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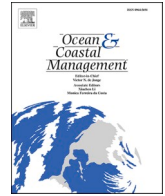
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## Review

# The concept of 'nature-based solutions' applied to urban coastal risks: A bibliometric and content analysis review

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## ABSTRACT

Nature-based solutions (NBS) are increasingly proposed as a response to the growing vulnerability of coastal areas to the risks of coastal erosion and flooding. These solutions rely on the functioning of ecosystems to mitigate the effects of coastal hazards. However, the ability of ecosystems to act as buffer zones is being compromised due to increasing urbanization in coastal areas. The implementation of NBS in urbanized coastal areas is becoming a major challenge for our societies, as coastal cities densely concentrate populations and valuable assets. This study has two main objectives: (1) to provide a structured overview of current NBS research and (2) to explore whether and how NBS are utilized in urban coastal risk management. A critical review of the literature serves as a foundation for understanding how NBS is conceptualized, identifies the factors contributing to the ambiguity of the term, and proposes five key elements for defining NBS. A systematic review of 3384 publications from Scopus shows that coastal issues represent a secondary focus in NBS research (14%). Coastal NBS studies primarily address coastal erosion and flooding exacerbated by sea level rise through natural coastal ecosystems. While urban issues related to climate change are at the heart of NBS research, the urban dimension has very little connection with coastal NBS. This article highlights the need for a multifaceted response to manage coastal risks in coastal cities, combining hard and soft engineering (hybrid solutions), inshore and offshore NBS, coastal and stormwater NBS, and regulating urbanization in flood-prone areas. The application of NBS in coastal risk management calls for incorporating natural coastline dynamics into land-use planning and rethinking our fixed modes of coastal occupation. This article provides keys to understanding the concept of NBS to facilitate its integration into coastal risk management plans.

## 1. Introduction

Faced with the increasing vulnerability of coastal areas to erosion and storm surge (Meur-Ferec et al., 2020), aggravated by the effects of climate change (IPCC, 2022; Vousdoukas et al., 2018), nature-based solutions (NBS) in coastal risk management are increasingly promoted by international institutions (IUCN French Committee, 2019; Plan Bleu, 2022; The Nature Conservancy, 2021; World Bank, 2016). Presented as an alternative to "grey" or "hard" infrastructures that artificially stabilize the coastline, they rely on the functioning of coastal ecosystems to limit coastal erosion and mitigate flooding (Van Coppenolle et al., 2018; Van Der Meulen et al., 2023). Coastal ecosystems are inherently mobile and require space to evolve, yet coastal areas worldwide are becoming increasingly densely urbanized (Neumann et al., 2015). This raises

questions about when this concept is relevant to coastal risk management in urbanized areas (Ocean & Climate Platform, 2023b), and how it can be integrated into existing policies.

NBS is defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (IUCN, 2016). The NBS concept is the latest in a series of successful concepts linking environmental and societal concerns (Nesshöver et al., 2017). It emerged fifteen years ago in international negotiations on climate agreements (IUCN, 2009). The term NBS was not immediately adopted by the scientific community, which was rather reluctant to embrace this new concept. It was not until 2015, when it was included in the European research agenda (European Commission,

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2015), that researchers took up the subject, defined its methodological contours, and broadened its research scope (Eggermont et al., 2015; Faivre et al., 2017; Kabisch et al., 2016; Maes and Jacobs, 2017; Nesshöver et al., 2017; Raymond et al., 2017). Barely 10 years later, it is clear that NBS are a growing research field in their own right.

How can we assess this decade of research on NBS today? How important is the issue of coastal hazards within it, and what are the links between NBS, coastal hazards, and urbanization? To date, and to our knowledge, there are no articles addressing this issue. Some literature reviews have been conducted on specific topics of NBS, such as urban stormwater management (Li et al., 2023), blue carbon (Zhong et al., 2023), and salinization of soils (Tarolli et al., 2024), while others focus on specific types of actions (Alamenciak et al., 2023), geographic areas (Zupo et al., 2022) or ways of monitoring and evaluating NBS (Anderson et al., 2023). A recent study on NBS research trends identifies “coastal protection” as a topic of interest but does not explore it further (Yang et al., 2024). This article aims to (1) provide an organized overview of current research on NBS and (2) examine if and how the concept of NBS is applied in coastal risk research, particularly in urbanized areas.

To do so, we employed bibliometric analysis techniques. Two tools were used: the Bibliometrix package in RStudio and VOSviewer software (Aria and Cuccurullo, 2017; Van Eck and Waltman, 2010). Standard bibliometric indicators allowed us to identify the characteristics of our research field (temporal evolution, funding sources, countries of scientific production). Content analyses (word occurrences and co-occurrences) then revealed thematic focal points and current research trends in NBS.

After presenting the theoretical basis of NBS (part 2), we outline our method for analyzing the selected bibliography (part 3), before presenting (part 4) and discussing (part 5) our findings on NBS, coastal NBS, and urban coastal NBS.

## 2. Theoretical background: the emergence, construction, and limitations of NBS as a scientific concept

### 2.1. A brief history of the conceptualization of NBS

The term “nature-based solutions” first appeared in a World Bank document on biodiversity and climate change adaptation in 2008 (World Bank, 2008). The following year, IUCN used the term in its position paper for COP15 in Copenhagen (IUCN, 2009). In this note, IUCN emphasizes the capacity of “natural solutions” to mitigate climate change and adapt to its impacts. NBS designate nature conservation actions that can contribute to achieving the objectives of two international conventions of the United Nations - the Convention on Climate Change and the Convention on Biological Diversity (IUCN, 2012a; World Bank, 2008).

This text marks IUCN’s growing commitment to NBS. In its 2013–2016 action plan, IUCN made the deployment of NBS one of its three strategic lines of action (IUCN, 2012b). The scope of NBS was then extended from the fight against climate change to all the UN sustainable development goals (Acharya et al., 2020; Dunlop et al., 2024). By considering NBS as a bridge between nature conservation and sustainable development goals, IUCN is positioning itself as a major political actor on this issue (Hrabanski and Le Coq, 2022).

In 2016, IUCN published a conceptual framework for NBS (Cohen-Shacham et al., 2016). This definition was adopted by IUCN members at the World Conservation Congress in 2016 (IUCN, 2016). NBS were defined as “actions to protect, sustainably manage and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”. Meanwhile, the European Union (EU), which was developing an interest in this new concept, published its guidelines and definition: NBS “are actions inspired by, supported by or copied from nature”, “in order to achieve desired outcomes, [...] and improve human well-being and socially inclusive green growth” (European Commission,

2015). These two definitions are currently the most widely used in the literature. IUCN then stepped up its efforts to promote the primary role of biodiversity in NBS. This led the various actors involved in the conceptualization of NBS to move towards a similar definition, broadly analogous to that of IUCN. In March 2022, the UN adopted a resolution to promote a common approach to NBS (UNEP, 2022).

Since 2016, IUCN’s work has focused on operationalizing the concept and documenting examples of NBS implementation around the world (Cohen-Shacham et al., 2019; Hessenberger and Popovicki, 2023; Luo et al., 2023; Popovicki et al., 2023). To promote common criteria for identifying an action as an example of NBS, IUCN published an International Standard in 2020 (IUCN, 2020). The EU, for its part, has focused its efforts on developing scientific research on NBS (see Davies et al., 2021 for a review of EU-funded projects to develop NBS research), and has also published reports on existing projects that it is funding (European Commission and Vojinovic, 2020; European Research Executive Agency, 2023).

Today, the term is widely used by intergovernmental and government bodies, as well as by the private sector, non-governmental organizations, and the general public (Kauark-Fontes et al., 2023; Yang et al., 2024). NBS appear to be a success story, but questions remain about the scientific scope of the concept, especially as regards its vague definition and complicated implementation (Brueder et al., 2023; Hanson et al., 2020; Nesshöver et al., 2017; Seddon et al., 2021; Sowińska-Świerkosz and García, 2022).

### 2.2. The limitations of NBS as a scientific concept

We believe that the very process by which the NBS concept emerged and was constructed contains some of the seeds of its vagueness.

#### i) The origins: a persuasive formula

The discourse built around NBS by IUCN initially took the form of a plea for “nature”, presented as the “solution” to climate change. Its incorporation into the international climate arena raised the profile of the biodiversity cause and attracted financial endowment (Drapier et al., 2023; Hrabanski and Le Coq, 2022). The idea was not new: several concepts and instruments were already pursuing this goal (ecosystem services, ecological compensation mechanisms such as the REDD + programme). But this time, the expression “NBS” was spreading in the discourse without a clear definition, leading some authors to worry about a possible “green communication tool” (Nesshöver et al., 2017). As a result, NBS was more of a persuasive expression than a rigorously defined scientific concept.

#### ii) Definition: a changing balance between nature and society

The strength of the NBS formula lies in its ability to generate an “ambiguous consensus” among different institutions (Palier, 2005). Indeed, it is open to a wide range of interpretations, allowing each stakeholder to incorporate the concept into its agenda while protecting its own interests (Drapier et al., 2023; Kotsila et al., 2021). While it is clear that NBS generate benefits for biodiversity and human societies alike, the balance between these two poles shifts according to the objectives and ideological positioning of each stakeholder. For example, the EU sets NBS in an economic and social perspective and links them mainly to the three pillars of sustainable development (Davies et al., 2021; Faivre et al., 2017; Maes and Jacobs, 2017), while IUCN defines biodiversity protection as the foundation of NBS through the ecosystem approach (Cohen-Shacham et al., 2016).

As a result, proposed definitions struggle to frame a minimum level of naturalness for NBS (Eggermont et al., 2015). This threshold has been debated since the emergence of the first conceptual frameworks, for example with the abandonment of biomimicry by the EU, and the debate is still ongoing (Osaka et al., 2021; Sowińska-Świerkosz and García,

2022; Van der Nat et al., 2016). In terms of NBS applied to coastal risks, artificial beach nourishment is a perfect illustration of this difference of opinions. One of the factors contributing to the vagueness of NBS therefore stems from the 'N' in NBS, implicitly questioning what everyone is prepared to accept as natural or not (Descola, 2014; Mace, 2014). By providing a broad definition of the concept, IUCN can count on a massive commitment to NBS from a variety of actors (Seddon et al., 2021), but runs the risk of "misusing the concept" (Nesshöver et al., 2017), as has been pointed out by several authors (Hanson et al., 2020; Seddon, 2022) and institutions (European Union, 2022; UNEP, 2022).

iii) The horizontal expansion process: a "super-umbrella concept"

NBS are defined as an "umbrella concept that covers a whole range of ecosystem-related approaches" (Cohen-Shacham et al., 2016). As such, NBS incorporate many pre-existing concepts (Appendix A), as "green infrastructure", "ecological restoration", or the "Building with Nature" approach, to name but a few. This status of "umbrella concept" gives more weight to the "NBS" terminology. However, these concepts already raise questions about their own definition and scope (Martin, 2017; Seiwert and Röbber, 2020; Vollet, 2023). They are heterogeneous: some relate to specific themes (integrated coastal zone management), while others are cross-cutting approaches (green infrastructure); some are action-oriented (ecological restoration), while others remain highly theoretical (ecosystem approach). Taken as a whole, these elements make NBS appear to be a kind of "super-umbrella concept" with blurred contours, leading some authors to question their place within the "green concept family" and their contribution to concepts already in circulation (Escobedo et al., 2019; Hanson et al., 2020; Nesshöver et al., 2017).

iv) The vertical expansion process: from notion to action?

As a result of this broad and vague definition, it is difficult to operationalize the concept. In recent years, the literature has mainly focused on two objectives: evaluating the co-benefits and efficiency of NBS (Barbier et al., 2011; Keesstra et al., 2018; Müller et al., 2020), and studying obstacles to the implementation of NBS (Davies and Laforteza, 2019; Frantzeskaki, 2019; Kabisch et al., 2016). On the institutional implementation side, public actors have launched a wave of calls for experimental projects. In the field of coastal risk management, these efforts to report case studies can be seen worldwide, for example in the Netherlands (Marijnissen et al., 2020; Marin-Diaz et al., 2023; Siegersma et al., 2023), the United States (Bridges et al., 2021), the UK (Apine and Stojanovic, 2024), Bangladesh (Rahaman et al., 2022; Smith et al., 2021), Malaysia (Chee et al., 2021), the Maldives (Duvat and Magnan, 2019). All this work represents a first step in evaluating and promoting NBS systems with a view to their wider deployment (DEFRA, 2021a; El Harrak and Lemaitre, 2023; NetworkNature, 2024; Warnell et al., 2023).

### 2.3. The five key elements of NBS

Making the flexibility of the NBS concept its strength therefore appears to be a gamble; it incurs the risk that a multitude of divergent definitions and typologies will flourish, thus rendering it impossible to establish a common vision for putting NBS into practice. While no single fixed definition has been established, it is possible to identify the key elements of NBS by studying the commonalities of the various definitions proposed. Based on the work of Hanson et al. (2020), we propose 5 key elements that must be included in NBS. NBS rely on ecosystem functions to (1) **address specific societal challenges** by generating (2) **benefits for biodiversity** and (3) **benefits for human societies**; they are (4) **multifunctional** and (5) **require the commitment of all stakeholders**.

The abundant literature that has developed on NBS since their appearance lends itself to bibliometric analysis.

### 3. Methodology: a two-stage bibliometric analysis

In order to characterize scientific production on NBS as a whole, and to study the place and content of publications on coastal NBS in this field of research, we created two sets of bibliographic references (Fig. 1). Each set was then subjected to a descriptive and a content analysis using bibliometric analysis methods.

#### 3.1. Data collection: building two sets

##### Set 1: Nature-based solutions

We began by collecting all scientific literature on NBS from the Scopus database. The aim was to collect all references whose main topic was NBS, so the query entered in Scopus was simply "nature-based solution\*" in the "article title", "keywords" and "abstract" fields. The number of publications matching this query was 3,384, published between 2012 and 2023.

##### Set 2: Nature-based coastal solutions

In order to identify more precisely how the concept of NBS is used in scientific publications dealing with coastal issues, we extracted from Set 1 the documents specifically related to this field. To do this, we added a search field with the terms "coast\* OR "sea level rise" to the initial query. The term "coast\*" is used to identify publications dealing with various coastal issues, including coastal risks, and the term "sea level rise" to add any uncaptured publications (12). The resulting Set 2 contained 465 publications published between 2014 and 2023. This represents 13.7% of all NBS publications.

#### 3.2. Application of quantitative analysis tools to the two sets

For each set, a general descriptive analysis was performed using a set of general bibliometric indicators, followed by content analysis based on word occurrences.

##### 3.2.1. Descriptive analysis: common bibliometric indicators

Firstly, quantitative analyses were carried out to identify the main characteristics of the sets: 1) the annual evolution of scientific production, 2) the institutions funding this research, 3) the countries to which the research centres behind the publications listed were affiliated. This helps identify who is developing and funding research on the concept, and applying it to coastal zone management. These initial bibliometric analyses were carried out using the analysis tool provided by Scopus and Excel software.

##### 3.2.2. Content analysis: word occurrences and co-occurrences

Keywords and abstracts were used for content analysis. The keywords were entered by the authors. They thus positioned their research within the scientific context with which they wished to identify (Davi et al., 2022; Rostaing, 1996). We therefore supplemented the analysis of keywords with analysis of abstracts, on the basis that the former describes "what authors think they do" and the latter "what authors do". Thus, two separate graphs, one for keywords and one for terms extracted from abstracts, were generated at each stage of content analysis.

The RStudio Bibliometrix package was used to perform the word occurrence analysis (Aria and Cuccurullo, 2017). The results of the analysis of the most frequently cited keywords and abstract terms were displayed in the form of word clouds. A thesaurus of synonyms and words to be excluded was added for each indicator (keywords and abstract terms). The synonym thesaurus groups identical keywords in singular and plural forms, with or without hyphens, under one form. In the thesaurus of words to be excluded, the expression "nature-based solutions" and all its spellings were eliminated because, on the one hand, the repetition of the main subject of the search does not provide us with



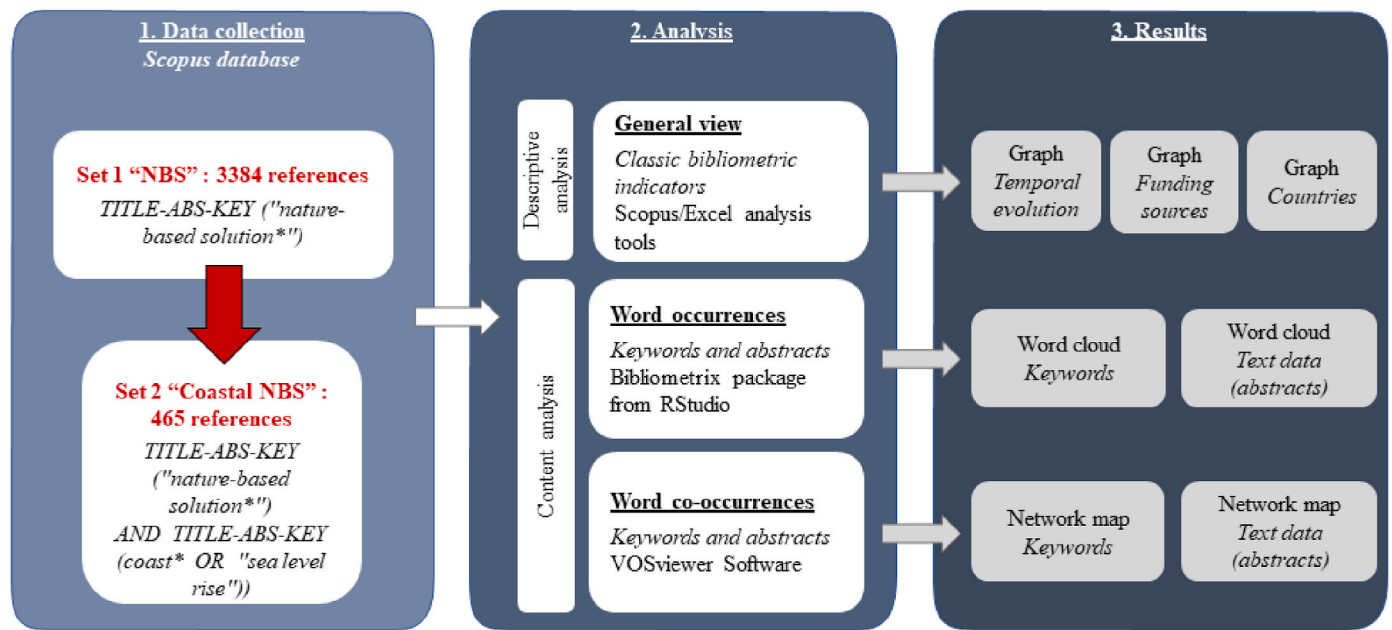


Fig. 1. Bibliometric method.

any information and, on the other hand, since authors tend to give priority to the keyword of the subject of the search, the term "NBS" is so prevalent that it overshadows all other words. The number of words to be displayed was set at 50. This number ensures a compromise between the readability of the graphical representation and the production of meaning.

VOSviewer software was used for co-occurrence analysis (Van Eck and Waltman, 2010). VOSviewer uses a distance-based representation method: the distance between two terms in the graph is proportional to the strength of their association (Van Eck and Waltman, 2007). The smaller the distance between two terms, the stronger their association in the set. Each term is represented by a dot. The size of the dot is proportional to the number of occurrences of the term in the set. Last but not least, VOSviewer offers a feature for drawing "clusters". Terms that are defined as statistically close to each other are grouped into clusters. These clusters are groups of terms that are frequently associated with each other within the set. Graphically, these clusters take the form of

dots of the same color.

Bibliometrix and VOSviewer are both free, open-source software packages.

#### 4. Results: coastal and urban NBS, an unhappy marriage

The results of the descriptive analyses of Sets 1 and 2 are initially presented together to compare the main indicators of the two sets. Content analyses are then performed independently for the "NBS" and "Coastal NBS" sets to explore the content of each set in more detail.

##### 4.1. Comparative descriptive analyses of sets 1 and 2: NBS, an emerging concept

The emergence of the NBS concept in the scientific literature corresponds to the beginning of the dissemination of the concept in the political sphere (Fig. 2).

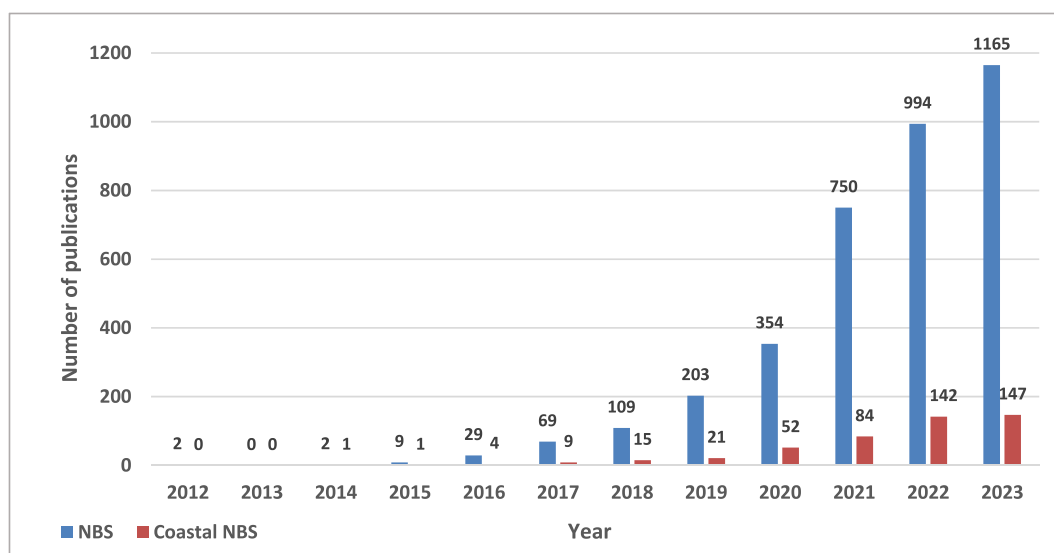


Fig. 2. Annual scientific production.

The first Scopus publication on this subject comes from the IUCN Commission on Ecosystem Management (Barrow et al., 2012). The annual evolution of scientific production on coastal NBS follows the global scientific production on NBS, with a very small-time lag. This time lag is an indication that coastal areas have been rapidly incorporated into the NBS perimeter. As with NBS research, coastal NBS research increased post-2015. It has accelerated significantly in the last 4 years. Thus, the boom in scientific literature on NBS seems to correspond to the European Union’s desire to develop this research topic (European Commission, 2015).

This assumption is supported by evidence that the European Horizon 2020 programme is the main source of funding for publications (Fig. 3). Horizon 2020 is the EU’s 2014–2020 research and innovation funding program.

Together, EU institutions funded about 20% of NBS scientific publications worldwide during this period. In comparison, the main source of non-European institutional funding was Chinese organizations, which funded 6.5% of publications. The EU remains the main contributor to coastal NBS research with 16% of publications funded, followed by funding from institutions in China (9%) and America (9%). The coastal theme therefore seems to receive less investment from the European Union than other NBS research themes (20% for Set 1 vs. 16% for Set 2).

Analysis of the main funding sources reveals the existence of strong institutional windows for NBS research worldwide, often linked to national governments or regional institutions. In addition to these main funding sources, international development actors are also present, as are international conservation organizations (Nature Conservancy, Wildlife Conservation Society). This is the case for both Set 1 and Set 2. Development banks are particularly interested in research on coastal NBS: half of the publications on NBS financed by the World Bank are dedicated to this topic.

The main countries developing research on NBS in general and coastal NBS in particular are similar: the western countries of the EU, the UK, the US, China and Australia (Fig. 4).

Two factors may explain this similarity: the high representation of

these countries in research in general, and the fact that these countries were quick to adopt the NBS approach. However, the involvement of these countries in Sets 1 and 2 is not the same. A good indicator of the differing interest in this topic is the ratio of publications on coastal NBS to all NBS publications by country (Table 1).

Germany, China, Italy, Sweden and, to a lesser extent, the United Kingdom, produce fewer articles on coastal NBS than on NBS in general, compared to the United States, the Netherlands, Australia, Spain, and France. Some countries are involved in several areas of NBS research, but focus less on coastal issues (Italy, Germany). Others are dedicated to specific issues (urban areas and carbon sequestration for China, vegetation and flooding for the UK). The countries prioritizing coastal NBS research tend to be those directly affected by sea level rise (SLR). Several countries known to be particularly vulnerable to SLR are among the top 25 contributors to NBS coastal research, including Bangladesh, Mexico, Thailand, and Singapore. Bangladesh, whose coasts are particularly exposed to coastal hazards, has a Set2/Set1 ratio of 45.4%. The Dutch research organization devotes 65% of its NBS research budget to coastal issues (Fig. 3); these are considered a national priority for this country, which is at the forefront of SLR. Thus, investment in this area of research is strongly correlated with exposure to coastal risks exacerbated by SLR.

4.2. Analyzing the content of Set 1: nature-based solutions, an urban concept partially adopted by coastal risk research

4.2.1. Occurrence of words: NBS to tackle climate change in urban areas

The most frequently cited terms in authors’ keywords and abstracts are represented in Figs. 5 and 6.

These terms can be divided into 4 different categories.

- (1) Concepts linked to the NBS approach. *Ecosystem services* is the most cited keyword in the set, closely followed by *green infrastructure*. Then, in decreasing order of frequency, we find the concepts of *disaster risk reduction*, *blue-green infrastructure*,

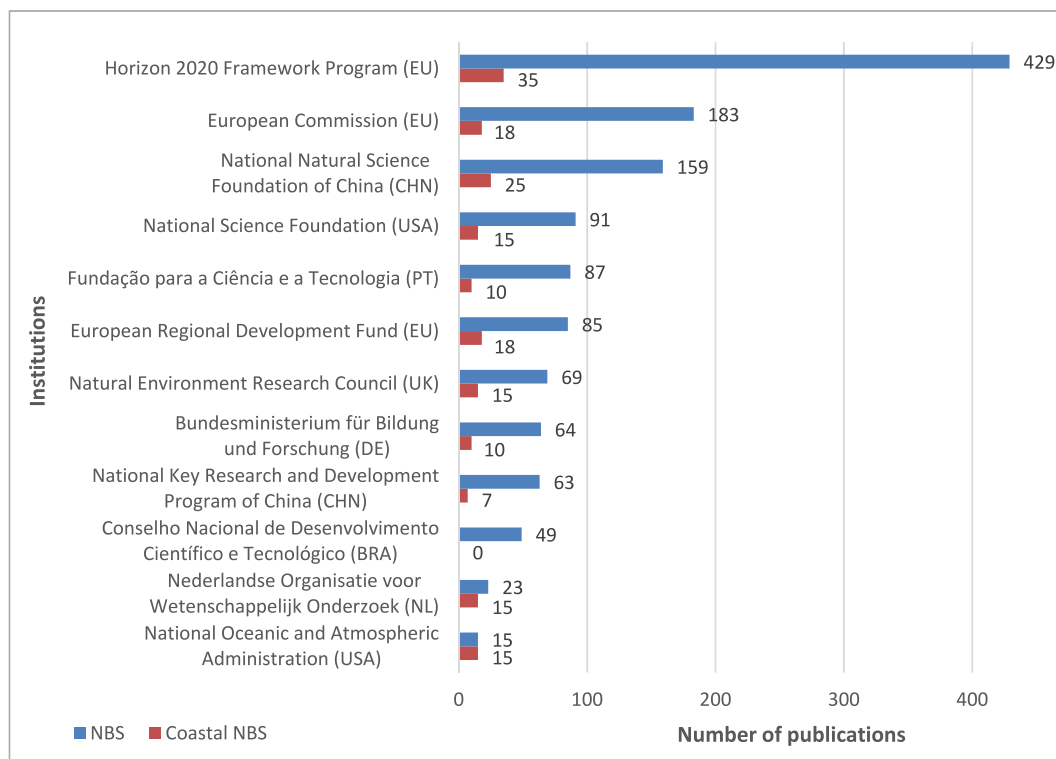


Fig. 3. Main funding sources (top 10, 2012–2023).

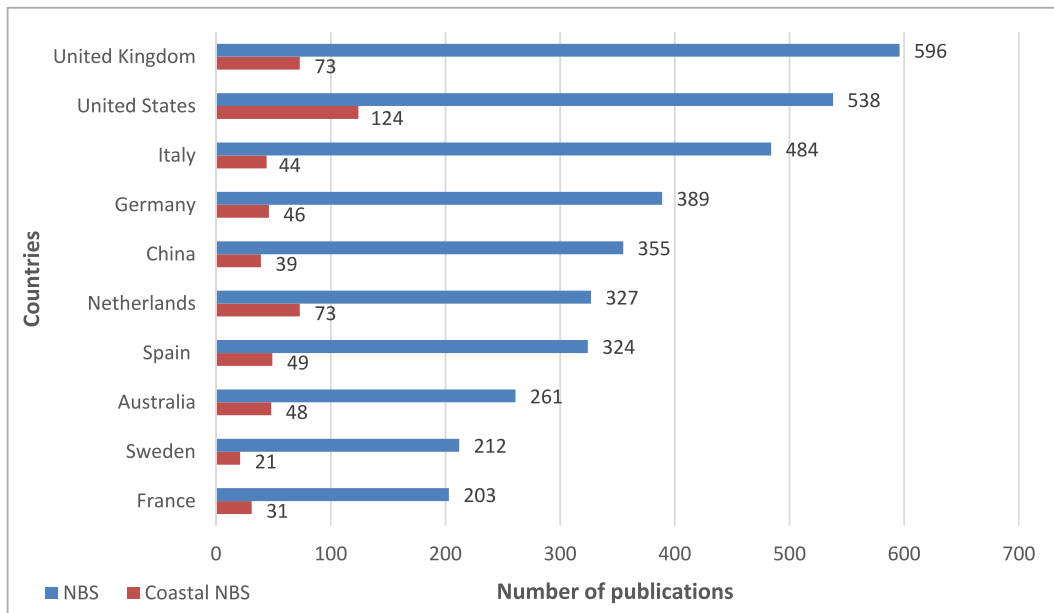


Fig. 4. Countries with the largest number of scientific production (top 10, 2012–2023).

Table 1

Ratio of coastal-related publications compared to all NBS publications, by country (2012–2023).

Country	Set 1 - Number of publications	Set 2 - Number of publications	Ratio
United States	538	124	23.05%
Netherlands	327	73	22.32%
Australia	261	48	18.39%
France	203	31	15.27%
Spain	324	49	15.12%
United Kingdom	596	73	12.25%
Germany	389	46	11.83%
China	355	39	10.99%
Sweden	212	21	9.91%
Italy	484	44	9.09%
Ratio Set2/ Set1	3384	465	13.74%



Fig. 6. Word cloud of Set 1 abstracts.

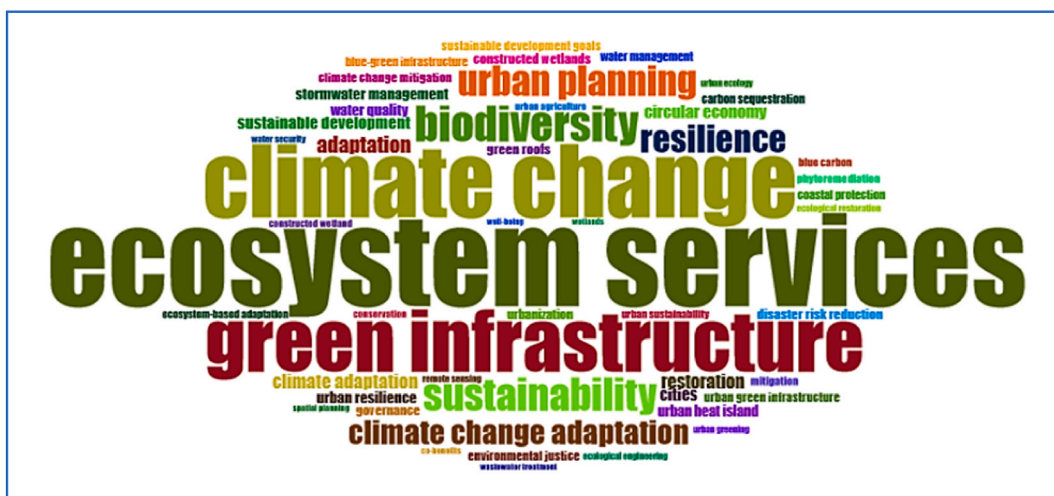


Fig. 5. Word cloud of Set 1 keywords.



ecosystem-based adaptation, ecological restoration, and ecological engineering.

- (2) Challenges facing NBS. *Climate change* is clearly the most important challenge facing NBS. Many of the terms cited fall within the scope of *climate change mitigation* and *adaptation*. Two other issues stand out in the application of NBS: challenges specific to the urban environment (*urban agriculture*, *urban heat island*), and *water management* and *treatment*. Last but not least, more anecdotal topics such as *coastal protection* are covered by isolated terms.
- (3) Areas affected by the implementation of NBS. These are mostly urbanized areas, as evidenced by the prominence of the adjective "urban" in the abstracts. The term "cities" is frequently cited in both keywords and abstracts, and a multitude of urban-related keywords appear in the set.
- (4) Challenges specific to the implementation of NBS. A number of terms underline the link between NBS and *sustainable development* objectives. The multifunctionality and *co-benefits* of NBS is emphasized, as are *well-being* benefits. The *challenges* of implementing NBS are central to the abstracts of the publications listed. Some terms indicate consideration of specific aspects or possible consequences of NBS implementation, such as *NBS governance* or

*environmental justice*. Finally, many terms highlight research carried out on NBS implementation and monitoring tools: *remote sensing*, *spatial planning*, *design*, *model*, *data*.

Coastal issues do not therefore seem to be a major theme in NBS research.

#### 4.2.2. Co-occurrence of words: coastal NBS and urban issues, few connections

The graph obtained from the keyword co-occurrences represents 222 terms divided into 9 clusters (Fig. 7). Eight clusters highlight specific issues (Table 2): nature in the city, disaster risk reduction, freshwater pollution, forests, coastal areas, urban heat peaks, urban wastewater management, and urban air quality. One cluster corresponds to a cross-cutting NBS theme: implementing policies to protect and restore ecosystems and biodiversity.

The graph obtained from abstract term co-occurrences represents 443 terms divided into 4 clusters (Fig. 8). It is divided into two main clusters (Table 3). The first (in red) presents NBS as a policy challenge, an urban governance innovation aimed at improving urban resilience. The second (in green) reflects a technical vision of NBS, perceived as engineering solutions. Between these two poles lie two other, more modest, clusters: the yellow cluster brings together publications dealing

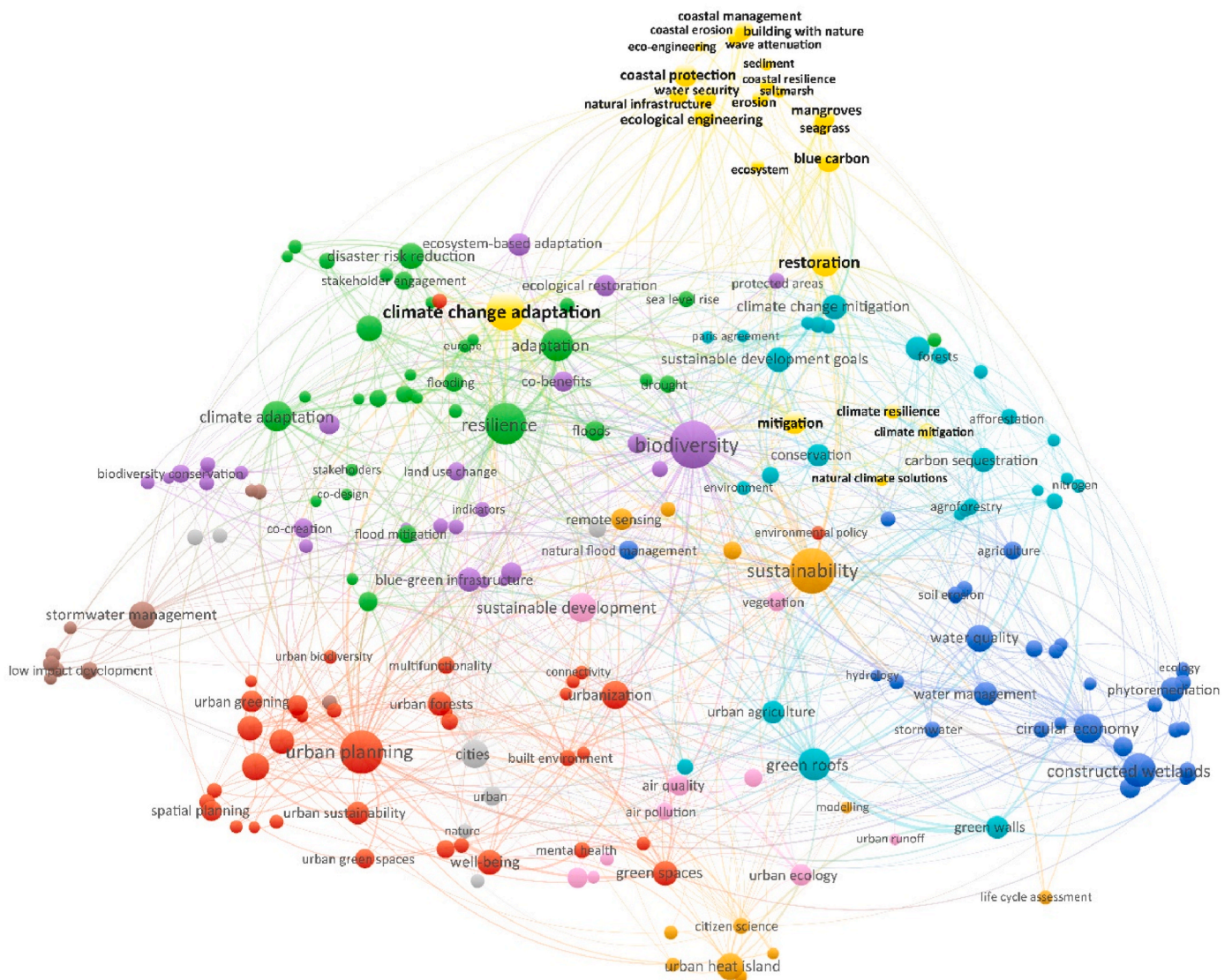
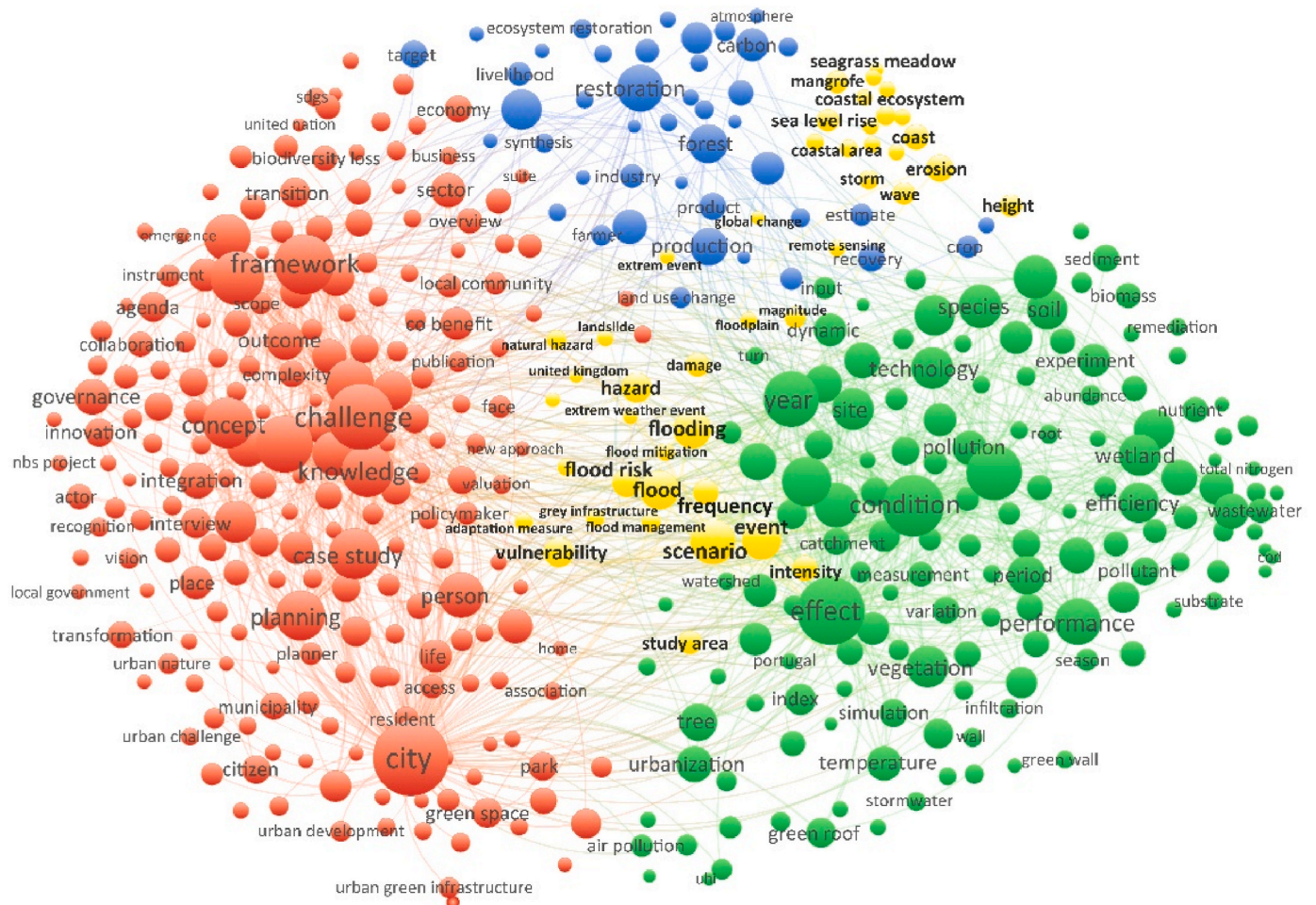


Fig. 7. Clustering of Set 1 keywords (coastal issues in bold).

**Table 2**  
Cluster analysis based on Set 1 keyword co-occurrences.

Cluster	Issue	Keywords	Number of keywords
Cluster 1 (red)	Planning nature in the city to improve residents' health and environmental justice	- Urban nature, urban parks, urban biodiversity - Urban transformation, landscape planning - Human well-being, mental health, Covid-19 - Environmental justice	37
Cluster 2 (green)	Reducing community vulnerability to disaster risk through stakeholder engagement	- Disaster risk reduction, natural hazards, sea level rise - Risk assessment, scenarios, simulation - Co-design, stakeholders, public perception	34
Cluster 3 (blue)	Using biological NBS to treat freshwater pollution	- Bioremediation, phytoremediation, biochar - Eutrophication, phosphorus, heavy metals, nutrients, agriculture - Water quality, water treatment, wetlands	32
Cluster 4 (cyan)	Protecting forests and vegetation to store carbon	- Carbon neutrality, carbon sequestration, Paris agreement, China - Afforestation, reforestation, Brazil	27
Cluster 5 (purple)	Protecting and restoring biodiversity and ecosystems together	- Biodiversity, ecological restoration, ecosystem restoration, protected areas, rewilding - Co-benefits, trade-offs, community engagement, monitoring, indicators	26
<b>Cluster 6 (yellow)</b>	<b>Adapting coastal areas to coastal risks through coastal and marine ecosystems</b>	- Climate change adaptation, coastal erosion, coastal resilience - Mangroves, saltmarsh, seagrass, sediment - Building with nature, eco-engineering, ecological engineering	<b>23</b>
Cluster 7 (orange)	Implementing NBS to manage global warming in cities	Urban heat island, land surface temperature, urban trees	13
Cluster 8 (brown)	Implementing NBS to manage urban wastewater	Sponge city, sustainable drainage system, Storm Water Management Model	12
Cluster 9 (pink)	Implementing NBS to manage urban air quality	Air pollution, air quality, particulate matter	11



**Fig. 8.** Clustering of Set 1 abstract terms (coastal issues in bold).



**Table 3**  
Cluster analysis based on Set 1 abstract term co-occurrences.

Cluster	Issue	Terms	Number of terms
Cluster 1 (red)	Implementing and governing an "NBS" ideology to improve the quality of life in the city.	<ul style="list-style-type: none"> <li>- Challenge, innovation, multifunctionality, best practice</li> <li>- Governance, European commission, Netherlands, United Nations</li> <li>- Social cohesion, local level, local community</li> <li>- Human well-being, public health, equity</li> <li>- City, urban context, urban system</li> <li>- Climate action, climate adaptation, climate resilience</li> </ul>	211
Cluster 2 (green)	Evaluating engineering solutions to specific problems	<ul style="list-style-type: none"> <li>- Measurement, efficiency, experiment, feasibility</li> <li>- Density, distribution, dynamic, depth</li> <li>- Contaminant, air quality, evapotranspiration, urban heat island, stormwater management, vegetation cover, sediment</li> </ul>	145
<b>Cluster 3 (yellow)</b>	<b>Studying the vulnerability of coastal areas to extreme weather events</b>	<ul style="list-style-type: none"> <li>- Coastal ecosystem, salt marsh, mangrove</li> <li>- Adaptation measure, scenario</li> <li>- Coastal erosion, extreme event, sea level rise, vulnerability, intensity, frequency</li> <li>- Flood management, United Kingdom</li> </ul>	44
Cluster 4 (blue)	Conserving and restoring forests to store carbon	<ul style="list-style-type: none"> <li>- Carbon sequestration, Paris agreement, policy</li> <li>- Reforestation, agroforestry, urban forestry</li> </ul>	43

with the vulnerability of territories to extreme events and climate change, and the blue cluster represents articles focusing on the restoration of forests to store carbon.

The keyword graph therefore reflects NBS research themes, while the abstract graph reflects contrasting ways in which scientists perceive and use the NBS concept. Coastal issues form a distinct cluster of NBS research themes in both graphs. They appear to have little connection with urban issues, which are nevertheless very present.

In the keyword graph (Fig. 7, cluster 6), the "coastal" cluster consists of three types of keywords: those related to coastal issues (*coastal resilience, coastal erosion, wave attenuation*), those related to coastal ecosystems (*mangroves, seagrass, salt marsh*), and those related to concepts (*building with nature, natural infrastructure, eco-engineering*). Note that the term "sea level rise" is not part of this coastal cluster, but is part of the cluster on disaster risk reduction and co-construction of adaptation. The urban theme appears to be diffuse and cuts across most of the NBS themes, while the coastal theme is grouped in a single cluster. The coastal cluster is the only one that does not contain any urban terms. It is diametrically opposed to the clusters specific to urban issues. Coastal and urban terms have little or no association with each other in the set of publications.

The "coastal" cluster in the abstract graph has a different morphology (Fig. 8, cluster 3): it is divided into two groups. In the centre of the graph, we find a set of terms related to flood risk. On the periphery, a group of words indicates a set of articles dealing with the vulnerability of

coastal systems to erosion-submergence risks. The terms in this second group refer to biophysical features of the coastal environment (*seagrass meadow, mangrove, shoreline*) and to coastal risks related to sea level rise (*coastal protection, coastal erosion, sea level rise*). Thus, it appears that the sub-clusters "Coastal risks and sea level rise" and "Flooding" have different characteristics. In particular, the former seems to be far away from urban conditions, while the latter is closer to them.

The composition of the coastal clusters indicates that the concept of NBS is mobilized in coastal research primarily to address issues related to erosion and flood risks in a global context of climate change. Coastal ecosystems play an important role in this context, correlating with the "N" in NBS; the urban dimension is virtually absent.

Content analysis of Set 2 will allow us to refine our initial findings on NBS applied to the coastal environment.

#### 4.3. Analyzing the content of Set 2: coastal NBS as a keystone between adaptation and ecosystem conservation

##### 4.3.1. Occurrence of words: coastal NBS to protect coasts from the impacts of climate change

The occurrence of words in Set 2 "coastal NBS" are presented in Figs. 9 and 10.

As with NBS in general, these terms can be analyzed in 4 categories.

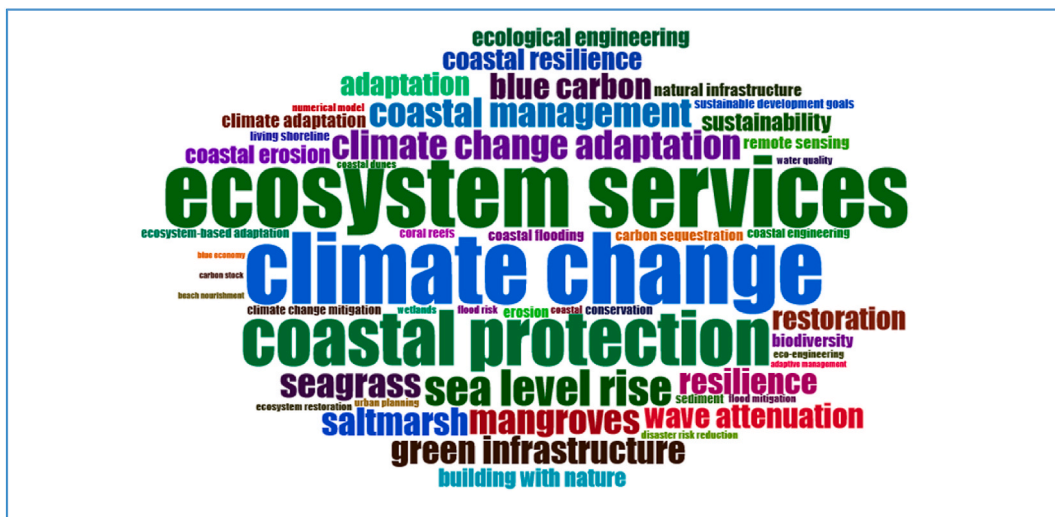


Fig. 9. Word cloud of Set 2 keywords.

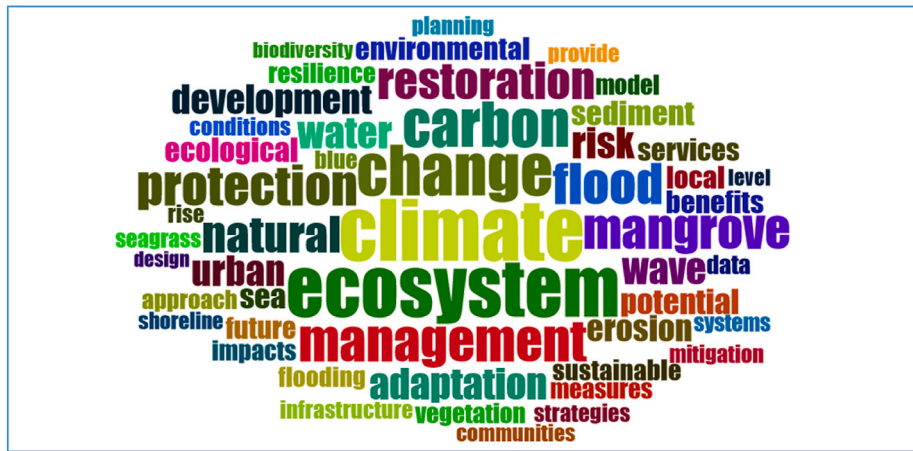


Fig. 10. Word cloud of Set 2 abstracts.

- (1) In terms of concepts, *ecosystem services* once again take the lead, followed by *green infrastructure*. Then, in decreasing order, we find the concepts of *building with nature*, *ecological engineering*, *natural infrastructure*, *ecosystem-based adaptation*, *living shoreline*, *disaster risk reduction*, *eco-engineering*, and *ecosystem restoration*.
- (2) In terms of issues, *climate change* crystallizes research on coastal NBS; it is the most frequently cited term in both keywords and abstracts. The lexical field of climate change includes *adaptation*, *resilience* and *mitigation*, in order of importance in the set. The issue of coastal risks is highlighted by hazards (*coastal erosion*,

- coastal flooding*) and management solutions (*wave attenuation*, *beach nourishment*). Several terms also indicate a research focus on *blue carbon*. As expected, urban issues are virtually absent.
- (3) Terms related to the implementation of coastal NBS can be divided into 3 subgroups. The *benefits* expected from their implementation are mainly linked to a *sustainable development goal* for the territory. The *challenges* are related to *coastal management*: the implementation of NBS raises the question of *adaptive management* of coastal areas subject to strong variability.

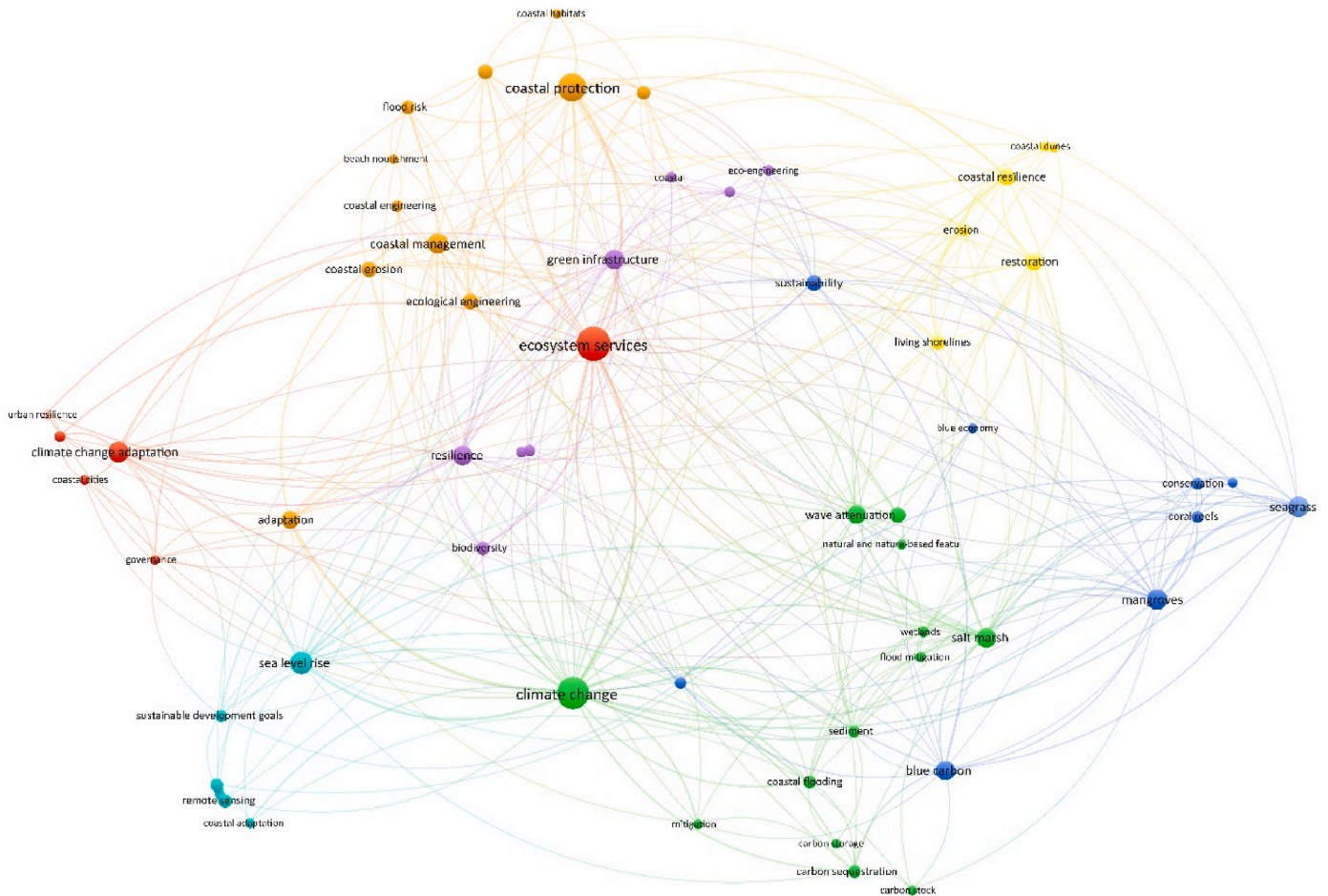


Fig. 11. Clustering of Set 2 keywords.

Tools used to study and implement NBS in coastal areas include *remote sensing, modelling and planning* policies.

- (4) The fourth group of words here involves ecosystems and geophysical elements specific to coastal environments. *Mangroves* are by far the most studied ecosystem in terms of coastal NBS. Also included are *seagrass meadows, salt marshes, coral reefs, coastal dunes, and wetlands*, and more generally all coastal *vegetation and sediment*. These terms appear to relate to *biodiversity* to be *conserved and/or restored*.

An analysis of word occurrences in Set 2 confirms that managing coastal risks exacerbated by climate change appears to be the main focus of NBS research on coastal issues. Urban issues appear anecdotally in this set (the only mention of "urban" in the abstracts). This confirms the distance between urban and coastal issues observed in the content analysis of Set 1.

#### 4.3.2. Co-occurrence of words: coastal NBS, biodiversity to conserve vs adaptation to plan

The graph obtained from the keyword co-occurrences represents 62 terms divided into 7 clusters (Fig. 11, Table 4).

The graph obtained from the abstract term co-occurrences represents 160 terms divided into 4 clusters (Fig. 12). The first cluster (red) corresponds to a vision of NBS similar to that observed in the majority cluster in Fig. 8, reflecting an implementation of NBS as a societal challenge to be co-constructed. The other three clusters, of exactly the same size, are characterized by well-defined themes: conservation and monitoring of coastal ecosystems, construction of high-performance defense infrastructures to stabilize the coastline, and adaptation of coastal societies to coastal risks and sea level rise, especially flooding risk (Table 5).

Coastal erosion and flooding risks feature prominently in Set 2. Coastal engineering, in particular ecological engineering, green infrastructure, and the "building with nature" approach are strongly mobilized to address these. Articles on erosion risk seem to have a focus on grey and green defensive infrastructure. They aim to review their performance and provide methodological guidelines for construction and monitoring. They focus primarily on dune systems and sediment transfer, but also include coral reefs, mangroves, marshes, and seagrass beds for their role in wave attenuation. Flood risk is addressed from a societal rather than a technical perspective. It seems to be a major concern given the vulnerability of coastal societies, and coastal cities in particular, to sea level rise. Finally, remote sensing and modelling mobilize a whole research field on coastal adaptation through NBS.

**Table 4**

Cluster analysis based on Set 2 keyword co-occurrences.

Cluster	Issue	Keywords	Number of keywords
Cluster 1 (green)	Using coastal ecosystems to limit flooding and store carbon	- Salt marsh, wetlands - Coastal flooding, flood mitigation, wave attenuation - Carbon sequestration, carbon stock	13
Cluster 2 (orange)	Adapting to and managing coastal risks through coastal engineering	- Climate adaptation, coastal erosion, flood risk - Coastal engineering, ecological engineering, beach nourishment	11
Cluster 3 (blue)	Preserving coastal ecosystems (for sustainable development)	- Conservation - Mangroves, coral reefs, seagrass - Sustainability, blue economy	9
Cluster 4 (purple)	Conceptualizing coastal NBS	Green infrastructure, eco-engineering, ecosystem restoration, disaster risk reduction, ecosystem-based adaptation	8
Cluster 5 (cyan)	Using digital tools to adapt to the effects of sea level rise	- Adaptive management, coastal adaptation - Sea level rise - Monitoring, numerical modeling, remote sensing	7
Cluster 6 (yellow)	Combatting erosion by restoring coastal dunes	- Restoration - Coastal dunes - Coastal erosion, living shorelines	6
Cluster 7 (red)	Managing climate change impacts in coastal cities	- Coastal cities - Climate change adaptation, urban resilience - Urban planning, governance, ecosystem services	6

A second line of research is developing around the conservation and monitoring of coastal and marine ecosystems (Fig. 12, cluster 2). Terms such as "ecosystem services" and "climate regulation" are used to emphasize the importance of these ecosystems. However, these ecosystems mostly seem to be interconnected. This indicates a tendency to study them for their intrinsic value. Here, as in Set 1, we find an opposition between two visions of NBS: coastal NBS perceived as a governance challenge to be implemented, and coastal NBS studied from a naturalistic point of view, oriented towards habitat and ecosystem monitoring.

Figs. 11 and 12 show the presence of a few articles dealing with coastal cities in Set 2, while urban aspects have received very little attention in coastal NBS so far. In particular, cluster 7 (Fig. 11, in red) shows the existence of a modest strand of research on coastal cities within coastal NBS research. This is entirely focused on the adaptation and resilience of coastal cities to the impacts of climate change. The same result can be seen in the graph of abstracts: urban terms (*city, coastal city, urban area, urbanization*) are all located in the cluster "vulnerability and adaptation of societies to risks associated with sea level rise" and are close to a "planning challenge" vision of NBS and flood risk. The urban cluster does not appear to have any connection to biodiversity, and is diametrically opposed to the keywords identifying coastal ecosystems and the cluster dedicated to their conservation in Fig. 11.

## 5. Discussion: implications for NBS practices applied to coastal risk management in urban coastal areas

The results show that a few publications on NBS address flood risk adaptation in coastal cities through urban planning (Figs. 11 and 12). These publications have little to do with coastal ecosystems (Fig. 11), despite the significant role coastal ecosystems play in NBS research (Fig. 7). This raises several questions: What are the NBS practices in coastal risk management? What are the NBS practices in urban coastal risk management? How are NBS being implemented in coastal cities to manage coastal risks?

### 5.1. The specific case of the NBS implementation in coastal cities to manage coastal risks: the need for a multifaceted response

According to the scientific literature, NBS for coastal risk management can be categorized into three types: natural coastal ecosystems, hybrid solutions, and sediment management. The first type, natural coastal ecosystems, plays a dominant role in coastal NBS research. These



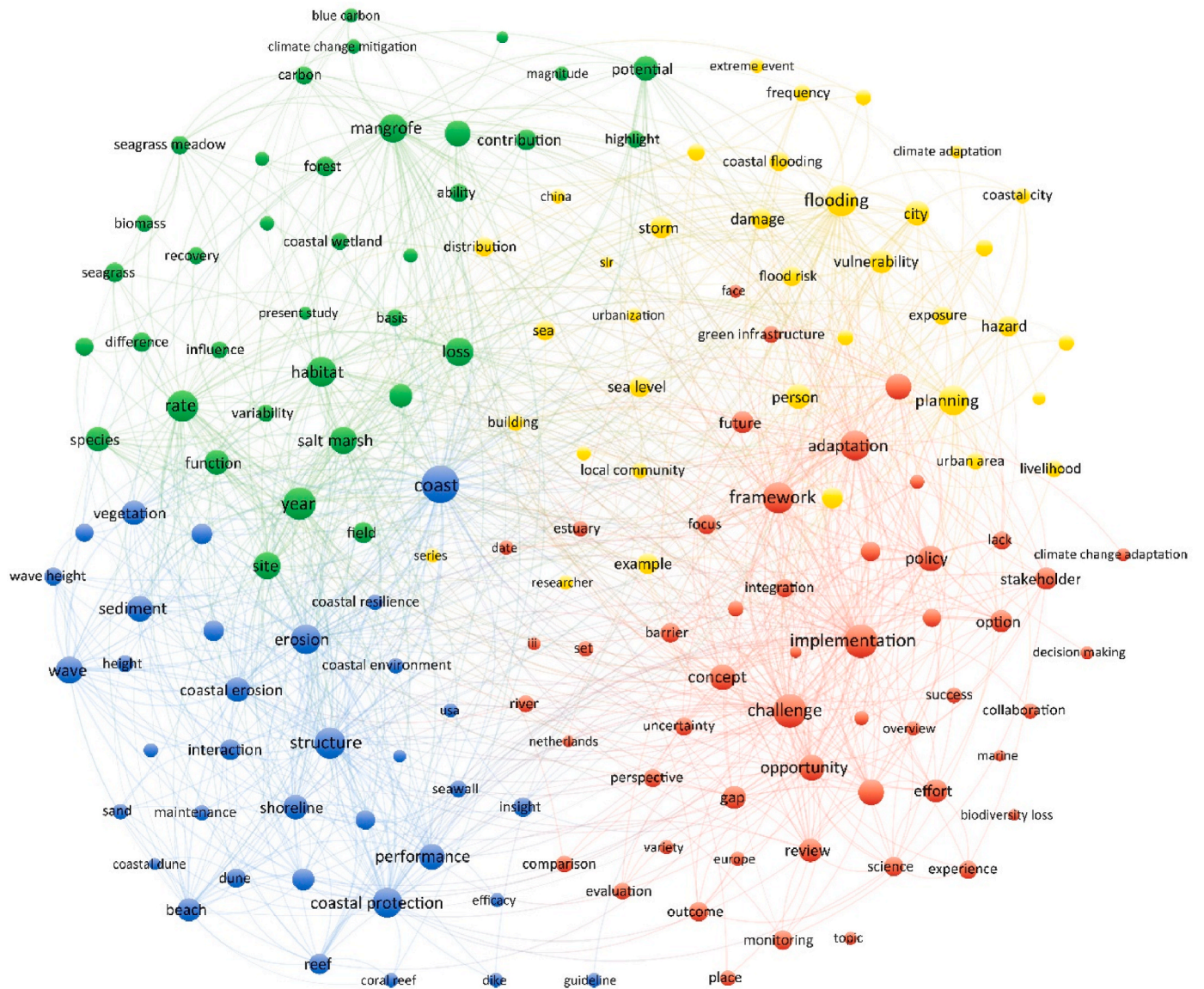


Fig. 12. Clustering on Set 2 abstract terms.

**Table 5**  
Cluster analysis based on Set 2 abstract term co-occurrences.

Cluster	Issue	Keywords	Number of keywords
Cluster 1 (red)	Designing and implementing innovative "solutions"	- Implementation, monitoring - Collaboration, stakeholder - Challenge, barrier, opportunity, uncertainty	52
Cluster 2 (green)	Monitoring and protecting coastal ecosystems	- Conservation, coastal wetland, mangrove forest, salt marsh, seagrass - Rate, variability, site	36
Cluster 3 (blue)	Addressing coastal risks through coastal engineering	- Blue carbon, climate change mitigation - Construction, maintenance, guideline - Breakwater, dike, seawall - Dune, reef, sand, sediment, vegetation - Height, performance	36
Cluster 4 (yellow)	Adapting to associated coastal risks and sea level rise	- Shoreline protection, coastal erosion - Adaptation strategy, planning - Local community, livelihood - Coastal city, urbanization, urban area - Exposure, damage, vulnerability - Sea level, flood risk, coastal flooding	36

studies focus on the functioning of coastal ecosystems to identify the factors influencing their ability to attenuate waves and coastal erosion (Chen et al., 2024; Jacob et al., 2023). Mangroves, seagrass, kelp forests, lagoons, reefs, dunes, and salt marshes are natural defense infrastructures that must be protected or restored (Jordan and Fröhle, 2022). Most of these articles examine the biophysical conditions necessary for these ecosystems to thrive and provide regulating ecosystem services. (Chong et al., 2021; Möller et al., 2014; Mosuela and Irish, 2022; Unsworth et al., 2022). This type of solution is essentially concerned with natural, non-constructed areas. A second category of coastal NBS involves "hybrid" solutions that combine grey infrastructure with natural elements (Bredes et al., 2024; Kuwae and Crooks, 2021). These hybrid solutions have highly variable degrees of naturalness (Almaghraby et al., 2022; Siegersma et al., 2023; Singhvi et al., 2022). The core element of this category is grey infrastructure associated with functional coastal ecosystems. Examples include the development of oyster reefs on submerged breakwaters (Vona and Nardin, 2023) or the creation of salt marsh terraces in seawalls (Slee et al., 2023). Finally, several articles focus on sediment management. They propose soft solutions to limit coastal erosion. These solutions range from local techniques, such as designing dynamic cobble berm revetments (Foss et al., 2023), to regional sediment budgets and national recommendations (Różyński, 2023). In that way, sediment management is a key aspect of coastal hazard mitigation (Schmitt and Minderhoud, 2023; Solan et al., 2023).

Focusing on articles that discuss NBS implemented in coastal cities, many do not address the risks of storm surges and coastal erosion. The primary risk highlighted in NBS research for coastal cities is a flood risk through extreme rainfall events and stormwater management issues (Gargiulo and Zucaro, 2023; Matamoros et al., 2020; Quagliolo et al., 2023; Salata et al., 2022). There is little consideration of the coastal characteristics of these cities and the projected sea level rise. These articles often link the risk of pluvial flooding to current and future impacts of climate change, particularly disruptions to hydro-meteorological systems (Ruangpan et al., 2020; Sánchez-Almodóvar et al., 2023). This may explain the strong connection between coastal cities, flood risk, and climate change adaptation seen in the results. NBS for managing stormwater flooding primarily rely on urban vegetation to absorb excess water and reduce runoff (Orta-Ortiz and Geneletti, 2022). Examples of such NBS include green roofs, bioswales, rain gardens and rain barrels, urban trees, riparian reforestation, porous pavements, floodable parks, and the management, restoration, and conservation of urban wetlands (Chaves et al., 2024; Guido et al., 2023; Sciuto et al., 2024).

Managing flood risk in coastal cities without systematically considering sea level rise projections is a growing concern for future local risk management. Indeed, coastal cities are increasingly experiencing compound floods caused by multiple hydrological, meteorological, and oceanographic factors. Compound floods occur when multiple flood drivers - storm surges, high tides, heavy rains, and river flooding - combine during extreme events like storms, hurricanes, or cyclones, amplifying their impacts (Chan et al., 2024; Ruan et al., 2024; Sebastian, 2022). These floods are often violent and sometimes difficult to predict, causing extensive damage. Coastal towns in estuaries are particularly affected (Cheng and Chen, 2017; Costanza et al., 2006). It is therefore essential to consider the multifaceted nature of coastal hazards (Mariano and Marino, 2022). Coastal risk management in estuarine cities should consider NBS infrastructures for storm surges and coastal erosion and those for runoff and drainage systems. Urban risk management policies for coastal cities should jointly integrate these different components. The scale of coastal risk management is therefore a key issue. NBS should be implemented across a watershed-city-coast continuum to avoid perverse effects (Normand and Heggy, 2024; Salata et al., 2022; Toledo et al., 2024).

A few articles, however, examine the possibility of implementing NBS in coastal cities to tackle the risks of coastal flooding and erosion. All point to the same challenge: the lack of available space. The dense

urbanization of coastal cities, particularly along the seafront, is a major obstacle to implementing NBS (Chan et al., 2022; Różyński, 2023). Closely linked to this issue is the lack of sediment. For example, Sánchez-Arcilla et al. (2024) explore the implementation of NBS on two types of urban beaches, using a case study of Badalona beach in Spain: urban and peri-urban beaches. While dune restoration, wetland restoration, and managed re-alignment are envisaged for peri-urban beaches, the narrowness of the urban beach limits the feasibility of "emerged" NBS. Only the restoration of seagrass meadows in front of the urban beach is proposed. Several other studies have suggested offshore NBS for various coastal cities, e.g. Boston (Hopkins et al., 2022), New York City (Karamouz et al., 2022), and Vejle (Ryu, 2023). The lack of space is a recurring problem when implementing NBS in coastal cities to address flooding risks because of ongoing urban development (Li et al., 2024; Marino et al., 2024). For example, Rojas et al. (2022) show how real estate development at the expense of a wetland in the Concepción metropolitan area (Chile) increases the risk of flooding. On the other hand, implementing NBS to mitigate the impacts of storm surges, coastal erosion, and sea level rise seems more feasible when coastal ecosystems are still present, even if degraded (Johnston et al., 2023; Lascrain, 2017; Taylor-Burns et al., 2024). Finally, the literature often advocates for hybrid solutions in coastal cities (Aziz et al., 2024; Xu et al., 2021). In response to increasing coastal risks in the context of climate change and growing urban pressures, adapting cities requires a multifaceted response (Li et al., 2024).

The increasing risks faced by coastal cities are a political concern, reflected in initiatives at the interface of science, policy, and practice, such as China's Sponge City program or Europe's Coastal City Living Labs, as well as extensive grey literature. Grey literature addresses NBS from an operational perspective.

## 5.2. Some insights from the grey literature on the management of NBS in coastal cities

A non-exhaustive analysis of the grey literature reveals four important and interrelated points for the implementation of coastal NBS.

### (i) Land-use regulation and urban planning

Grey literature highlights the expansion of urbanization as an obstacle to the implementation of coastal NBS (De Moraes et al., 2021; UNDRR, 2024; UNEP/MAP and Plan Bleu, 2020). Coastal squeeze degrades coastal ecosystems and increases the population's exposure to coastal risks. It is therefore essential to establish land-use policies at the local level that prohibit urban development in flood-prone areas. Land use regulations should be implemented as early as possible, as relocation is both socially and economically challenging (Warnell et al., 2023). Currently, poor management remains a major cause of disasters related to flooding and coastal erosion (World Bank, 2022). To create more space for nature in urban planning, local officials and managers can rely on international frameworks (such as the European Commission's Nature Restoration Law European Commission (2022)), national regulations (e.g., national "Coastline Acts") and local plans (e.g., urban planning, risk management plans, biodiversity plans). An example of the use of integrated development plans is the coastal city of Xiamen, China, where the success of coastal NBS implementation is largely attributed to the early adoption of local strategies that integrate environmental protection and management (Luo et al., 2024).

### (ii) Adaptive management

Adaptive management is a dynamic and flexible approach that evolves based on feedback and lessons learned. It is essential for coastal NBS due to the complexity and uncertainties of coastal socio-ecosystems, including sea level rise and climate change impacts (DEFRA, 2021a). Regular monitoring and evaluation, based on reliable



data and indicators, will enable adjustments in response to changing coastal ecosystems and ensure that implemented NBS meets the needs of local people (European Commission, 2021; Ocean & Climate Platform, 2024). For example, the LIFE Vimine project aims to protect the salt marshes of the Venice Lagoon by implementing small but spatially diffuse soil bioengineering protection works along the shores. Subject to very regular monitoring, this "no regrets" solution complements the wide range of measures already in place in Venice (Barba and Tenez, 2024).

(iii) Stakeholders participation and co-creation

Involving all stakeholders from the outset is a key factor in the success of NBS projects. It ensures solution acceptance, integrates local knowledge, prioritizes co-benefits, and enhances long-term performance and maintenance (European Commission, 2023; NetworkNature, 2024; Wegman et al., 2023; White House, 2022). Stakeholder engagement is particularly important for coastal NBS, where creation and management often spark divergent interests among local actors (DEFRA, 2021a). Identifying stakeholders early and involving them throughout the process - via regular consultations, working groups, transparent result-sharing, and democratic decision-making - is essential (Brill et al., 2022; El Harrak and Lemaitre, 2023; UNDRR and UNU-EHS, 2023). Effective engagement can facilitate NBS management, as seen in habitat restoration at Abbott’s Hall Farm, Blackwater Estuary, UK, while poor consultation and communication can hinder its implementation, as in the case of the creation of a depoldered area between Belgium and the Netherlands under the Sigma Plan (De Moraes et al., 2021).

(iv) Funding and co-benefits

Attracting funding for NBS projects is a major challenge for policy-makers and managers, as highlighted by the recent grey literature. Key barriers include high initial costs (if land acquisition), longer and less predictable returns on investment compared to grey infrastructure, high perceived private investment risk, and difficulties in monetizing co-benefits (DEFRA, 2021b; European Investment Bank, 2023; White House, 2023). Funding sources are diverse but fragmented, and current legal frameworks rarely position NBS as economically viable. Proposed solutions include building robust business cases, seeking financial technical assistance, forming public-private partnerships, leveraging innovative financing mechanisms, and showcasing co-benefits (European Investment Bank, 2019; GIZ, 2023; UNEP, 2024; UNFCC,

2021). For example, coastal erosion protection in Saly, Senegal, was funded by national and World Bank resources, with anticipated tourist-driven economic co-benefits ensuring investment viability (Ocean & Climate Platform, 2023a).

6. Conclusion

This review examines a decade of scientific research on the concept of “NBS”, focusing on the role of coastal issues within this body of work. The intense scientific debate sparked by this emerging concept has revealed both its limitations and opportunities, fostered new research directions, and highlighted its value in addressing societal challenges. Regarding coastal risks, NBS research is flourishing, building on pre-existing concepts and practices that rely on coastal ecosystem functions and benefiting from strong political support.

However, the use of NBS to manage coastal risks in urbanized areas remains underexplored despite the significant human and economic stakes involved. Limited space and sediment availability significantly constrain the options for coastal cities, leading current solutions to favor offshore or hybrid NBS – and grey infrastructures. Regulating urbanization emerges as a key lever for implementing NBS, complemented by the need for more adaptive and integrated risk management practices and reforms to legal and financial frameworks. Implementing NBS in coastal urban areas thus requires adapting fixed coastal occupation practices to the natural dynamics of coastal systems.

This critical review clarifies a key yet often misunderstood concept, offering stakeholders insights into the opportunities and limits of NBS in coastal urban policies. Future research on legal and financial levers and deeper exploration of grey literature, often limited to national languages, would further support NBS implementation.

CRediT authorship contribution statement

**Aubrée Louarn:** Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Conceptualization. **Catherine Meur-Ferec:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Nathalie Hervé-Fournereau:** Validation, Supervision, Project administration, Funding acquisition.

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**Table A**  
Concepts closely related to NBS (according to the results of content analysis in 3.2.1. and 3.3.1.)

Concept	Definition(s)	Main references	Link with the NBS concept
<b>Ecosystem services</b>	"Ecosystem services are the benefits people obtain from ecosystems." (MEA, 2005).	MEA, 2005. A Report of the Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.	NBS are inextricably linked to ecosystem services, as their aim is to rely on or develop them in order to address societal challenges: NBS "share the overall goal of addressing major societal challenges through the effective use of ecosystem and ecosystem services" (Cohen-Shacham et al., 2016, p.5)
<b>Green infrastructure/ Blue-green infrastructure</b>	"[GI is] a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas." (European Commission, 2013)	European Commission (2013). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (GI) — Enhancing Europe’s Natural Capital, COM/2013/0249 final.	Just like NBS, GI is closely related to ecosystem services. The concept is used simultaneously to designate a systemic approach, a spatial planning tool and a structure, which makes its definition unclear. GI is often considered to be the opposite of grey infrastructures. Because of these similarities with NBS, NBS and GI have often been used as synonyms, particularly by the European Commission. GI is more often used in an urban context than NBS.
<b>Natural infrastructure</b>	Synonym for GI	UNEP (2014). Green Infrastructure Guide for water management: Ecosystem-based	Natural infrastructure is similar to GI. The term refers primarily to the role of wetlands

(continued on next page)

Table A (continued)

Concept	Definition(s)	Main references	Link with the NBS concept
<b>Ecosystem-based adaptation</b>	EbA is the "sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities" (CBD, 2010) "EbA aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change." (CBD, 2018)	management approaches for water-related infrastructure projects. CBD, 2010. Decision X/33 adopted by the Conference of the Parties to the Convention on Biological Diversity at its tenth meeting, "Biodiversity and climate change", UNEP/CBD/COP/DEC/X/33.CBD, 2018. Decision 14/5 adopted by the Conference of the Parties to the Convention on Biological Diversity, "Biodiversity and climate change", UNEP/CBD/COP/DEC/14/5.	in water management. Its application does not appear to extend to other issues. EbA can be seen as an SFN approach applied to the challenge of climate change adaptation. EbA is based on "the use of biodiversity, ecosystem functions and services" to improve the resilience of societies to climate change. It brings benefits for people and biodiversity, promotes stakeholder engagement and highlights the multifunctionality of EbA. It is a holistic approach. EbA is closely linked to the ecosystem-based approach, the conceptual framework of the CBD.
<b>Disaster risk reduction</b>	DRR is a global approach to disaster risk, consisting of identifying, quantifying, preventing, reducing and managing disaster risk (UNDRR, 2017). Eco-DRR is a specific branch of DRR, closely related to NBS: "Ecosystem-based disaster risk reduction is the holistic, sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development." (CBD, 2018)	UNDRR, 2017. The Sendai Framework Terminology on Disaster Risk Reduction, <a href="https://www.undrr.org/drr-glossary/terminology">https://www.undrr.org/drr-glossary/terminology</a> (accessed on March 12, 2024) CBD, 2018. Decision 14/5 adopted by the Conference of the Parties to the Convention on Biological Diversity, "Biodiversity and climate change", UNEP/CBD/COP/DEC/14/5.	DRR is the general framework of the UN to protect people from disasters. Eco-DRR can be seen as an NBS approach applied to disaster risk reduction. It is based on ecosystem services. Like EbA, it is part of the conceptual framework of the CBD, so it places the emphasis on stakeholder engagement and multifunctionality. Eco-DRR is closely linked to the ecosystem-based approach, the conceptual framework of the CBD.
<b>Ecological Restoration</b>	"Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed." (SER, 2004)	SER (2004). Society for Ecological Restoration International Science & Policy Working Group. The SER International Primer on Ecological Restoration.	Ecological restoration, or ecosystem restoration, aims to restore ecological functions and services, and therefore to develop NBS. Ecological restoration is a concrete application of the concept of NBS.
<b>Ecological Engineering</b>	Ecological engineering is defined by Mitsch (2012) as "the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both". Ecosystem restoration is considered to be "a sister field" of ecological engineering; for Mitsch, ecosystem restoration is the ideal type of ecological engineering (Mitsch, 2012).	Mitsch, W. J. (2012). What is ecological engineering?, <i>Ecological engineering</i> , 45, 5–12. Mitsch based his definition on the work developed by Odum in the 1960s, and subsequently by Jørgensen and Mitsch.	Ecological engineering is clearly related to ecosystem services, and produces benefits for people and nature. EE is action-oriented; it also can be seen as a concrete application of NBS as a concept.
<b>Building with Nature</b>	Building with Nature is "a new approach to hydraulic engineering that harnesses the forces of nature to benefit environment, economy and society." (Ecoshape, 2024)  "Waterman defines Building with Nature as 'flexible integration of coast and water by making use of materials, forces and interactions present in nature, in the context of hydrological and morphological situation' (Waterman et al., 1998; Vikolainen, 2012)	Ecoshape, 2024. Building with nature. <a href="http://www.ecoshape.org/en/">http://www.ecoshape.org/en/</a> (accessed on March 12, 2024) Waterman, R.E., Misdorp, R., et Mol, A., 1998. Interactions between Water and Land in The Netherlands. <i>Journal of Coastal Conservation</i> , 4 (2), 115-26. <a href="https://doi.org/10.1007/BF02806503">https://doi.org/10.1007/BF02806503</a> . Vikolainen, V., 2012. Nature at Work. The Feasibility of Building with Nature Projects in the Context of EU Natura 2000 Implementation. Thesis defended on December 21st, 2012, at the University of Twente.	The BwN concept was developed as part of a coastal management plan by a Dutch engineer, R. E. Waterman, in the 1990s. The Building with Nature approach is based on the understanding of processes impacting sediment transport in order to use natural dynamics in coastal management. BwN is considered to be an NBS approach applied to coastal risk management. It is an integrated approach that takes account of the local context. BwN is based on nature, but the scope of natural elements here extends to sedimentary dynamics, in contrast to the IUCN view that restricts "nature" to the living. The BwN approach was first clearly oriented towards the use of ecosystem services for the benefit of society, but the current definition incorporates all the pillars of sustainable development.
<b>Living shoreline</b>	"Living shoreline" refers to a dynamic shoreline stabilization technique based on natural endemic elements. It protects the coastline while conserving, restoring or creating natural ecological functions, thereby providing multiple benefits. It can be used in combination with harder engineering approaches, but in this case the natural elements should predominate to support the ecological functions of coastal ecosystems. It is fundamentally opposed to grey infrastructure, allowing habitats to evolve and maintaining the land-sea continuum (NOAA, 2024; Bilkovic et al., 2017)	National Oceanic and Atmospheric Administration, 2024. What Is a Living Shoreline? <a href="https://oceanservice.noaa.gov/facts/living-shoreline.html">https://oceanservice.noaa.gov/facts/living-shoreline.html</a> (accessed March 12, 2024)  Bilkovic, D. M., Mitchell, M., Toft, J., LaPeyre, M., 2017. A Primer to Living Shorelines, in: Bilkovic, D. M., Mitchell, M., LaPeyre, M., Toft, J. (eds), <i>Living Shorelines: The Science and Management of Nature-Based Coastal Protection</i> , CRC Press, pp. 3–9. <a href="https://doi.org/10.1201/9781315151465-2">https://doi.org/10.1201/9781315151465-2</a> .	Like BwN, living shoreline is considered to be an NBS approach applied to coastal risk management. Living shoreline is based on ecosystem services and generates benefits for people and nature. NOAA underlines the multiple benefits of living shoreline. This approach also includes biophysical elements (sand, rocks).

## 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.

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## Data availability

No data was used for the research described in the article.

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