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*Review*

# Review on Urban Forests and Trees as Nature-Based Solutions over 5 Years

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**Abstract:** As human living environments face increasing challenges with resilience, the concept of nature-based solutions (NBS) was proposed in recent years as a way to promote sustainable living in urban environments. Urban forests and trees play important roles in urban ecosystems, while their potential as an NBS is promising. A bibliometric analysis was first conducted to explore the research pattern of NBS in urban environments. Studies of urban forest and tree-based green infrastructure in NBS research were further investigated using a systematic literature review method. The initial studies on NBS have increased since 2015 with 493 documents published from 142 sources in over 70 countries and regions. Keyword analysis showed green infrastructure had a rather high frequency of utility and received considerable attention. As for urban forests as nature-based solutions (UF-NBS) research, the most prominent study approaches used at different scales and the main benefits and typologies of urban forest studied in the articles were identified. UF-NBS research is still relatively scarce at present. Despite the role of urban forest and trees in addressing environmental challenges being well recognized, UF-NBS studies still need to be conducted in a more comprehensive context, taking social and economic aspects into account.

**Keywords:** bibliometric analysis; urban forest; green infrastructure; green spaces; nature-based solutions; ecosystem services



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## 1. Introduction

Human living environments are facing more and more severe challenges at present, including desertification, drought, land degradation, freshwater scarcity, loss of biodiversity and climate change, which collectively pose one of the greatest challenges for human beings [1–7]. Nowadays, 54% of the world population lives in cities, a number which is expected to rise to 70% by 2050 [8]. Therefore, increasing livability in cities and communities has become a key global priority [9]. The concept "nature-based solutions" (NBS) first appeared in the early 21st century and has been widely used in research on climate change [10]. The NBS concept grew over the past decade and has further been vigorously promoted by prominent organizations such as the Nature Conservancy and the International Union for Conservation of Nature [11,12]. In Europe, NBS has also become a priority area of the EU Horizon 2020 vision, involving biodiversity and ecosystem services [13]. More recently, greening and re-naturing cities are keywords of the EU Biodiversity Strategy for 2030. European Commission calls on European cities of at least 20,000 inhabitants to develop ambitious "Urban Greening Plans" by including the promotion of green infrastructure, nature-based solutions, and by planting at least 3 billion additional trees in the EU by 2030 [14]. NBS has received increased attention in more countries and regions worldwide in recent years, such as NBS studies in the USA on air improvement, stormwater retention,

coastal protection and so forth [15–17], China has also carried out design and planning referring to NBS to improve resilience of the cities, "sponge cities" are created to deal with flood risk [18,19].

Since NBS is relatively new, an overall accepted term is missing due to the broad framework of its use, thus the meaning of NBS is vague and has not been clearly defined [20–22]. The latest definition from the European Commission defined NBS as solutions that "are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" [23]. There are also some mainstream definitions besides the EC definition of NBS, for example, the International Union for Conservation of Nature (IUCN) considers NBS as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits" [24]. The concept of NBS can be generally broad, since a number of research papers have defined NBS differently, it can be understood as a metaphor or an umbrella concept, and the practice of NBS emphasizes the knowledge of various disciplines and research fields to achieve sustainable development goals and also requires the stakeholders and the policy-making to combine NBS implementation with the local situation, and to consider the natural and cultural contexts that include traditional, local and scientific knowledge [25–28]. In addition, NBS can improve the biodiversity of urban ecosystems and be used to solve the problem of reintroducing natural processes and functions into the built environment in order to restore, reconstruct or recreate nature in the artificial landscape [29,30]. Thus, NBS are increasingly being adopted to guide the design of resilient landscapes and cities, enabling them to achieve economic development goals and bring environmental and social benefits.

The concept of NBS is closely related to and builds upon concepts such as sustainability, resilience, blue and green infrastructure, and ecosystem services. The concept of ecosystem services has been widely used in urban areas over the past several decades prior to NBS appearing [31–34], and it has been published in the Millennium Ecosystem Assessment [35]. A nexus of urban forests and green infrastructure and NBS is occurring [21]. As an important part of green infrastructure, urban forests provide various kinds of ecosystem services for the built environment, as well as other social and economic benefits [36–39].

The relationship between the urban forest, green infrastructure, ecosystem services, and NBS is closely connected. The four terms often appear alternately in the research on urban forest ecosystems in the context of NBS. As part of the green infrastructure [40], the urban forest plays a vital role in improving urban ecosystems resilience and offers diverse welfare for citizens. Ecosystem services were considered an indispensable consideration and closely related to NBS [41]; by implementing a series of measures in NBS, urban forest and trees can be more resilient and sustainable, thus providing better ecosystem services for human beings. Compared to ecosystem services assessment, NBS applications have expanded to include, in particular, applications that address a range of initial and increasingly serious urban environmental, socio-political, and ecological challenges [21].

NBS are considered to be a broader notion than green infrastructure, a useful guide for developing these, and they also rely on the benefits they provide [27,40,42]. NBS have the focus and immediacy that green infrastructure lacks for solving problems [43]. The concept of NBS covers broader ideas and 'nature-based' views, and it is solutions oriented towards environmental challenges, which can be severe [40]. NBS have the ability to improve the ecosystem service provided by green infrastructure in solving urban problems [27], can be used to better guide the management of urban forests to mitigate climate change, and used to properly maintain existing green infrastructure [2,43].

As an important part of green infrastructure, urban forests provide various kinds of ecosystem services for the built environment, contribute to human wellbeing and bring economic value for society [36–39]. Unlike the relatively new status of NBS, urban forestry

and the use of trees in society has had a long history since thousands of years ago in the Middle East region [44]. Urban forestry as a formal definition first occurred in 1965 and built upon the concept of shade tree management (e.g., the care of trees in communities) that was advanced in North America over several centuries [44,45]. It has evolved as a discipline that integrates the management of social, economic, and ecologic science. The urban forest has been described as "the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan areas" [46]. Urban forestry research in recent years has expanded into the following aspects: cultural ecosystem services and ecological benefits provided by urban and peri-urban green infrastructure [47–50], planning and management of urban forest [51,52], quantifying urban forest structure [53,54], and improving urban environments [7,55,56]. The urban forest is part of the green infrastructure and has been increasingly used and studied over the past several decades [46], and studies often use the concept of ecosystem services to identify the contribution of urban trees and urban forests to human welfare.

Research into urban forests as a nature-based solution shows promise and appears to be increasing. Protection from flooding and soil retention/restoration issues are two examples [6,57–63]. Blue and green infrastructures are considered as effective NBS to reduce storm induced flooding at least partially in urban environments. Versini et al. [64] demonstrated that if blue and green infrastructure were widely used, the infrastructure combination could reduce stormwater runoff by 90 percent. However, the potential use of urban forests in NBS is relatively unknown by decision makers, managers, and practitioners, and urban trees are often undervalued and underused as an NBS approach. To lay the groundwork of our study, we use the concept of urban forests as nature-based solutions (UF-NBS) proposed by CLEARING HOUSE project, the project is funded by the European Union's Horizon 2020 Research and Innovation Program, and the focus on addressing global challenges in European and Chinese cities in their request to develop more resilient and livable cities. The CLEARING HOUSE project defined UF-NBS as "a subset of nature-based solutions that build on tree-based urban ecosystems to address societal challenges, simultaneously providing ecosystem services for human well-being and biodiversity benefits" [65]. Therefore, we consider urban forest in our research as all urban and peri-urban forests, including forested parks, trees in public and private spaces, green spaces that include forest and trees and tree-based green infrastructure. Despite research and practice on NBS increasing in recent years, few studies have focused on urban forests and trees in the context of nature-based solutions. To better implement UF-NBS in cities, we need to further understand the role of urban forests as NBS in cities, and current trends in UF-NBS research.

Therefore, the aim of this article is to identify the current place and potential of urban forest as well as tree-based green infrastructure, which are the basis for UF-NBS, in nature-based solution research based on a literature review [65]. To be more specific, the study has three objectives. First, to explore a brief research pattern of NBS studies and understand the current place of urban forest in the NBS research field. Second, this study explored the UF-NBS related articles to analyze the research area and methods at different spatial scales. Third, to delineate the most frequent benefits and urban forest types studied in UF-NBS research. By analyzing the related literature, we discuss the main findings of urban forest and tree studies in the context of NBS critically, and put forward the future expectations of UF-NBS studies.

## 2. Materials and Methods

In this study, bibliometric analysis was first used to quantify NBS research, its development, and to identify related trends. This method has been commonly used to study the development process of an academic research field, explore current research hotspots, and predict future research directions [66]. Research and applications of urban forest and tree-based green infrastructure in the context of NBS were further investigated using a systematic literature review.

The process of literature searching was conducted according to the PRISMA flow diagram [67], shown in Figure 1. The Web of Science (WOS) was used since it is one of the most inclusive and largest worldwide-used academic databases containing comprehensive formats and uniformed citation information crucial for this study [68,69], and it was also recommended by most bibliometric analytical software. ScienceDirect and Google Scholar were used to search for missing significant papers using the same search criteria used in WOS. During January 2021, we searched for all published articles and reviews from the past two decades (2000 to 2020) in the Web of Science core collection database using the following search term: TS = "nature-based solution*" OR "nature based solution*" OR "nature-based-solution*" as the research topic (title, abstract, and keywords). We did not focus on the research specifically in cities at first, to better explore the articles that actually study urban forest and trees as NBS in the further analysis. The language of the literature included all languages. The downloaded data were saved in a text format. Each bibliographic record in SCI contains the author, title, source, abstract, and keywords defined by the Web of Science.

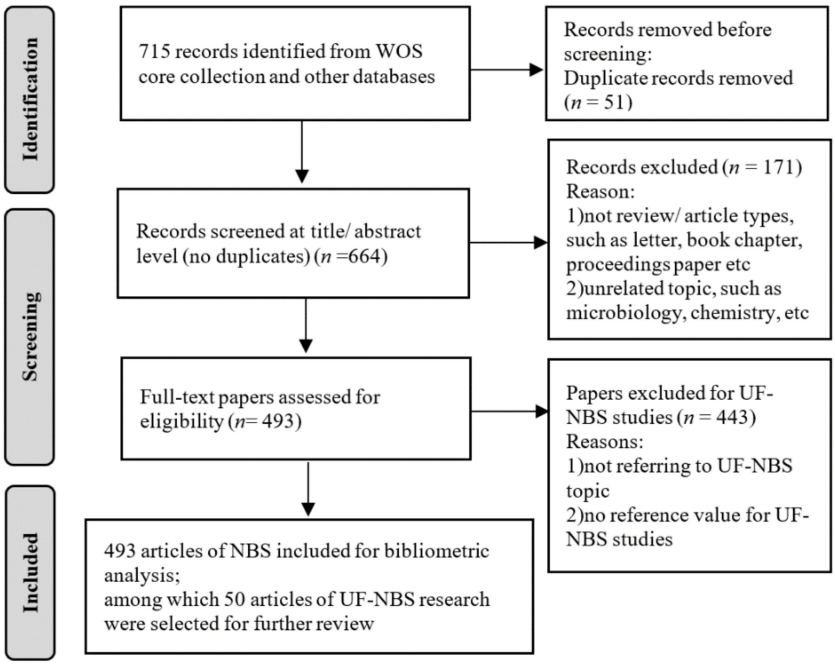


**Figure 1.** The literature selection process inspired by PRISMA flow diagram.

A total of 715 records was identified from the database. After an initial review of the yield results of the articles by reading their titles and abstracts, publications (e.g., letter, book chapter, proceedings paper), a lack of essential information for bibliometric analysis such as keywords, and studies not related to NBS were excluded from the review, a total number of 493 documents was included for NBS development investigation. The language of the searched documents was all written in English. The research pattern of NBS studies was quantitatively analyzed using bibliometric indicators. Since keywords can be understood as the key of research articles, they are representative for research purposes, the methodologies and concepts of articles [70]. Therefore, keyword analysis was used as a method to map the patterns of NBS research. The analytical and visualization software approach includes HistCite 12.03.17 [71] and CiteSpace V (Drexel University, Philadelphia, PA, USA). The text files from the downloaded literature were imported into Histcite 12.03.17 and CiteSpace V to analyze the selected literature. First, Histcite was used to analyze the main information of NBS publications from the Web of Science core collection from 2015 to 2020, these main information variables were publication year, the number of authors, sources, cited references and the annual production (the number of publications every

year), also the top 10 most related countries (as entered in the address field of the articles recorded in Web of Science, each article may have over one related country) were listed. The year 2015 was the first year with reference to NBS. Then the text files were imported into CiteSpace V to identify the trends and hotspots of the research using co-occurrence of the keywords analysis. The CiteSpace burst detection function was also used to detect abrupt changes in the number of references and other types of information over a certain period of time [72].

To further analyze UF-NBS studies, articles that discussed urban trees in the NBS context were selected from the 493 documents mentioned above. Then, documents were screened according to their titles and abstracts and articles were excluded if they were not related to the UF-NBS topic. For the remaining papers, full texts were then retrieved and assessed for eligibility. Study contents that contained urban and peri-urban forests, forested parks, trees in public and private spaces, green infrastructure that includes forest and trees were all considered. Studies that only marginally referred to the term and have little reference value for UF-NBS studies were excluded. In total, 50 documents were selected for this review part. The geographical distribution of UF-NBS studies was analyzed based on the case study location. We also identified the spatial scale at which the study was done and methodological approaches used, the urban forest type used in study, and detailed benefits provided by them. This entailed reading the articles in full, extracting information from them, and classifying them according to the different defined categories mentioned above (Table 1). The classification items used were not pre-determined but rather extracted from the articles, for example, the "urban forest type" used in our analysis refers to the specific research objects in different studies. We did not classify the categories in advance, to avoid bias from predetermined and unsuited categories that are insensitive to the article content.

**Table 1.** Categories and themes that were defined for analyzing the selected UF-NBS articles.

| Classification Items | Categories |
| --- | --- |
| Scale | Global<br>Multinational<br>National<br>Regional<br>Local |
| Methods | Literature review<br>Field research<br>Spatial analysis (GIS/remote sensing)<br>Social survey (questionnaire/interview)<br>Model and simulation<br>Statistical methods<br>Planning/framework design |
| Typologies | Urban parks<br>Green blue infrastructure<br>Green infrastructure<br>Urban gardens<br>Urban forest<br>Concave green land<br>Urban trees<br>Green space |
| Benefits | Environmental benefits<br>Social benefits<br>Economic benefits |

## 3. Results

### 3.1. Bibliometric Analysis of NBS Research

#### 3.1.1. General Statistics of NBS Studies

The main information variables about NBS research publications and the number of publications are found in Table 2 and Figure 2. A total number of 493 NBS documents from 142 sources were published with 2389 authors, mostly (99.2%) as multi-authored documents (Table 2). The first publication about NBS in the WOS database appeared in 2015, and the number of articles has increased over the years. There were few studies on NBS for the first two years (from 2015 to 2016), and then NBS research experienced a development period from 2017 to 2018, when the number of annual publications reached over 50. During the last two years, there was an apparent increase with over 100 and 200 documents published in 2019 and 2020 respectively (Figure 1).

**Table 2.** Main information of NBS publications from the Web of Science between 2015 to 2020.

| Main Information Variables | Statistic (No.) |
|---|---|
| Timespan (Year) | 2015 to 2020 |
| Sources (Total No. of Journals, Books, etc.) | 142 |
| Documents (Total No.) | 493 |
| Authors (Total No.) | 2389 |
| Single-authored Documents (Total No.) | 20 |
| Cited References (Total No.) | 28935 |
| Countries (Total No.) | 79 |
| Language | English |

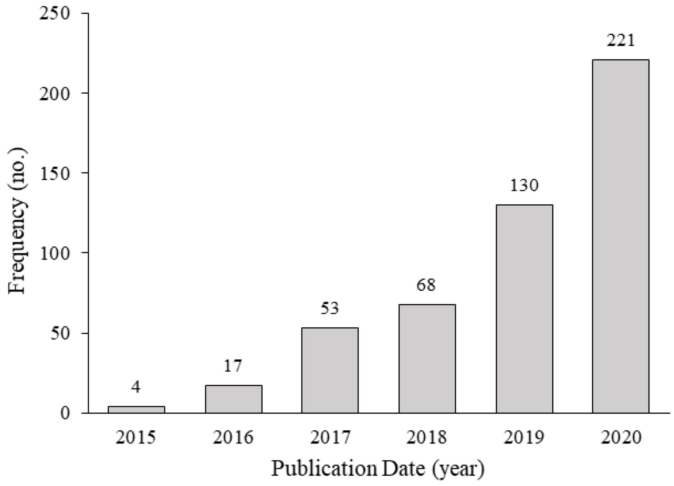


**Figure 2.** The change in publication frequency over time from 2015–2020 as recorded in the Web of Science for the keyword nature-based solution.

Over 70 countries and regions had NBS publications within a location, indicating a wide range of distribution in the NBS research field (Table 3). As shown in Table 3, the UK ranked first in terms of research output with 99 publications, followed by Italy with 88 publications. Germany and the USA ranked third with 70 publications. Netherlands, Spain and Sweden associated researchers also published over 50 documents, with 66, 57, 54 papers, respectively.

**Table 3.** The 10 countries most commonly associated with NBS.

| Country | Publications (No.) |
|---|---|
| United Kingdom | 99 |
| Italy | 88 |
| Germany | 70 |
| United States of America | 70 |
| Netherlands | 66 |
| Spain | 57 |
| Sweden | 54 |
| China | 46 |
| France | 39 |
| Australia | 37 |
| Total | 626 |

### 3.1.2. Research Keywords Analysis

This study analyzed the keywords most related to NBS articles (Figure 3). The purple rings indicate the betweenness centrality of the keywords, which represents the great transformation potential of a scientific contribution [72]. Keywords like environmental studies, ecology, water sources and urban studies show NBS studies involved with various kinds of subjects. The most frequent keywords appearing in NBS articles were nature-based solution, ecosystem service, climate change, management, green infrastructure and city. Among them, the nodes of climate change, management and city had purple rings, which represent these topics receiving constant attention from researchers. Although the nodes of conservation, pollution, air pollution and risk were relatively small; their purple rings indicated high betweenness centrality. This representation reveals the development of NBS research focus.

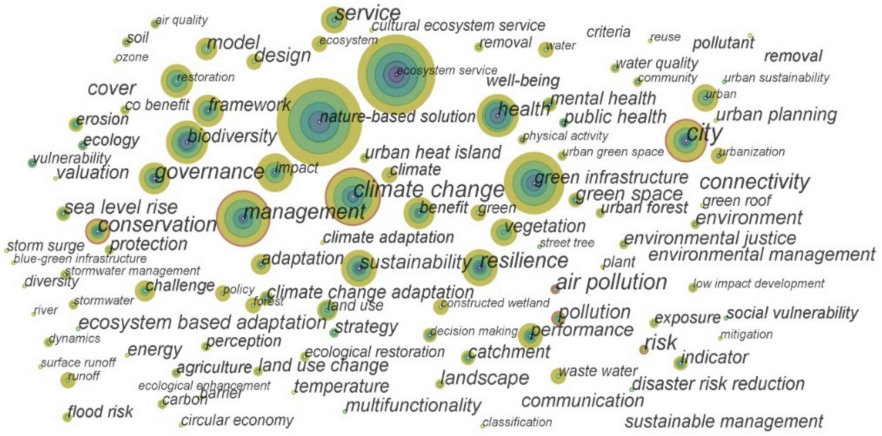


**Figure 3.** Major keywords of nature-based solution research. The size of the node represents the frequency of keyword occurrence.

Keywords related to UF-NBS studies were green infrastructure, green space, urban forest, street tree and so forth, among which green infrastructure was used at the highest frequency, reflecting it received much more attention from researchers than other terms.

### 3.1.3. Emerging Trends

Figure 3 displays the 20 most common keywords with the strongest citation bursts since 2015. A burst is detected through two attributes, strength and duration [73]. The red line segment of the column means the time period of burst detections of the keywords. For example, biodiversity, green space, valuation, behavior, conceptual framework and so forth were early on keywords showing the strongest citation burst in NBS research (Figure 4). More recently, the citation burst of keywords into 2020 were street tree, opportunity, multi-

functionality and disaster risk reduction as hotspots in NBS. Health, biodiversity, green infrastructure, strategy, green space and sustainability had the strongest burst strengths of over two. UF-NBS studies' related keywords such as green spaces experienced a burst earlier than others, and had a relatively high strength. Green infrastructure exhibited the highest strength of 3.02 from 2017 to 2018. Hence, researchers had a high tendency to focus on green infrastructure in UF-NBS studies during this period. Street tree became a new interest of research from 2017 to 2020, while the strength is not high.


**Figure 4.** The 20 most common keywords with the strongest citation bursts since 2015. The short red lines represent the time period of burst detections.

### *3.2. Studies on Urban Forest as a Nature-Based Solution*

#### 3.2.1. Research Area Distribution

Articles that first referred urban forest/green infrastructure and nature-based solutions simultaneously appeared in 2016, with a total of 50 found through 2020. The distribution of urban forest related NBS research is shown in Figure 5 (based on the case study location). Twenty three research countries were found in total, and the majority of the studies were from European countries. Italy ranked first in terms of the highest number of research output with eight articles (16.3%), followed by the UK and Portugal with five papers (10.2%). The USA and Spain had the same number of publications (four articles, 8.2%).

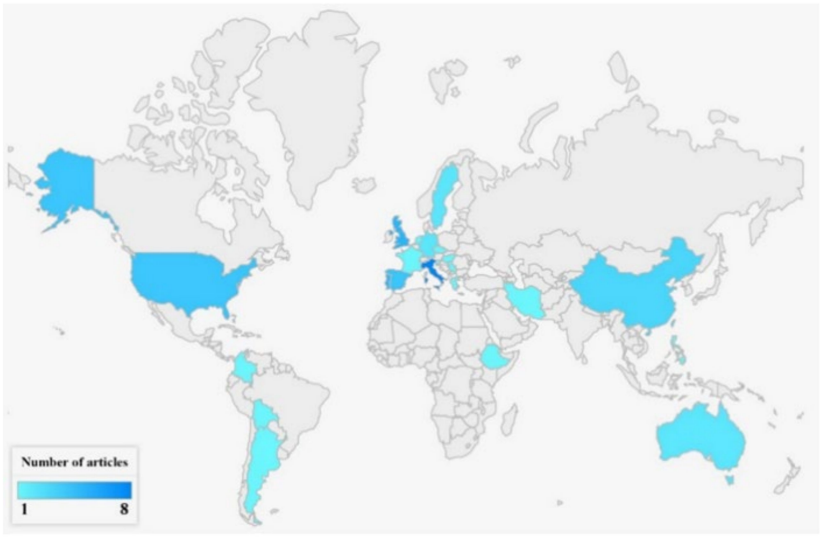


**Figure 5.** Geographical distribution of UF-NBS research countries (based on the case study location).

#### 3.2.2. Research Method Used in UF-NBS Research at Different Scales

Different methods used in UF-NBS research were reviewed at different scales (i.e., global/multinational/national/regional/local). Both qualitative and quantitative research methods were used for UF-NBS studies (Table 4). Some of the studies had more than one research method typology, but the most frequently used were models and scenario simulation, literature review, social survey and statistical methods. Over 65% ($n$ = 37) of the studies were conducted at a local scale, few studies (six articles, 10.7%) were carried out in different countries to make a cross-case comparison, and most (eight articles, 14.3%) of the literature review was analyzed from a global perspective. The largest number of articles used quantitative methods to study the role and impact of urban forests and green spaces on urban environment and human beings, thus providing guidance for the implementation, planning, design and management of UF-NBS.

**Table 4.** Typologies of research methods and research scales in analyzed articles.

| Methods | Local Scale | Regional Scale | National Scale | Multinational Scale | Global Scale |
|---|---|---|---|---|---|
| Literature review | 1 | - | - | 1 | 8 |
| Field research | 3 | - | 1 | - | - |
| Spatial analysis (GIS/remote sensing) | 4 | - | 1 | 1 | - |
| Social survey (questionnaire/interview) | 7 | 1 | 1 | 1 | - |
| Model and simulation | 12 | 1 | - | 2 | - |
| Statistical methods | 7 | - | - | - | - |
| Planning/framework design | 3 | - | - | 1 | - |

#### 3.2.3. Typologies of Urban Forest and Benefits Related with UF-NBS Research

Different typologies, ecosystem services and benefits that were provided by urban forest and green infrastructures are shown in Table 5. Some research studied one type of ES or benefit, while some studied more than one typology. Regarding the types of urban forest referred to in the studies, despite trees all being included in the literature, the scope and forms varied. Broader research areas such as greenspaces and green infrastructure were studied, and more specific ones such as urban trees were also referred to in the studies. Compared to social and economic aspects, research on environmental aspects was

the most prevalent concern of researchers, involving multiple areas including air quality improvement, cooling effects, water management, and climate regulation.

**Table 5.** The typologies of urban forest and presence of benefits in analyzed papers.

| Types of Urban Forest [1] | Environmental Aspects | Social Aspects | Economic Aspects |
|---|---|---|---|
| urban parks | 5 | 4 | - |
| green blue infrastructure | 5 | 1 | - |
| green infrastructure | 12 | 5 | 3 |
| urban gardens | 1 | 3 | - |
| urban forest | 4 | 3 | 1 |
| urban trees | 4 | 1 | - |
| concave green land | 1 | - | - |
| green space | 4 | 5 | - |
| not mention | 8 | - | - |

[1] The research objects (i.e., the types of urban forest counted in this study) of the UF-NBS studies are all tree-based or contain tree elements, others are excluded from our study.

Most of the articles focused on ecosystem services and benefits provided by urban forests to address environmental or social challenges, such as flood and stormwater reduction ($n$ = 8), urban heat mitigation ($n$ = 6) or health and wellbeing promotion ($n$ = 9); only a few articles referred to the economic benefits in their research ($n$ = 4). As for social benefits, human health was the main focus of researchers, and it was often assessed through social survey methods and literature reviews. The impact of urban forest and GI on psychological/mental health ($n$ = 9) has received more attention from researchers than physiological health ($n$ = 4), including dementia, ego depletion, depression, anxiety, stress and so forth. A small number of studies have focused on the relationship between urban forests and the health of different age groups, while other social issues, such as recreation and social cohesion, have received very little attention in UF-NBS studies.

## 4. Discussion

This study first had a general review of NBS since 2015 to better understand the current pattern of NBS studies and the place of UF-NBS research based on 493 articles, and then examined the 50 UF-NBS studies from NBS research papers to explore the approaches used to investigate urban forest and trees as NBS at different scales, and what typologies and benefits were found in the literature.

### *4.1. Research Pattern of NBS in Recent Years*

The research occurrence of NBS worldwide grew annually from 2015 to 2020. According to the report of Eggermont et al. [74], the concept of NBS was first used in the early 2000s as part of the integrated action on climate change mitigation and adaptation, biodiversity conservation and sustainable livelihoods. In 2015, NBS was listed as a priority area in the EU Horizon 2020 research program, involving biodiversity and ecosystem services [13]. Therefore, policy support may have led an increased number of researchers to focus on the NBS research field and test postulated ideas. As for the countries that published relevant literature, European countries make up the majority of total publications, the USA was most prolific in North America and China produced the most NBS literature among Asian countries. Other countries outside Europe have few studies on NBS, besides, current NBS studies were conducted mostly in developed countries, while developing countries are still lacking in related research [68].

Research in NBS was most common within the environment field. In addition, the keywords nature-based solution and ecosystem services occurred most frequently, indicating the extensive use of the concept of ecosystem services in the analysis of NBS studies to identify various benefits provided by NBS. NBS most recently received increased attention from researchers in improving urban environments and providing health benefits for citizens, and green infrastructure plays a vital role in achieving the purpose. Although the number

of UF-NBS studies occupy a relatively small proportion of total NBS articles, our keyword analysis shows that green infrastructure is one of the most frequently used keywords and the citation burst analysis also indicates that researchers have a high tendency to focus on urban forest related content recently. As urban forests and urban parks were found to be among the most important types of urban green infrastructure studied in previous studies [48,70], it is essential to have a further investigation into studies focused on urban forest and trees as nature-based solutions.

### 4.2. The Analysis of Urban Forests and Trees in UF-NBS Studies

By summarizing the existing case studies of urban forests as NBS, this review found that UF-NBS studies mainly focused on the role of urban forests and their potential to address environmental problems, including identifying the functions of urban forests and GI, and the ecosystem services or disservices (e.g., allergenic, greenhouse gasses emission, tree risk) or benefits they provide [75–79]. While less attention has been paid to the impact of urban forests on economic and social issues such as physical health and social contact for people [4].

Most UF-NBS studies, which focused on the environmental issues and conducted their analysis using quantitative methods, and some specific indices were used to quantify the environmental functions of urban forest, such as PM10 removal capacity for air quality evaluation [75,79]. In regard to the social aspects of UF-NBS studies, such as human health, researchers used social surveys or interviews among citizens, professionals, or local stakeholders [1,80,81]. The use of GIS and remote sensing data has become an effective way to analyze the distribution and temporal and spatial change of research objects such as urban trees [82–84].

As for the analysis tools, various models and scenario simulations in different areas to study urban forest and green infrastructure as NBS were commonly used by researchers, especially in the application of water management, including built hydraulic scenarios through various models and simulations [17,19,64,85–89]. In addition, some meteorological and energy balance models such as ENVI-met and function models like i-Tree were used to quantify the climate regulation functions and carbon sequestration of urban forests [2,90–93].

Differences were also found within research scales. Studies were conducted at local scales most frequently, which were suitable for modelling and statistical methods with local surveys. As for a multinational scale, researchers often made cross-case comparison in different countries, or aimed to develop site-specific principles and planning at the local level [26,82,88,94]. Three case studies were conducted in England and Germany where biodiversity-led green infrastructure was embedded into cities, and explored the incorporation of multifunctional design into planning and policy development [94]. However, studies conducted over one city or over one country are still scarce. More comparative studies are needed to enrich the research analysis. While European countries lead in the number of articles published in the world, there is a relatively low article output in Eastern Europe countries.

### 4.3. The Typologies and Benefits Provided by Urban Forests and Trees in UF-NBS Studies

Our study showed that environmental benefits provided by the urban forest and trees were assessed by most UF-NBS articles with quantitative methods. Fewer studies assessed social benefits, and most of them were focused on human health (especially mental health), and economic benefits were evaluated with the lowest frequency. These findings were consistent with the results of Li, Cheshmehzangi, Chan and Ives [68]. Green infrastructure was the type that was most used in studies, and some studies further indicated the specific research objects such as urban forest and trees, or trees and green roofs as green infrastructure [86,95].

Studies revolved around the influence of urban forests on the urban environment and drew the conclusion that urban greenspace or blue and green infrastructure had a

positive effect on urban hydrology, $CO_2$ mitigation, urban heat reduction and climate adaptation [78,85,91,92,94,96–99]. Researchers also showed that the urban forest and trees can improve air quality through pollutant removal, such as PM10 [75,79]. However, it should be noted that the effects of green spaces are not all the same for the provision of air purification; some green infrastructure could promote an increase of air pollutants [100]. In general, articles focused on the relationship between urban natural environments and public health found that urban green space had a positive effect on both physical and mental health as well as human wellbeing [1,81,101–105], while Kabisch, et al. [106] found that the impact on children and on elderly health remain uncertain. A few studies discussed the importance of urban forest ecosystem management and put forward advantages and disadvantages of current management [26,77,107]. It is essential to note that the design and planning of NBS should consider not only the benefits and ecosystem services provided by urban forest and trees, but also the potential disservices they could bring. Studies in Spain and Germany found that there was a high percentage of allergenic tree species in some parks and residential areas, which could be harmful to citizen wellbeing [76,108]. Therefore, the implementation and management of NBS must be considered in comprehensive ways to maximize the ecosystem services and benefits, and to reduce the disservices.

### *4.4. Opportunities and Challenges for Future Research*

Our study reviewed the general development of NBS studies and a comprehensive analysis of UF-NBS articles. While there are still some limitations in this research, the extensive Web of Science core collection database contains mostly English language literature, and the analyzed articles are not exhaustive. For example, Urban Forestry and Urban Greening (UF & UG) is not included in WOS before 2009 and the Journal Arboriculture and Urban Forestry (AUF) is not indexed to date. Still, a large number of the main relevant journals have been indexed in the WOS database and no articles were missed in UF&UG as no NBS papers in WOS occurred before 2015 and a review of all volumes and issues of AUF showed no NBS papers.

We can find some phenomena in UF-NBS research in terms of study methods, models and scenario simulations play important roles in assessing regulation of ecosystem services and addressing environmental issues, while local surveys and interviews were suitable for social studies such as human health and urban forest management. Although models are considered to be convenient, relatively comprehensive and cost-effective to solve various ecological problems, the long-term practical validation of UF-NBS studies is lacking, and most of the relevant studies have been evaluated without considering the economic value. For example, Wild, Henneberry and Gill [97] valued NBS for urban water management based on empirical studies over 10 years in Sheffield and other European cities and regions and found that, although citizens were willing to pay for greener options, the increased costs of the development of green infrastructure for private developers would exceed income. Furthermore, they emphasized the important role of governments and social organizations in developing and investing in green infrastructure as nature-based solutions. Hence, the long-term costs are often uncertain and require more comprehensive consideration of NBS implementation by stakeholders. In addition, in reviewing the methodology, we found that there is a gap in UF-NBS research with regard to the development of frameworks for implementation. It is also necessary to develop methods and indicators related to monitoring NBS efficiency and the capacity of providing ecosystem services and benefits over time. Several indicators and parameters related to environmental benefits, such as air, water and soil quality, provided by NBS in the urban areas have been proposed, and NBS themselves can also be considered as suitably designed monitoring stations within urban context [109]. Many UF-NBS studies refer to NBS only as a term, while few provide more comprehensive solutions, where the implementation of NBS should be based on its multifunctionality and co-benefits to achieve sustainability, rather than concentrating or focusing too much on a single benefit [20,88].

Current UF-NBS studies have increased interest in identifying the multiple environmental benefits of urban forests and trees, such as stormwater or flood regulation, air quality improvement, $CO_2$ sequestration, and urban heat island mitigation [2,86–88,100]. However, various conclusions about the impact of the urban forest and trees on air purification were found, and further mechanism studies are still needed to determine the specific effects of urban forest on air quality. As for social benefits, UF-NBS research often concerned the effect of urban green spaces on human health, especially on mental health improvement [1,81,102–104,106,110]. Although human health and wellbeing has been widely investigated and discussed by researchers in UF-NBS studies, more attention should be paid to some special group of people; some current studies noticed the health of different age groups [104,106], while more studies are needed on different groups of gender and ethnicity, physical and mental condition, healthy people and those with underlying health problems and other factors. Our findings also showed a gap in other cultural ecosystem services evaluation and social benefits in UF-NBS studies like social cohesion and community activities, which is similar to a previous review on NBS studies [68].

The study on UF-NBS research still needs to be more comprehensive, although there have been a certain number of articles that focused on understanding the potential of urban forests for addressing urban environmental issues, most of them remain difficult in translating the research findings into social and economic benefits. So far, a few studies on water and flood protection or UF management studies are relatively comprehensive in considering socio-ecological effects of NBS [42,77,83,89,96]. In addition, while urban forests have been considered to bring considerable economic benefits [111], there were few UF-NBS studies that consider economic assessment of the urban forest and trees [2,95–97]. If urban forests and trees are taken as NBS to address social challenges, then there is a need to evaluate the benefits in a more complementary way. Most research on heat mitigation and air quality improvement still needs to discover the linkages between ecological benefits and socio-economic ones.

Although the role of urban forests and trees, as well as green infrastructure, in improving urban resilience and human health is well recognized, there are still problems and challenges in practices and application. The successful cases of NBS in other aspects (such as land restoration and flood control, etc.) have valuable experience for urban forestry. For example, phytoremediation has been used to improve contaminated land [112,113]. So far, various kinds of new concepts and frameworks related to NBS are being developed [114–118]. An assessment framework for an urban forest ecosystem in the NBS context is needed as well, which allows managers and stakeholders to evaluate the operation of urban forests comprehensively (in environmental, social and economic aspects) in order to better improve and adjust implementation process and timing.

## 5. Conclusions

Based on the bibliometric analysis of NBS literature and a systematic review of UF-NBS articles, this study explored a brief research pattern of NBS studies and highlighted the fact that the analysis of urban forest and trees differed in types of benefits and scales, with a large body of research focusing on addressing environmental issues in improving the resilience of cities and societies. Although current UF-NBS studies account for a relatively low proportion of the overall NBS research field, using urban forests and trees as nature-based solutions, has been gradually gaining attention from researchers based on keyword analysis.

The geographical distribution and study methods of UF-NBS studies are various, while the regional dominance of Europe was clear, mostly at a local scale. Most UF-NBS studies used quantitative methods to address the environmental issues and often conducted their analysis by using various models and scenario simulations, especially in the application of water management. As for social aspects, researchers prefer to use social surveys or interviews to assess the social benefits of urban forests.

This review also helped to identify gaps in current UF-NBS studies. Despite the role of urban forests and trees in addressing environmental challenges, such as stormwater management, air pollution reduction, urban heat mitigation, and providing social benefits like human health improvement (especially mental health), being well recognized, more research is needed for social concerns such as improving human wellbeing and providing social benefits for different groups of people. In addition, more UF-NBS studies are needed for the economic assessment of the urban forest and trees in NBS studies.

Further research is still needed to understand the issues in a more comprehensive context, taking economic value assessment into account is essential for the long-term practice and implementation of urban forest as NBS. This also reveals a gap in developing complete frameworks and planning strategies for UF-NBS studies, which requires trans-disciplinary knowledge and integration of multiple ecosystem services and co-benefits for decision-making.

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