e.g., agricultural or mountainous areas).

In general, our findings indicate that there is now much evidence available regarding NBS outcomes and policy/governance issues. This is quite encouraging, as evaluating and ensuring successful outcomes of NBS projects is critical for promoting their scaling up and wider adoption, while science-based policymaking/governance related to NBS is a critical factor to ensuring successful outcomes. Further systematic reviews related to social issues, barriers/enablers, and private sector involvement, however, may be warranted; All three are important aspects that need to be considered in the planning phase of NBS projects to ensure that the projects have successful CCA outcomes and do not exacerbate social/economic inequality [91,66].

### 3.6. Constraints of this study

Our overall objective in this study was similar to that of a mapping review (Table 2), so our systematic review protocol was also like that of a mapping review in that the level of comprehensiveness of the literature search was determined by the time restraints and the scope of the research question. The main constraint of our literature search was that it focused solely on systematic reviews that *self-identified* as relating to nature-based or ecosystem-based approaches/interventions, and this was a result of our defined search queries (see Section 2.1.). Our rationale was that these reviews were likely to be the most closely related to the concepts of NBS/EBA (i.e., the criteria listed in Table 1), so we decided to conduct a more detailed analysis of these reviews rather than a shallower analysis of a broader range of reviews (e.g. reviews related to other concepts/terms having similar meanings to NBS and EBA). This search constraint also served to reduce bias in our analysis towards a particular type of environment (see Section 3.3.), as some terms having similar meanings to NBS/EBA are mainly applied in a particular geographic context e.g., the terms “Green Infrastructure” or “Blue Infrastructure” in studies on urban/built-up areas [92]. Nonetheless, due to the existence of various terms that are closely or partly related to the “usage” of ecosystems/ecosystem services to mitigate climate (change) hazards, we should note that there are undoubtedly more reviews related to the topic of NBS-CCA than those that were identified and presented here.

## 4. Conclusions

In this study, we conducted a systematic review of 91 systematic reviews on the topic of nature-based solutions for climate change adaptation (NBS-CCA). We found the number of systematic reviews has been increasing significantly since 2017, and that reviews had been published in 45 different peer-reviewed journals as well as a few gray literature sources. This large (and growing) base of evidence for NBS-CCA is very encouraging, and is representative of a growing interest and increasing number of primary studies on the topic. Most systematic reviews entailed searches of the Scopus and Web of Science databases for relevant literature on NBS-CCA, with fewer reviews involving searches of other peer-reviewed or gray literature databases/sources (e.g. Google Scholar, institutional websites, or newspaper articles). Efforts to consolidate the gray literature on NBS-CCA, in particular, are likely needed to make it more efficient to search and include this type of literature in future systematic reviews, as the gray literature is currently scattered over a variety of different organizations’ websites.

The research scopes/objectives of the prior systematic reviews tended to be relatively narrow, with most focusing on a specific aspect of NBS-CCA projects and/or on NBS-CCA within a particular geographic context. The very detailed analyses conducted in these focused reviews have highlighted various types of NBS that have been analyzed or implemented in different geographic contexts, as well as important economic, social, and policy/governance issues related to NBS-CCA, which can help to guide future scientific efforts and policymaking on this topic. Of the prior reviews that focused on NBS-CCA within a specific geographic context, most focused on urban/built-up and coastal areas, possibly due to their high levels of climate change exposure and hazard, respectively. Of the reviews that focused on a specific aspect of NBS-CCA planning/implementation, most focused on monitoring and evaluating project outcomes (e.g. through meta-analysis or development of relevant indicators), on policy and governance issues, and on public participation and education. Fewer reviews focused on social issues, barriers/enablers of NBS, or the role(s) of the private sector, so further reviews on these topics may be useful to help inform the planning and implementation phases of NBS projects. Notably, very few systematic reviews focused on financing issues related to NBS. The availability of funding for NBS-CCA activities, one of the key barriers identified in prior reviews [85]), is still significantly lacking globally [93], so there is likely a need for further primary studies and systematic reviews on this topic to help enable the wider adoption and scaling-up of NBS.

Finally, while it is clear the prior systematic reviews have provided much valuable information on particular aspects and particular geographic subsets of NBS-CCA, a broad and comprehensive systematic review on the topic, i.e. including an analysis of all available peer-reviewed and gray literature, is still lacking. This is probably because the strict literature search and appraisal protocol that must be followed for systematic reviews, e.g., the need to conduct a comprehensive search of literature related to the defined research question, makes it very challenging to address broad research questions. Nonetheless, due to the high interest in NBS-CCA and its growing role in international environmental agreements, a large international effort may be warranted to conduct a comprehensive systematic review of NBS-CCA, e.g. an IPBES or IPCC Assessment Report on NBS-CCA.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

We have shared the data used in this article as a supplementary file.

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### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nbsj.2022.100042.



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