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Review

Nature-based solutions for coastal risk management in the Mediterranean basin: A literature review

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ABSTRACT

The Mediterranean basin is one of the most vulnerable regions worldwide due to its population density, the concentration of economic activities along the coasts and borderline climatic balance. It is identified as one of the most critical erosion hotspots in Europe, mainly due to the degradation of coastal areas, overexploitation and unsustainable practices affecting beach tourism, agriculture and fishing. The region is also affected by other phenomena such as storms and floods, which are exacerbated by climate change. To mitigate and adapt to these environmental and climatic changes, Nature based Solutions (NbSs) are considered a promising step-forward. However, despite their global recognition in both research and policy, few scientific papers and documents on the state of NbSs implementation for coastal risk management in the Mediterranean exist.

This paper aims to provide an understanding of the status of NbS adoption for coastal risk management in the Mediterranean through a literature review. Out of 162 scientific papers and documents, only 23 were found to be relevant to the study. Through the definition and support of an innovative matrix-based approach, the analysis of the state of adoption of NbSs have been performed. Despite the limited information on the state of the adoption of NbSs for coastal risk management in the Mediterranean due to the low numbers of scientific research and documents available, some key considerations have been revealed.

1. Introduction

The Mediterranean basin's high population density, high concentration of economic activity along the coast, and its borderline climatic balance, place it among the most vulnerable regions worldwide to climatic changes (Ferragina and Quagliarotti, 2008). The basin is characterized by a unique and peculiar dynamic regime governed by the Strait of Gibraltar (Foti et al., 2020), and a coastline that is about 54% rocky and 46% sedimentary (Brochier and Ramieri, 2001).

A rapid population growth rate has seen over a third of the Mediterranean population concentrated along its coastal regions. As a popular and successful tourist destination, (Perry, 2003; Salvati, 2014; EEA, 2020), the high concentration of population and tourism in the Mediterranean coastline increases anthropogenic pressures in the region (Brochier and Ramieri, 2001; Cramer et al., 2018; Malek et al., 2018). These pressures stem from infrastructure and coastal development that modifies the coastline in order to support residential, tourism, commercial and transportation activities (EEA, 2020).

Generally, these human-induced pressures are contributing to processes of coastal erosion, which is currently affecting close to 30% of the Mediterranean Basin's coastal areas (EEA, 2020). This is further worsened by the impacts of increased incidence of storms, floods and sea-level rise that is exacerbated by climate change (UNEP/MAP and Plan Bleu, 2020; EEA, 2020; Satta et al., 2017). The rise in sea level increases the risk of coastal flooding, which can affect communities and infrastructure, leading to significant shoreline modification (UNEP/-MAP and Plan Bleu, 2020). As a matter of fact, 37% of the Mediterranean coastal areas are at moderate to high risk from coastal erosion and flooding (Ali et al., 2022). Moreover, some studies show that without coastal protection or adaptation strategies, and in the face of the most sever climate scenarios, there could be a 48% increase in the land area globally susceptible to flooding by 2100, posing a threat to 52% of the world's population and 46% of its assets (Sarkar et al., 2022).

Overall, the degradation of coastal areas and the overexploitation and unsustainable practices along the Mediterranean coasts and in the sea, are expected to negatively affect economic activities such as tourism, agriculture, and fishing activities (UNEP/MAP - Barcelona Convention, 2012).

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In the past, the protection of coastal areas from erosion and flooding has been mainly based on conventional "hard" engineering infrastructures, such as seawalls, groins, sloping structures and offshore structures. Yet, the acknowledgment that these technically focused coastal risk management strategies are inadequate to address the rising and intensifying coastal risks associated with climate change (Pranzini et al., 2015) has heightened the demand for more adaptable, cost-effective, resilient, sustainable, and environmentally friendly management measures (Eggermont et al., 2015).

One of the latest and potentially most promising approaches to protect coastal areas is through the implementation of Nature-based Solutions (NbS) (Gómez Martín et al., 2020). The European Commission, European Commission, Directorate-General forResearch and Innovation, 2022: 7) defines NbS as "… living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits". This definition emphasizes the importance of biodiversity and ecosystem functions and processes within a comprehensive adaptation strategy aimed at adapting and mitigating the effects of climate change (Gómez Martín et al., 2020).

As a matter of fact, NbS are one such measure that have been suggested as an effective alternative for addressing societal, financial, and environmental problems caused by climate change, by converging various innovative, efficient and holistic ecosystem approaches with funding and policy, legislation (Su, 2022) to achieve several evaluated societal, environmental and economic benefits (Eggermont, et al., 2015). Nature-based Solutions within coastal climate risk management are characteristically designed to improve coastal structures, or work with natural coastal habitats and features, to provide a range of benefits to people and the coastal environments. Their designs can include the enhancement of manmade structures with ecological features, as well as enhancing natural coastal habitats or landscapes to cope with climate risks (UNEP/MAP and Plan Bleu, 2020). Some examples of these kind of NbS are beaches, dunes, saltmarshes, mangroves, sea grasses, coral and oyster reefs and wetlands. For instance, the restoration or protection of coastal ecosystems can reduce the vulnerability of eroding coasts against current and projected increases of floods, offering numerous benefits to the social-ecological system (Gómez Martín et al., 2020).

Despite the simplicity of the concept of Nature-based Solutions, and their multiple co-benefits, the design, and uptake of Nature-based Solutions vary greatly depending on regions. While some countries and regions exhibit greater uptake of these interventions others, such as the Mediterranean, still lag (Su et al., 2021). Additionally, the success of Nature-based Solutions when compared to their intended goals also varies with differences in environmental conditions and social-ecological processes of the contexts within which the interventions are implemented (Su et al., 2021). Different parameters and methodologies of implementing Nature-based Solutions have been reported to affect the coordination, application, and overall evaluation of Nature-based Solutions principles within various interventions (Cohen-Shacham et al., 2019). Therefore, examining the various parameters and methodologies that determine the design, implementation, coordination, and general application of Nature-based Solutions is vital to understand the levels of knowledge and overall adoption (Su et al., 2021).

With an overarching objective of bringing a preliminary understanding of the state of the adoption of Nature-based Solutions for coastal risk management in the Mediterranean basin, this study analyses past and current Nature-based Solutions efforts for coastal risk management in the Mediterranean. The research is based on a systematic literature review, performed by deliberately limiting the search in mentioning Nature-based Solutions and the Mediterranean basin.

The research is guided by the overarching question:

To what extent are Nature-based Solutions used for Mediterranean Coastal risk management?

To guide the answer, the following sub-questions are used: i) What kind of Nature-based Solutions have already been used for coastal risk management in the Mediterranean? ii) For what purpose have been Nature-based Solutions implemented? iii) Are the Nature-based Solutions achieving the intended goal? iv) What kind of process has been performed for their definition, design, implementation and maintenance? And who is in charge of their implementation and maintenance? Who bears the cost of interventions? v) What potential impact(s) can climate change have on Nature-based Solutions?

2. Framework of the analysis

Starting from the operationalized classification performed in the study of Gómez Martín et al. (2020), the framework for this work has been structured (Fig. 1).

As is it possible to see in Fig. 1, Nature-based Solutions have been divided into three types, according to the adopted level of human interventions: i) low human interventions; ii) medium human interventions; and iii) high human interventions. The first category refers to approaches that aim to preserve and maintain the ecosystems' well-functioning; the second to all strategies that support the sustainable and multifunctional ecosystem services enhancement; the third refers to higher ecosystem modifications (e.g. hybrid solutions). Moreover, four dimensions have been identified as necessary aspects to be investigated in order to obtain a comprehensive understanding of the state of the adoption of Nature-based Solutions for coastal risk management in the Mediterranean basin, which are: D1) purpose of the implementation of the NBS; D2) achievement of the intended goal in the implementation of the NbS; D3) type of process performed for the NbS definition, design, implementation and maintenance; and D4) impacts of climate change on the NbS.

As shown in Fig. 2, each dimension has been then subdivided into factors and sub-factors to be able to better specify and disaggregate the necessary information.

For D1, five factors have been identified. First of all, the understanding of the type of risk for which the Nature-based Solution is expected to protect the coastal areas (coastal erosion, flooding, debris-mud flow) is of great importance. Moreover, coastal areas can be of different types due to different physical characteristics (wetlands, lagoons, deltas, natural protected areas, or sandy, rocky, stony, or urban). Another aspect to be considered is the main land uses and/or activities occurring in the coastal area. In this sense, it is necessary to identify if the Nature-based Solution refers to natural, agricultural, touristic, residential with high or low density, or industrial/port uses and activities. Moreover, NbSs can have impacts on different scales (regional, metropolitan, urban or neighborhood) and can have short or long-term effects.

To be able to define if the adopted Nature-based Solutions achieved the intended goal (D2), three factors have been identified. The first one refers to the effects (positive, negative, mixed, unclear, no effects) of the Nature-based Solution to the achievement of the intended goal. Furthermore, negative and positive effects need to be investigated. In this sense, the encountered barriers (structural complexity, economic investments, available space to implement the NbS and the ability of the NbS to changing conditions or disturbances) and benefits (primary or secondary, social, environmental, economic, or management) are analyzed.

Another important dimension to be investigated is the one related to the type of process performed for implementing the Nature-Based Solution (D3). To obtain information about this dimension, the type of governance (decentralized, co-management, external, adaptive management or co-adaptive management), participation (active or passive), knowledge (local or expert), and funding (public or private) are analyzed.

As stated by Gómez Martín et al. (2020), the potential climate change impacts on NbSs need particular attention because they will affect NbS performance and effectiveness. The Nature-based Solution capability to

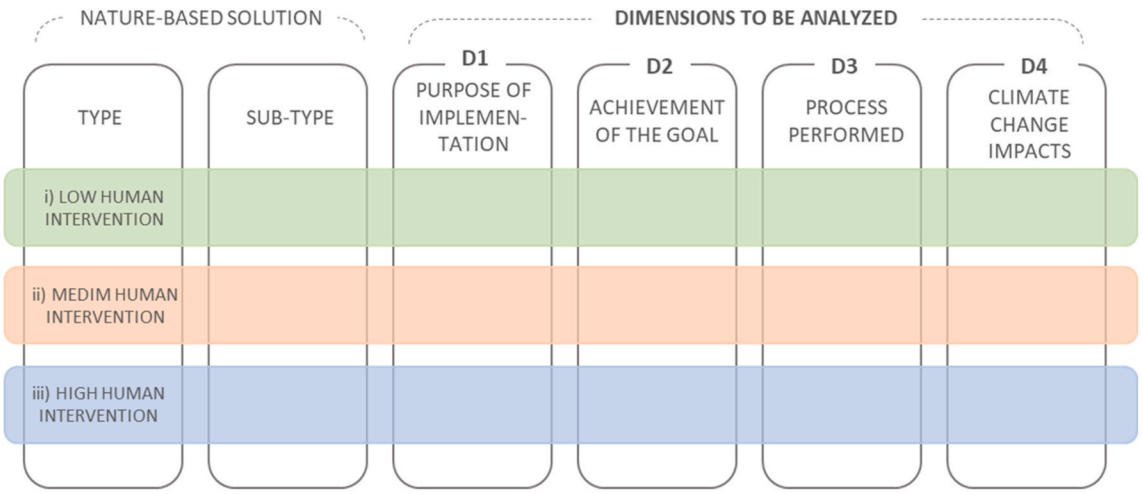

Fig. 1. Framework of the analysis (adapted from Gómez Martín et al., 2020).

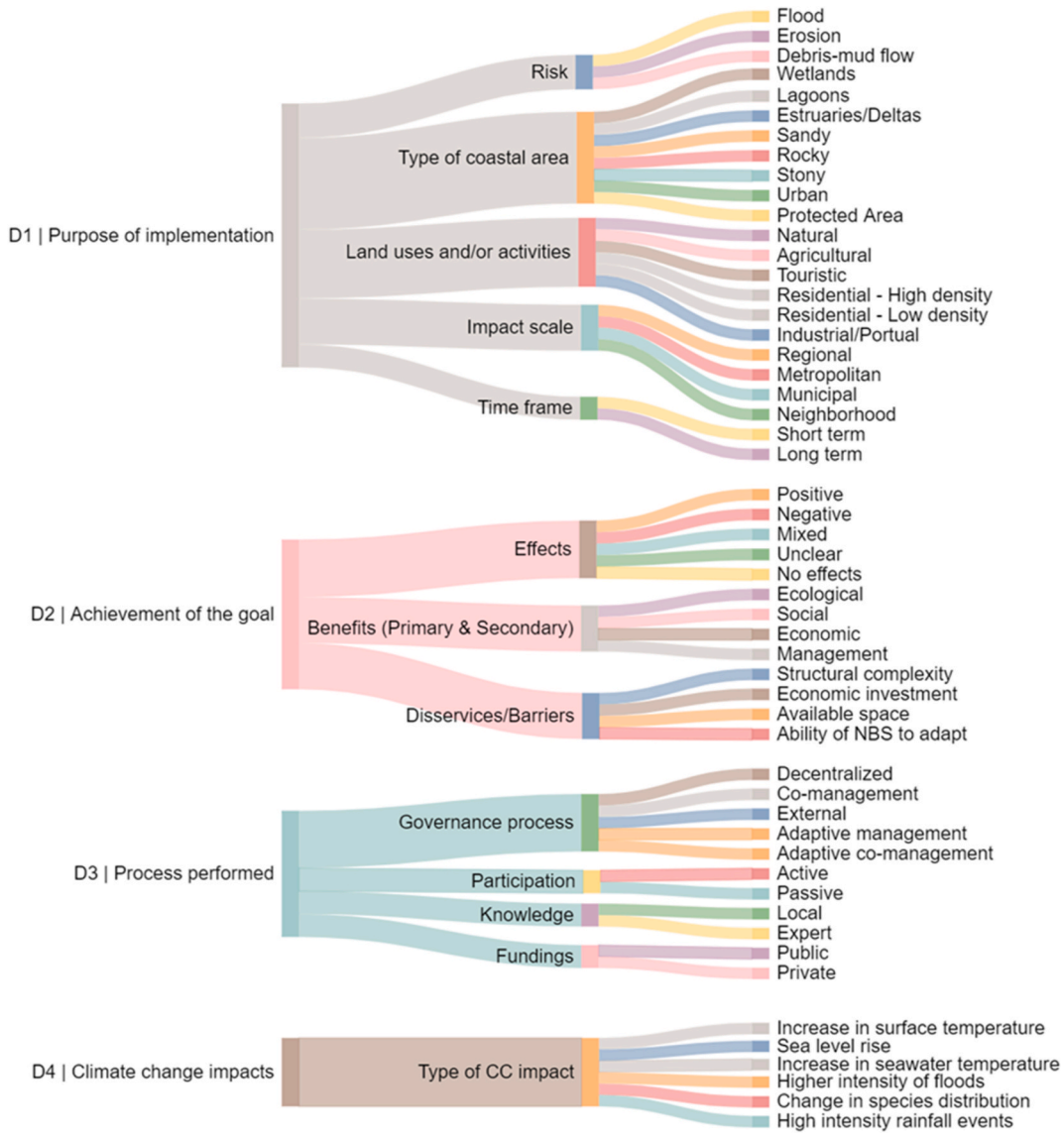

Fig. 2. Dimensions, factors and sub-factors for a comprehensive understanding of the state of the adoption of Nature-based Solutions.

resist, recover or adapt to future conditions is directly related to the potential impacts of climate change. For this reason, the last dimension refers to this aspect (D4) and the following sub-factors have been identified: increase in seawater temperature, increase in surface temperature, sea level rise, higher-intensity of floods, change in species distribution and high intensity rainfall events.

2.1. Data collection through literature review

As shown in Fig. 3, the analysis on adopted Nature-based Solutions for coastal erosion and flooding risk management in the Mediterranean has been performed by using different sources to find scientific papers and documents until the end of 2022, and by following the Preferred Reporting Items for Systematic Review (PRISMA) recommendations (Moher et al., 2009). In light of the research question and associated sub-questions mentioned earlier, a careful selection of keywords has been conducted to facilitate data collection. These keywords are as follows: i) Nature-based Solution, ii) Mediterranean, iii) coast, iv) risk, v) flood, and vi) erosion. These keywords have been chosen strategically to ensure that the collected data are relevant to the specific focus of the research, which centers around exploring the role of Nature-based Solutions in mitigating risks related to flooding and erosion along the densely urbanized Mediterranean coastlines. By incorporating these keywords into the data collection process, we aimed to gather pertinent information that addresses the research objectives and contributes to a deeper understanding of the topic at hand.

The first search of documents has been done by using the Scopus Search platform, by using the following query: *Nature-based solution" AND "risk" AND "mediterranean" AND "coast" AND ("flood" OR "erosion")*. To allow a wider and more complete search of available scientific papers, other sources have been adopted by using the predefined keywords. The used platforms are Web of Science, Cross-ref, Google

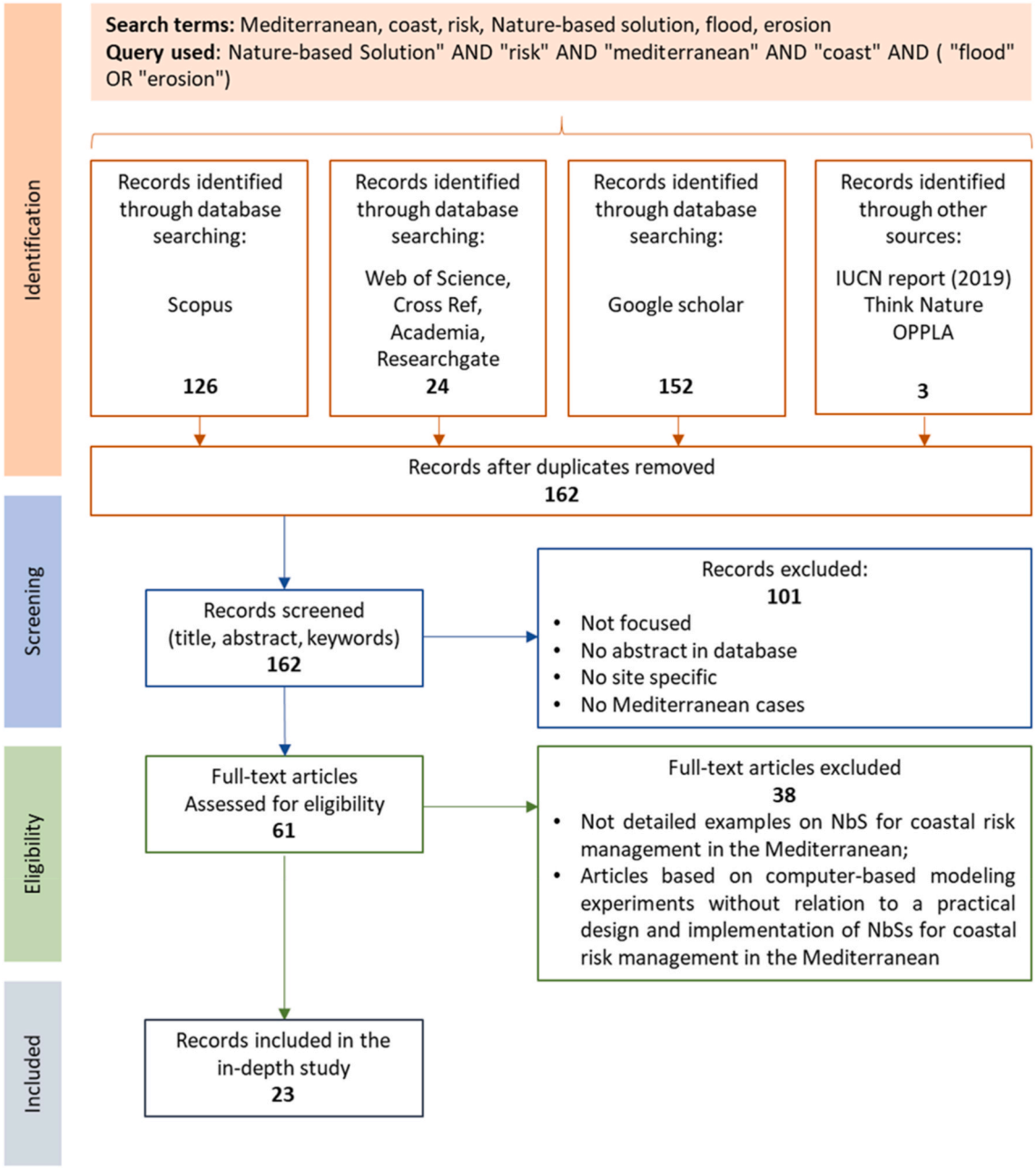

Fig. 3. Flow diagram illustrating records identified following the PRISMA statement (Moher et al., 2009).

Scholar, Researchgate and Academia. Moreover, to gather as much information as possible, the IUCN Report "Towards Nature-based Solutions in the Mediterranean" (2019) has been analyzed, as well as a search through the OPPLA and ThinkNature Platforms has been performed. The initial search provided 126 records for Scopus, 24 for Web of Science, Cross Ref, Academia, and Researchgate, 152 for Google scholar and 3 for other sources (IUCN report, Think Nature and OPPLA platforms).

After removing duplicates, 162 records have been screened by reading titles, abstracts and keywords, and those not focused, with no abstract, no site-specific and no Mediterranean-focused have been excluded. Then, 61 full-text articles have been assessed for eligibility. Those scientific research have been fully read and the ones with no detailed examples on NbS for coastal risk management in the Mediterranean and the ones based on computer-based modeling experiments without relation to a practical design and implementation of Nature-based Solutions for coastal risk management in the Mediterranean have been excluded. Finally, 23 scientific research and documents have been included in the in-depth study and the list is available in Appendix A.

3. Results

Starting from a general overview, the word cloud represented in Fig. 4, shows the principal keywords gathered from the literature review. As expected, "coastal" is the most representative term, followed by "change", "climate", "water", "beach" and "mediterranean". The word cloud also reveals the most described NbS, which is "seagrass".

Taking into account the three types of Nature-based Solutions (Low, Medium and High human intervention) illustrated in Fig. 5, the analysis shows that only one NbS has been recognized as a "Low human intervention" (seagrass conservation), six as "Medium human intervention" (seagrass restoration, dune restoration, beach nourishment, restoration of sediment delivery, wetland restoration and forest restoration) and four as "High human intervention" (infrastructural drainage systems, coastal barriers, stone wall terraces and dune construction).

Seagrass is the most described Nature-based Solution within the analyzed documents (3 documents relate to "seagrass conservation" and 5 to "seagrass restoration"), which further confirms the results from the word cloud in Fig. 4.

To thoroughly examine all documents and address the main question and sub-questions, a matrix was employed to break down the various types, dimensions, factors, and sub-factors of the Nature-based Solutions (NbSs) being studied (refer to Fig. 6). Initially, it becomes apparent that there is a shortage of information across the factors within the four dimensions required to address the research question and sub-questions of this study. Specifically, there is limited information available on the disservices and barriers associated with NbS, as well as on the impacts of climate change on NbS.

For a deeper comprehension of the utilization of Nature-based Solutions in Mediterranean coastal risk management, additional comprehensive analysis has been conducted by categorizing the findings into three types of NbS.

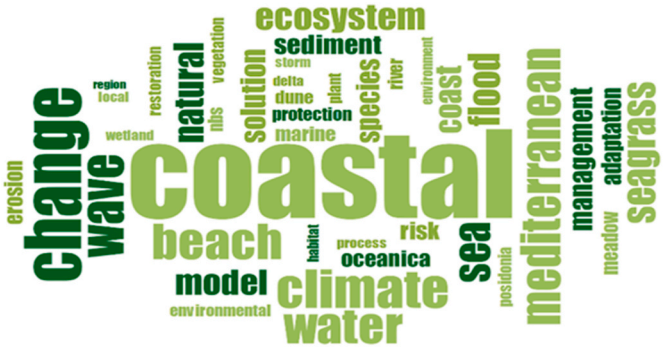

Fig. 4. Word cloud of the main keywords derived from the analysis performed.

3.1. Nature-based Solutions of Type 1 "low human intervention"

Seagrass conservation has been identified as the only NbS of Type 1 in three documents (Pranavam Ayyappan Pillai et al., 2022; Marinelli, 2020; Sánchez-Arcilla Conejo et al., 2017).

Starting from the first dimension "Purpose of the NbS implementation" it is possible to draw some preliminary results. 2 out of 3 NbS have been implemented for managing both coastal erosion and flooding. Even if no information is given on the type of coastal area, it is possible to observe that seagrass conservation has been mainly performed in touristic and residential (with high density) coastal areas. Only in one case the impact scale is clear and it refers to the municipal one, however, there is no information about the time frame, and the NbS effects are unclear in two cases and missing in the third.

Moving to the second dimension "Achievement of the intended goal", the lack of information is clearly observable. Only in one case, benefits are reported: the primary benefit is identified as ecological and the secondary as management.

Completely absent is information about the third dimension "Type of process performed" and the fourth dimension "Climate change impacts".

3.2. Nature-based Solutions of Type 2 "medium human intervention"

Six different NbS have been categorized as Type 2.

Dune restoration, mentioned four times (Mirauda et al., 2022; Della Bella et al., 2021; D'Alessandro et al., 2020; IUCN Centre for Mediterranean Cooperation, 2019), has been implemented to counteract coastal erosion, and in one case also for coastal flooding. The type of coast in which the NbS has been adopted is described only ones, which is a Protected natural area, with sandy and stony beaches. In two circumstances, the main land uses are touristic and only ones it is recognized the presence of residential use with low density and the municipal impact scale. Differently from the NbS of Type 1, in one case it is reported the long-term time frame of the proposed intervention. Lastly, mixed effects are described in one example, while in the other, there are unclear effects. Considering the second dimension, two out of four examples have ecological and management primary benefits, whilst as secondary are reported mostly social and economic ones. Disservices and barriers are not reported. Differently from the NbS of Type 1, some information about Dimension three is given. In one case, adaptive management has been adopted with the active involvement of stakeholders. Moreover, in two out of four documents, both local and expert knowledge has been used within the process and in most cases, public funding has been used to implement the whole process for the dune restoration. In one study, it is reported a negative climate change impact on the NbS which is the change in species distribution.

Forest regeneration, identified only ones (Turconi et al., 2020), has been applied to managing the risk of debris-mud flow in a protected natural area characterized by rocky beaches. It was implemented in a mainly touristic area with an impact scale at the municipal level. However, the effects of such NbS are unclear. To understand the achievement of the intended goal, primary and secondary benefits are reported; the former is a management benefit, and the latter is ecological, social and economic dimensions. Also for this case, no information about disservices and/or barriers is given. Less evidence is given to the type of process performed, where there is only a mention of the funding, which is public. Regarding the last dimension, high-intensity rainfall events are recognized as potential climate change impacts on this NbS.

Another NbS of this Type is beach nourishment, which has been implemented for mitigating coastal erosion in three cases (Andreadis et al., 2021; Bergillos et al., 2018; Maiolo et al., 2020). One of them has been explicitly adopted to deal with flooding risk. This solution has been

Fig. 5. Types of NBS with the specification of the different Nature-based Solutions described in the analyzed scientific literature and documents.[11]

adopted in touristic urban sandy beaches, with a municipal or neighborhood impacts scale. In one case, the intervention has been adopted for a short-term time frame and it has led to positive effects. Considering the second dimension, the primary benefit of beach nourishment is economic, with management benefits being recognized as secondary. As in the previously analyzed NbS, no disservices and/or barriers are mentioned.

Regarding the type of process performed, there is a low level of information. Only one case describes the type of knowledge used, which is only expert knowledge. No data for analyzing the dimension of climate change impacts on NbS have been reported.

Restoration of sediment delivery has been used in two cases as an intervention to deal with coastal erosion and flooding (Ibáñez and Caiola, 2021; IUCN Centre for Mediterranean Cooperation, 2019). It has been adopted in wetlands and estuaries/deltas with natural and agriculture as the main land uses. In one case, the impact scale was the municipal one with a long-term time frame. In both cases, positive effects have been registered. Regarding the second dimension, only benefits are recognized, without any information about disservices and/or barriers. The primary benefits are ecological and the secondary are economic. In one case, a co-management process has been performed, with the active involvement of actors, the use of both local and expert knowledge, as well as public and private funding. Lastly, sea-level rise has been recognized as a potential climate change impact on such NbS.

The adoption of wetland restoration has been performed to mitigate coastal flooding only in one case, in an industrial area used as saltworks for decades (Segura et al., 2018). No information is given in relation to the impact scale, the time frame and the effects. Relating to the second dimension, the primary benefit is management and the secondary benefit is ecological. No disservices and/or barriers have been highlighted. The process performed to implement this NbS has been adaptive management, however, no information is present about participation, knowledge and funding factors. Once again, no mention has been made of the possible impacts of climate change on the proposed NbS.

The last NbS of Type 2 is seagrass restoration, which has been reported in five documents (Boudouresque et al., 2021; Maiolo et al., 2020; Sierra et al., 2017; Ondiviela et al., 2014; Jordà et al., 2012). Three of them are explicitly about coastal erosion, one about mitigating coastal flooding and one for both. Less information is available on both types of coastal areas and land uses and/or activities. Only one document clearly reports that seagrass restoration has been adopted in sandy beaches, and specifically in a harbor area. Impacts vary from neighborhood to regional scale. There is only one specification of the time frame and it relates to the short term. Moving to the second dimension, the majority of the effects are unclear, however, one case registered no effects and another case identified mixed effects. Only one case reports both benefits (primary and secondary) and disservices and/or barriers. In this case, the primary benefits are ecological and management, whilst the secondary is economic. Structural complexity, high economic investment and the less ability of the NbS to adapt to changing conditions and disturbances are the main disservices and barriers. There is no information about the type of process performed, whilst some data is available for the Climate change impacts dimension: in two examples the increase in seawater temperature has been identified as a climate change impact on the NBS and in another case, sea level rise is mentioned.

3.3. *Nature-based solutions of Type 3 "high human intervention"*

Four Nature-based Solutions have been recognized as Type 3 "High human intervention".

Coastal barriers, mentioned only in one document, have been implemented to mitigate both coastal erosion and flood risks (Ciampa et al., 2021). They have been adopted in a touristic urban area characterized by a sandy beach. This intervention has had positive effects with impacts on the municipal scale. However, no information related to the time frame is available.

The analysis of the second dimension reveals that both benefits and disservices/barriers have been identified. The primary benefits are management and the secondary are ecological, social and economic. Structural complexity, high economic investment and less ability of the NBS to adapt to changing conditions and disturbances are recognized as the main disservices and barriers. The performed process is a co-management one, in which active participation and both expert and local knowledge have been used. However, no information about funding is available. Even no climate change impacts on the NBS have been reported.

Infrastructural drainage systems, adopted to mitigate coastal flood risk in one case (Nóblega-Carriquiry et al., 2022) and both flood and erosion risk in another one (Ciampa et al., 2021), have been implemented in urban coastal areas, where agricultural, touristic, residential with high density, and industrial/portual uses and activities are present. The present NbS has a municipal-to-metropolitan level of impact whit both short and long-term time frames. The dimension to analyze the achievement of the intended goal shows positive effects in one case and unclear effects in the second one with management primary benefits and ecological, social and economic secondary benefits. In addition, the high economic investments are identified as a disservice and barrier to achieving the intended goal. One example underlines the process performed, which is the adaptive co-management with the active participation of various actors, with the usage of both local and expert knowledge. No information is given to the last dimension regarding the potential climate change impacts on Nature-based Solutions.

Stone wall terraces, identified as a Nature-based Solution of Type 3, have been ones reported to mitigate debris-mud flow at a municipal level in a Protected Natural area characterized by rocky beaches

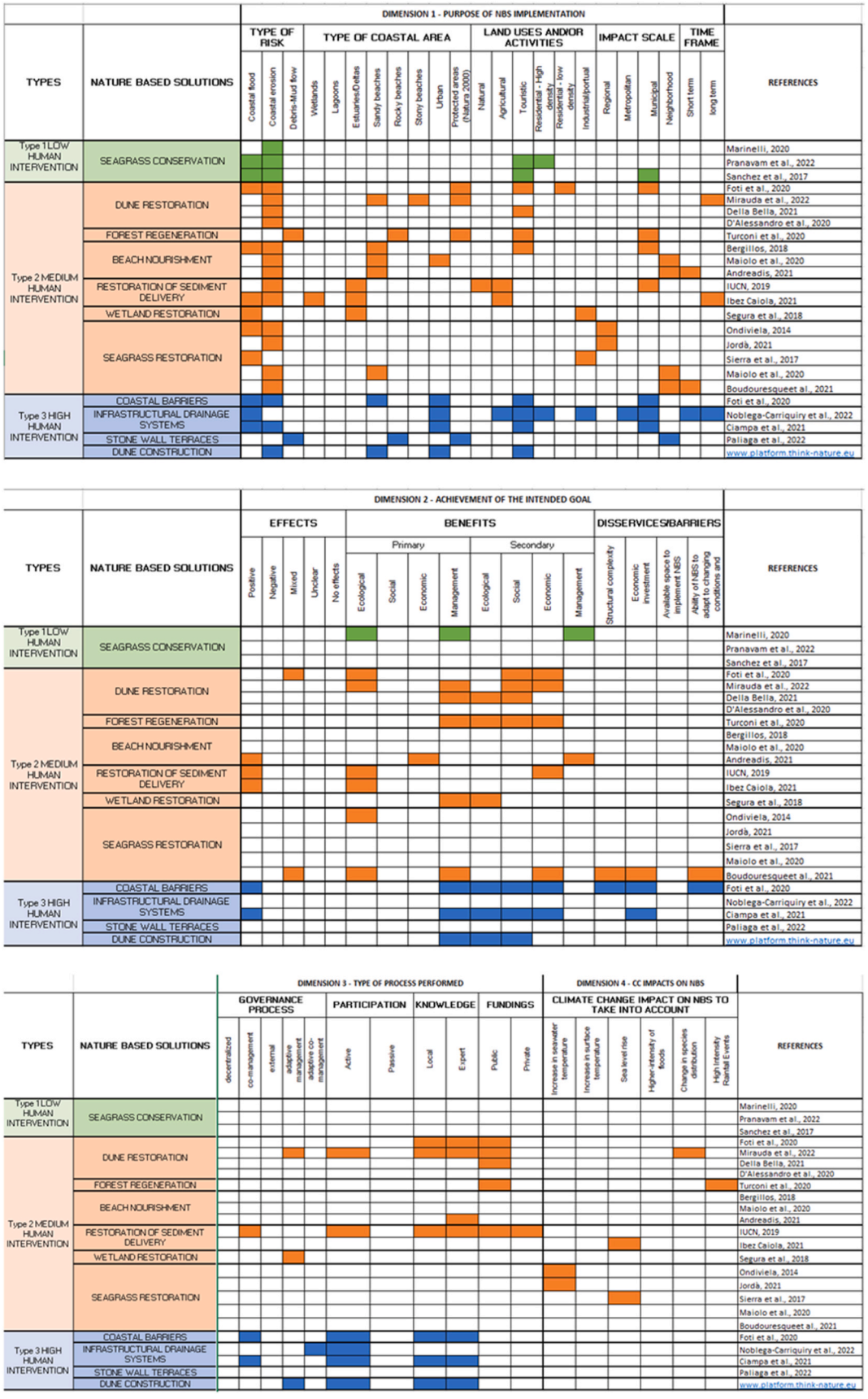

Fig. 6. Analysis of the identified Nature-Based Solutions.

(Paliaga et al., 2022). No information is given on the time frame for the NbS to achieve the intended purpose. The effects are unclear and no evidence emerges for understanding the achievement of the intended goal, the type of process performed and the potential climate change impacts on the proposed NbS.

Dune construction has been reported in one case with the purpose to counteract the risk of erosion in a touristic urban coastal area characterized by sandy beaches (www.platform.think-nature.eu/nbs-case-study/17274). The impact scale and the time frame are not specified. Considering the second dimension, unclear effects and no disservices and barriers have been reported. However, management is recognized as the primary benefit, with ecological and social secondary ones. An adaptive management process was performed, with the active participation of stakeholders and the use of both local and expert knowledge. No evidence emerges in relation to funding. Even in this case, no information is available about the climate change impacts on the implemented Nature-based Solution.

4. Discussion

This paper has reviewed scientific research and documents on adopted Nature-based Solutions for coastal risk management in the Mediterranean. The aim has been to bring a preliminary understanding of the state of the implementation of such Nature-based Solutions. The present review focuses on six keywords (Nature-based Solution, Mediterranean, coast, risk, flood, and erosion). As a result, only 23 scientific research and documents were eligible for the in-depth study. Despite the limited information on the state of the adoption of Nature-based Solutions for coastal risk management in the Mediterranean due to the low numbers of scientific research and documents available, some key considerations can be revealed.

Generally, the frame developed to perform the present review brings important elements to understand the role of interdisciplinary efforts for coastal protection in the Mediterranean Basin. In fact, the study investigates physical, ecological, economic and social assets related to the implementation of NbS for coastal risk management. Although there is an increasing recognition of the importance of adopting interdisciplinary approaches to managing risks, our analysis shows a marked sectoriality of the solutions proposed in the various documents analyzed. In fact, there are no studies highlighting the importance of adopting multidisciplinary approaches nor of integrating multiple Nature-based Solutions or NbS with hard engineering solutions.

Furthermore, on one hand, this study endeavors to address certain limitations outlined by Gómez Martín et al. (2020) by enhancing the existing framework and applying it to assess the implementation of Nature-based Solutions in Mediterranean coastal risk management.

On the other hand, in accordance with the sub-questions outlined in Section 1, specific in-depth insights can be emphasized.

4.1. What kind of nature-based solutions have already been used for coastal risk management in the mediterranean?

The most adopted Nature-based Solutions for coastal risk management in the Mediterranean are the ones classified as Type 2 “Medium human intervention” and, thus, aiming at supporting sustainable and multifunctional ecosystem services enhancement. Within this type of NbSs, seagrass and dune restoration are the most used, followed by beach nourishment, restoration of sediment delivery, wetland restoration and forest regeneration. The most implemented Nature-based Solutions of Type 3 “High human intervention”, that lead to higher ecosystem modifications, are the infrastructural drainage systems, followed by dune construction, coastal barriers and stone wall terraces. Only one NbS of Type 1 “Low human intervention” was revealed from the review and relates to seagrass conservation.

4.2. For what purpose have been nature-based solutions implemented?

Purpose-wise, most Nature-based Solutions applied for coastal risk management in the Mediterranean are primarily used to mitigate the risk of coastal erosion. Coastal flooding risk is also considerably represented, but in most cases, it goes hand in hand with coastal erosion. The review reveals also another coastal risk that has been mitigated through the adoption of NbSs, which is debris-mud flow. This coastal risk has been addressed by implementing forest regeneration (Turconi et al., 2020) and stone wall terraces (Paliaga et al., 2022).

Most of the analyzed Nature-based Solutions have been implemented on neighborhood and municipal scales mainly in urban and touristic coastal areas, with the main purpose of protecting sandy beaches. These findings can primarily be related to the high concentration of population along the Mediterranean coasts and the extensive touristic usage of such coastal areas. However, there is limited information about the time frame scheduled for the Nature-based Solutions to be defined, designed and implemented.

4.3. Are the Nature-based solutions achieving the intended goal?

Regarding the achievement of the intended goal, the prominence of the unclear effects and the absence of disservices and barriers of the NbSs, restrict drawing comprehensive insights. As a matter of fact, the limited availability of information about the disservices and implementation barriers of Nature-based Solutions is aligned with the limitations identified by Gómez Martín et al. (2020).

However, it can be deduced that most of the Nature-based Solutions are intended to achieve both ecological and management primary benefits, while social and economic benefits are considered additional benefits or co-benefits. These findings are aligned with the general definition of Nature-based Solution given by the study of Maes and Jacobs (2017), which describes NbS as living solutions inspired by, supported by and continuously utilizing nature, designed to address different societal challenges in a cost-effective and adaptable way and to co-currently provide economic, social, and environmental benefits.

4.4. What kind of process has been performed for their definition, design, implementation and maintenance? And who is in charge of their implementation and maintenance? Wwo bears the cost of interventions?

As highlighted in Section 1, the growing recognition that traditional grey infrastructures are not sufficient to cope with the increase and intensification of climate change-related coastal risk has amplified the urge and attention to devising and implementing more adaptive and sustainable processes through the active involvement of multiple experts, policymakers and stakeholders and the use of both expert and local knowledge.

Concerning the processes of implementing Nature-based Solutions for coastal risk management in the Mediterranean, there is minimum scientific research evidence on the governance, participation, knowledge and findings factors. However, within these limited results, co-management and adaptive management are relatively utilized with the active participation of various stakeholders. In both these management processes, knowledge was elicited through expert and local sources. Funding for the implementation of Nature-based Solutions is mostly public with limited evidence of private involvement.

4.5. What potential impact(s) can climate change have on nature-based solutions?

In line with the limitations Gómez Martín et al. (2020) highlighted in their study, the review revealed a profound scarcity of information

[1] The number of documents can differ from the number of NbS because one document may include more than one example of NbS.

regarding the potential climate change impacts on the implemented Nature-based Solutions. In light of the already existing scientific evidence on the impacts of climate change on ecosystems and the services that they deliver, this raises concerns about the long-term sustainability of Nature-based Solutions.

5. Conclusions

This paper investigates the state of the adoption of Nature-based Solutions for coastal risk management in the Mediterranean basin.

Nature-based Solutions are globally heralded in both research and policy, as a promising alternative or complement to traditional grey infrastructures for addressing the increase and intensification of climate change-related risk. The UN Sustainable Development Goals and Paris Agreement respectively highlight and emphasize the importance of utilizing biodiversity and the functioning of ecosystems in order to maintain economic activities and the well-being of local communities, and the need for integrated land use practices and landscape restoration approaches to facilitate greater climate ambition. Additionally, the Sendai Framework for Disaster Risk Reduction (2015–2030) explicitly recognizes and encourages the strengthening and sustainable use and management of ecosystems for building resilience to disasters.

Despite its global recognition, this study unveils a scarcity of scientific evidence and of interdisciplinary efforts in adopting NbS for coastal risk management, possibly stemming from the experimental phase of implementation in the Mediterranean region. The limited understanding of the various dimensions, factors, and sub-factors may portray Nature-based Solutions (NbSs) as a less appealing option compared to conventional approaches. Consequently, this could impede decision-making regarding future investments in nature-based projects. Furthermore, in numerous instances, Nature-based Solutions compete for land use change with economic objectives, particularly as the majority of the Mediterranean coastline sustains the local economy through tourism.

Starting from these first findings, future investigations will be performed by analyzing other kinds of tools, such as EU Projects focusing on NbS adoption for coastal risk management in the Mediterranean.

CRediT authorship contribution statement

Giulia Motta Zanin: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Simon Peter Muwafu:** Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **María Máñez Costa:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2024.120667.

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