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Research article

A conceptual framework to help choose appropriate blue nature-based solutions

Géraldine Pérez [a], Bethan C. O'Leary [b,c], Elena Allegri [d,e], Gema Casal [f], Cindy C. Cornet [g], Silvia de Juan [h], Pierre Failler [g], Stein Fredriksen [i,j], Catarina Fonseca [k,l], Elisa Furlan [d,e], Artur Gil [k,m], Julie P. Hawkins [b], Jean-Philippe Maréchal [n], Tim McCarthy [f], Callum M. Roberts [b], Ewan Trégarot [g], Matthijs van der Geest [o], Rémy Simide [a,*]

[a] Oceanographic Institute Paul Ricard, Embiez Island, France
[b] Department of Ecology & Conservation, Faculty of Environment, Science and Economy, University of Exeter, Penryn Campus, Penryn, TR10 9FE, United Kingdom
[c] Department of Environment and Geography, University of York, York, YO10 5NG, United Kingdom
[d] Centro Euro-Mediterraneo sui Cambiamenti Climatici and Università Ca' Foscari Venezia, CMCC@Ca'Foscari – Edificio Porta dell'Innovazione, 2nd Floor – Via della Libertà, 12, 30175, Venice, Italy
[e] Department of Environmental Sciences, Informatics and Statistics, University Ca' Foscari Venice, I-30170, Venice, Italy
[f] National Centre for Geocomputation, Maynooth University, Co. Kildare, Maynooth, Ireland
[g] Centre for Blue Governance, Portsmouth Business School, University of Portsmouth, Portsmouth, PO1 3DE, United Kingdom
[h] The Mediterranean Institute for Advanced Studies, IMEDEA (UIB-CSIC), C/Miquel Marques 21, Esporles, Balearic Islands, Spain
[i] Institute of Marine Research, Nye Flødevigveien 20, 4817, His, Norway
[j] University of Oslo, Department of Biosciences, PO Box 1066 Blindern, 0316, Oslo, Norway
[k] cE3c – Centre for Ecology, Evolution and Environmental Changes, Azorean Biodiversity Group, CHANGE – Global Change and Sustainability Institute, Faculty of Sciences and Technology, University of the Azores, 9500-321, Ponta Delgada, Portugal
[l] MARE – Marine and Environmental Sciences Centre/ARNET – Aquatic Research Network, Faculdade de Ciências, Universidade de Lisboa, Portugal
[m] IVAR - Research Institute for Volcanology and Risk Assessment, University of the Azores, 9500-321, Ponta Delgada, Portugal
[n] Nova Blue Environment, Schoelcher, Martinique, France
[o] Wageningen Marine Research, Wageningen University & Research, P.O. Box 57, 1780 AB, Den Helder, the Netherlands

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ABSTRACT

Biodiversity loss and climate change have severely impacted ecosystems and livelihoods worldwide, compromising access to food and water, increasing disaster risk, and affecting human health globally. Nature-based Solutions (NbS) have gained interest in addressing these global societal challenges. Although much effort has been directed to NbS in urban and terrestrial environments, the implementation of NbS in marine and coastal environments (blue NbS) lags. The lack of a framework to guide decision-makers and practitioners through the initial planning stages appears to be one of the main obstacles to the slow implementation of blue NbS. To address this, we propose an integrated conceptual framework, built from expert knowledge, to inform the selection of the most appropriate blue NbS based on desired intervention objectives and social-ecological context. Our conceptual framework follows a four incremental steps structure: Step 1 aims to identify the societal challenge(s) to address; Step 2 highlights ecosystem services and the underlying biodiversity and ecological functions that could contribute to confronting the societal challenge(s); Step 3 identify the specific environmental context the intervention needs to be set within (e.g. the spatial scale the intervention will operate within, the ecosystem's vulnerability to stressors, and its ecological condition); and Step 4 provides a selection of potential blue NbS interventions that would help address the targeted societal challenge(s) considering the context defined through Step 3. Designed to maintain, enhance, recover, rehabilitate, or create ecosystem services by supporting biodiversity, the blue NbS intervention portfolio includes marine protection (i.e., fully, highly, lightly, and minimally protected areas), restorative activities (i.e., active, passive, and partial restoration; rehabilitation of ecological function and ecosystem creation), and other management measures (i.e., implementation and enforcement of regulation). Ultimately, our conceptual framework guides decision-makers toward a versatile portfolio of interventions that cater to the specific needs of each ecosystem rather than imposing a rigid, one-size-

* Corresponding author. Institut océanographique Paul Ricard, Iles des Embiez, 83140, SIX-FOURS-LES-PLAGES, France.
E-mail address: remy.simide@institut-paul-ricard.org (R. Simide).

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fits-all model. In the future, this framework needs to integrate socio-economic considerations more comprehensively and be kept up-to-date by including the latest scientific information.

1. Introduction

Marine and coastal ecosystems are complex, highly productive, and biodiverse habitats (IPBES, 2020; IPBES & IPCC, 2021) that more than 775 million people globally are highly dependent on, in particular for food provisioning and coastal protection (Selig et al., 2019). Marine vegetated ecosystems, such as mangrove forests, salt marshes, and seagrass beds not only absorb a significant amount of land-based nutrients, therefore improving water quality (Trégarot et al., 2021a; Sousa et al., 2010; Soumya et al., 2015), but also contribute to climate regulation by sequestering large quantities of atmospheric carbon per unit area (McLeod et al., 2011). Their presence also prevents coastal erosion and mitigates flooding, with, for instance, coral reefs absorbing up to 90% of waves' energy on shorelines (Ferrario et al., 2014). These ecosystems also contribute to the economic development of coastal populations through, for example, the development of ecotourism (Himes-Cornell et al., 2018; Tuya et al., 2014) and the improvement of mental health and human well-being (Himes-Cornell et al., 2018). However, the ongoing loss of biodiversity and the degradation of marine and coastal ecosystems are well known to be associated with a reduced capacity of ecosystems to provide the multiple services human societies depend on (Cardinale et al., 2012; Duffy et al., 2016; Soliveres et al., 2016). Therefore, the assessment of the health of Nature, namely an ecosystem's ecological condition, is crucial, requiring not only considering ecological aspects but also the entire socio-ecological system (IPBES, 2019; IPCC, 2023). Indeed, the management and monitoring of ecosystems should not be disconnected from the people who live within them, and the type of assessment chosen should reflect this duality (Dudley Nigel, 2008; IPCC, 2023).

In the context of increasing impacts from climate change (IPCC, 2019) and associated biodiversity loss (IPBES, 2019) and continuous degradation of marine and coastal ecosystems (IPBES, & IPCC, 2021), the flow of ecosystem services on which we depend is jeopardized putting the socio-ecological systems at risk. Therefore, implementing effective actions that reduce biodiversity loss and help mitigate and adapt to climate change must be accelerated and upscaled (IPCC, 2023). Consequently, international institutions such as the International Union for the Conservation of Nature (IUCN), the European Commission (EC), the United Nations for Disaster Risk Reduction (UNDRR), and the United Nations Environment Program (UNEP) are promoting Nature-based Solutions (NbS), a framework that brings together the concepts of protection, restoration, and other management measures to holistically reduce the impacts of human activities on Nature (EC, 2021; IUCN, 2016, 2020; UNDRR, 2020; UNEP/EA.5/Res.5, 2022). Although several definitions have been provided (IUCN, 2016; EC, 2021; UNEP/EA.5/Res.5, 2022), all emphasize the importance of working with Nature to tackle societal challenges by bringing benefits to biodiversity and human well-being, and all have defined their societal challenges based on the 17 United Nations' Sustainable Development Goals (SDGs) (UN, 2015). Despite the great potential for NbS in marine and coastal ecosystems (hereafter referred to as blue NbS), their application has lagged behind compared to terrestrial and urban systems (Chausson et al., 2020; EC, 2021; O'Leary et al., 2023).

Implementation strategies for blue NbS required a great reflection to fulfill their potential. Many factors have contributed to slow blue NbS application so far, including a lack of operational experience and a lack of fundamental knowledge on the functioning of some marine and coastal ecosystems and the ecosystem services they provide from a local to an ecoregional level (O'Leary et al., 2023). Although these are essential for NbS uptake and implementation, we argue one main obstacle is the lack of an integrated framework to support the decision-making process for identifying a range of contextually-appropriate interventions that could be considered a blue NbS. Such frameworks exist but either focus on urban areas (Croeser et al., 2021), social collaboration barriers (Giordano et al., 2021), or only on ecosystem services, specific ecosystems, or interventions (e.g., Wyant et al., 1995; Hopfensperger et al., 2007; Harrison et al., 2018; Lilli et al., 2020). Moreover, existing frameworks do not take into account the specificity of marine and coastal environmental management or the overlay of human activities typical of marine and coastal ecosystems, nor do they focus on ecosystem services delivered by those ecosystems. However, no one framework exists that unites the relationship between ecological condition and ecosystem services with societal challenges more broadly to explicitly help users select appropriate interventions for achieving their goals in their specific context. Therefore, this study presents a conceptual framework that will guide decision-makers and practitioners through the initial blue NbS planning stages by identifying a portfolio of suitable blue NbS or ecosystem-based interventions (protection, restorative activities, and/or other management measures). Using our conceptual framework, blue NbS can be identified as addressing the targeted societal challenge(s) at a relevant spatial scale based on the existing or potential ecosystem(s). By considering the ecosystem services delivered, they will help maintain a suitable environmental context for the ecosystem(s).

The next section presents the conceptual framework, flowing through the four steps designed to align blue NbS objectives and the socio-ecological context: Step 1 – Challenge orientation, Step 2 – Ecosystem services, Step 3 – Environmental context, and Step 4 – Intervention options. Section 3 then discusses the application of our conceptual framework together with the limitations of the approach and further development options before providing our conclusions in Section 4.

2. Conceptual framework for identifying potential blue nature-based solutions

Our conceptual framework was designed within the scope of blue NbS, considering the three most used and current definitions (EC, 2021; IUCN, 2016, 2020; UNEP/EA.5/Res.5, 2022). While our framework considers both Nature and human societies through the consideration of societal challenges and links these through ecosystem services, it focuses on the ecological side of the socio-ecological system we live in. As such, our approach consists of four steps that help identify a selection of potential blue NbS among a portfolio of interventions: (1) challenge(s) orientation; (2) actual and potential flow of ecosystem service(s); (3) environmental context; and (4) intervention options to maintain or enhance the biodiversity and the system functionality (Fig. 1). Each step is provided with guidance on how to follow the framework, including alternative pathways if some information and data are unavailable in a local specific context.

This work is part of the European Horizon 2020 research project 'MaCoBioS' (www.macobios.eu). Consequently, our conceptual framework and approach to NbS have been developed from a Global North perspective. Looking beyond this, it is essential to note that NbS must empower local people, embed knowledge from Indigenous People and Local Communities, and center on the inseparable interdependencies in People-Nature relationships. As such, the conceptual framework is based on the premise that Nature provides humanity with services and that declining ecosystem's conditions will reduce Nature's ability to provide these, thereby threatening human health and well-being.

2.1. Step 1: Challenge(s) orientation

To be considered a NbS, an intervention must bring Nature to the center of the solution while simultaneously contributing to alleviating a societal challenge; collectively, this approach will benefit human health and well-being (IUCN, 2020). A societal challenge denotes a major human objective that needs to be reached to improve human living conditions. From the societal challenges defined by the IUCN (2020), the European Commission (2021), and the UNEP (UNEP/EA.5/Res.5, 2022), we selected seven that are considered relevant in marine and coastal contexts to build our conceptual framework (Fig. 1 - Step 1).

These seven societal challenges are grouped into three categories: climate change mitigation, climate change adaptation, and those required for an intervention to be defined as NbS. The "Climate change mitigation" category is defined on its own and corresponds to the contribution of natural environments in mitigating climate change through their natural processes (e.g., carbon sequestration) (Amado-Filho et al., 2012; Filbee-Dexter et al., 2022). The "Climate change adaptation" category consists of four different societal challenges. "Disaster risk reduction" relies on the ability of natural environments to reduce the risk of natural hazards (e.g., storms, floods (Smale et al., 2013; Trégarot et al., 2021a)). The "Water security" challenge aims to

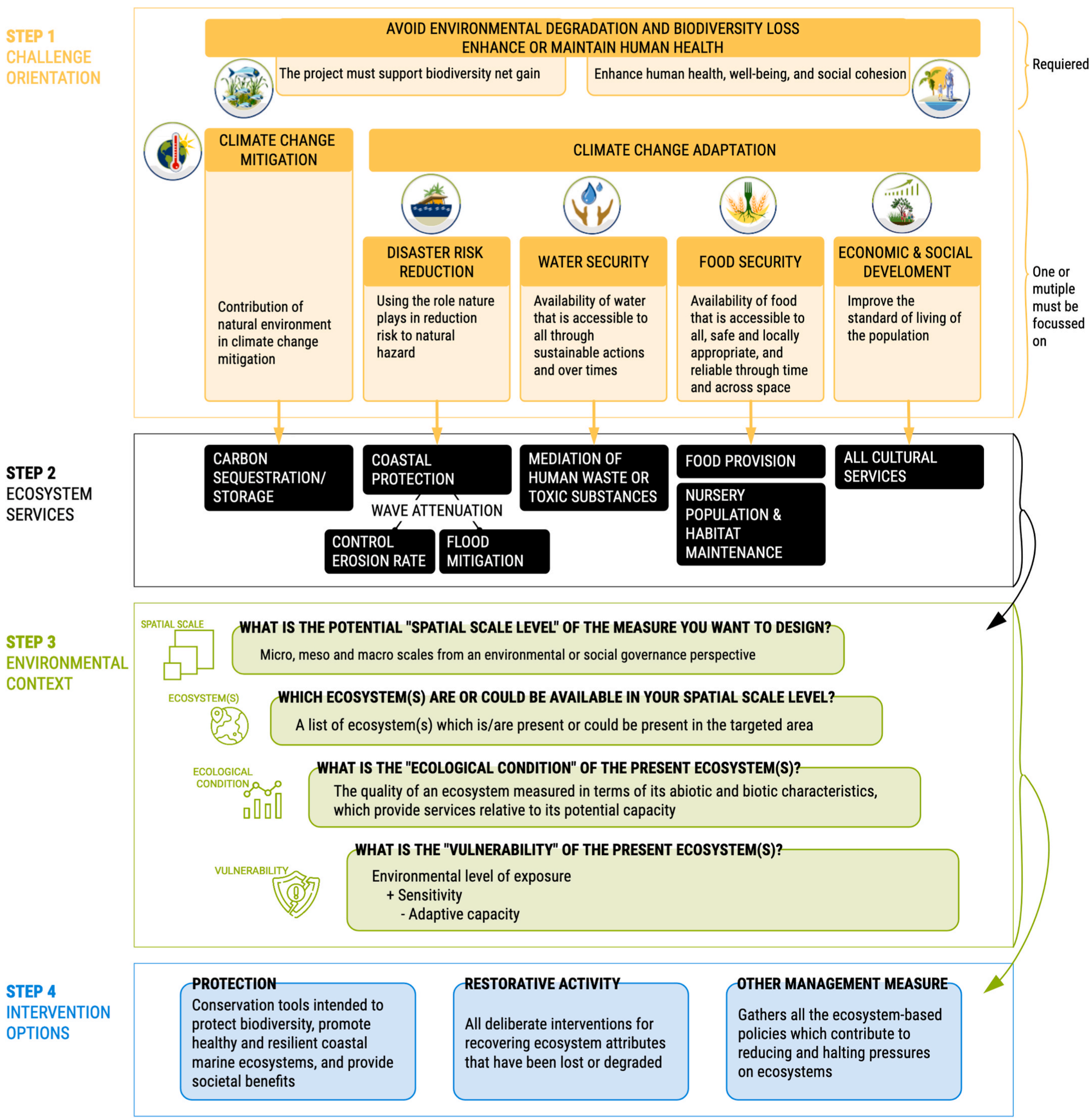

Fig. 1. Conceptual framework for identifying suitable blue Nature-based Solutions. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

ensure the availability of water for all through sustainable actions and over time (e.g., filtration of wastewater, prevention against eutrophication; Lamb et al., 2017; Trégarot et al., 2021b). The "Food security" challenge seeks to provide food that is accessible for all, safe, and locally appropriate through time and across space (e.g., support for fisheries; Costa et al., 2020; Tuya et al., 2014). The "Economic and social development" challenge aspires to improve the standard of living of the population (e.g., the development of activities like ecotourism; Giry et al., 2017; Kittinger et al., 2016). Finally, in alignment with international definitions of NbS, "Avoid environmental degradation and biodiversity loss" is set as a mandatory objective for every NbS project. At the same time, "Enhance or maintain human health and well-being" is considered an outcome of co-addressing biodiversity loss and one or more of the five other societal challenges. This is because biodiversity underpins societies and economies through ecosystem services. Indeed, biodiversity enhances human health and well-being by providing cultural services (e.g., recreation, spirituality, knowledge, aesthetics), securing potential healthcare value (e.g., enjoying Nature through outdoor sport or enhancing mental health), and yet undiscovered pharmaceutical products. Considering these two mandatory societal challenges, this eliminates some management approaches from being considered a NbS intervention. This includes biodiversity and carbon offsets, such as implementing compensation measures for damaging existing native ecosystems, as well as financing a restoration or protection project to compensate for polluting activities in another area (e.g., planting trees to compensate for carbon emissions from economic activities; Fady et al., 2021).

Challenge orientation strongly depends on understanding Local Community concerns and policies (Bouamrane et al., 2016; Esmail et al., 2023). In some places, disaster risk reduction may be the most pressing challenge to address; in others, it may be water security. Following the recommendation of the Convention on Biological Diversity (CBD) to include consideration of "the knowledge, innovations, and practices of indigenous and local communities" (UN, 1992 - Article 8), researchers have recognized that including Local Communities with policies from the first step of planning to the final implementation of an intervention increases the likelihood of a project succeeding (Bouamrane et al., 2016; Esmail et al., 2023). Moreover, different stakeholder groups may also have different perspectives despite using, living, and/or working in the same space (Bouamrane et al., 2016; Hölting et al., 2020; Cormier-Salem, 2014). Therefore, there is not a 'one size fits all' approach that can be taken when selecting NbS, and instead, there needs to be a focus on place- and People-based innovation policies (Seddon et al., 2020). Stakeholder engagement is strongly required to enhance the effectiveness of any NbS in addressing societal challenges. To identify the challenge(s) to be addressed and the subsequent development and implementation of the chosen NbS (Jupiter et al., 2014). Consequently, determining, together with all stakeholders, the needs of the socio-economic system is essential in challenge(s) orientation.

When going through the challenge(s) orientation step, it is essential to consider all the potential linkages and effects arising from different interventions for potential trade-offs. In that way, designing a habitat restoration project to enhance biodiversity and improve water quality may enhance fish stocks (food security) and, subsequently, fishing income (economic and social development). For example, a habitat restoration project in Maunalua Bay (Hawaii) involved removing invasive algae to enhance biodiversity and fishing resources (food security) and also cultural activities (economic & social development) (Kittinger et al. 2016). Alternatively, protecting and/or restoring marine coastal habitats for climate change mitigation may displace some local human activities and, therefore, could reduce economic and social development. For instance, the expansion of Ruaha National Park in Tanzania has led to land-change conflicts from agricultural to tourism practices, where Local Communities do not perceive they are benefitting from that change (Sirima and Backman, 2013).

2.2. Step 2: ecosystem services

Marine and coastal ecosystems provide various ecosystem services that can help address different societal challenges. The ecosystem services concept describes how people use, benefit from, and value Nature by identifying ecosystems' contributions to human well-being and the products people produce or receive from ecosystems (United Nations, 2021). It, therefore, takes an anthropocentric lens to the importance of Nature. However, the interdependencies between People and Nature mean that we can use this concept of ecosystem services to achieve goals for Nature through a People-centric approach. It represents an essential component of NbS because of its social construct: human actions impact Nature, human actions are manageable, and human actions, perceptions, and resources influence the success of management measures for both People and Nature.

The System of Environmental-Economic Accounting (SEEA) has developed a reference list of ecosystem services (United Nations, 2021), aligning knowledge from leading experts in ecosystem services assessment and classification with the crosswalk of five different classifications developed successively: Millennium Ecosystem Assessment (Millennium Ecosystem Assessment (Program), 2005); The Economics of Ecosystems and Biodiversity (TEEB, 2010); Common International Classification of Ecosystem Services (Haines-Young & Potschin et al., 2018); Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Díaz et al., 2018); and the National Ecosystem Services Classification System (Plus) (Newcomer-Johnson et al., 2020) Based on this most recent classification, we selected ecosystem services relevant to the seven societal challenges, namely: carbon sequestration and storage; coastal protection (erosion and flood control through wave attenuation); mediation of human waste or toxic substances; provision of food; nursery population and habitat maintenance; and all cultural services. How these relate to societal challenges is shown in Fig. 1 (orange arrows between steps 1 and 2).

Each ecosystem has its own specific functions and processes related to its particular biodiversity (Harrison et al., 2014), leading to distinct services (provisioning/regulating/cultural) that bring goods and benefits to human society (Babí Almenar et al., 2021; Braat and de Groot, 2012). For example, mangrove forests, salt marshes, and coral reefs are well known to protect the coastline from erosion (Escudero et al., 2021; Friess et al., 2020; Möller et al., 2014), but only mangrove forests and salt marshes also deliver the service of mediation of human wastes or toxic substances (Sousa et al. 2010; Trégarot et al., 2017; Himes-Cornelle et al., 2018). Therefore, the level of such functions and processes depends on the ecosystem(s) present and its/their ecological context (Hamel and Bryant, 2017; IPBES, 2019). In order to choose a suitable intervention option that maximizes the quality and quantity of service delivered to the best answer, the societal challenge(s) targeted in the environmental context must be carefully assessed.

2.3. Step 3: environmental context

The choice of any intervention needs to be set within the specific ecological and governance context (IPBES, & IPCC, 2021). In that way, defining a specific spatial scale for the potential NbS sets the boundaries of the ecological and social governance system within which the potential intervention(s) will occur. Then, the ecosystem condition of the ecosystem(s) targeted, as well as its/their vulnerability to human and natural stressors, need to be assessed to characterize the specific environmental context of the area of interest (Adger, 2006; Ellison, 2015; IPCC, 2007, 2014).

To guide users' decisions, we separate and define each relevant parameter with four specific questions. All responses from these questions need to be analyzed and considered together to choose the best intervention approach (es). The links among management measures, vulnerability components, and ecological conditions are presented in Fig. 2, as well as the output of ecosystem services.

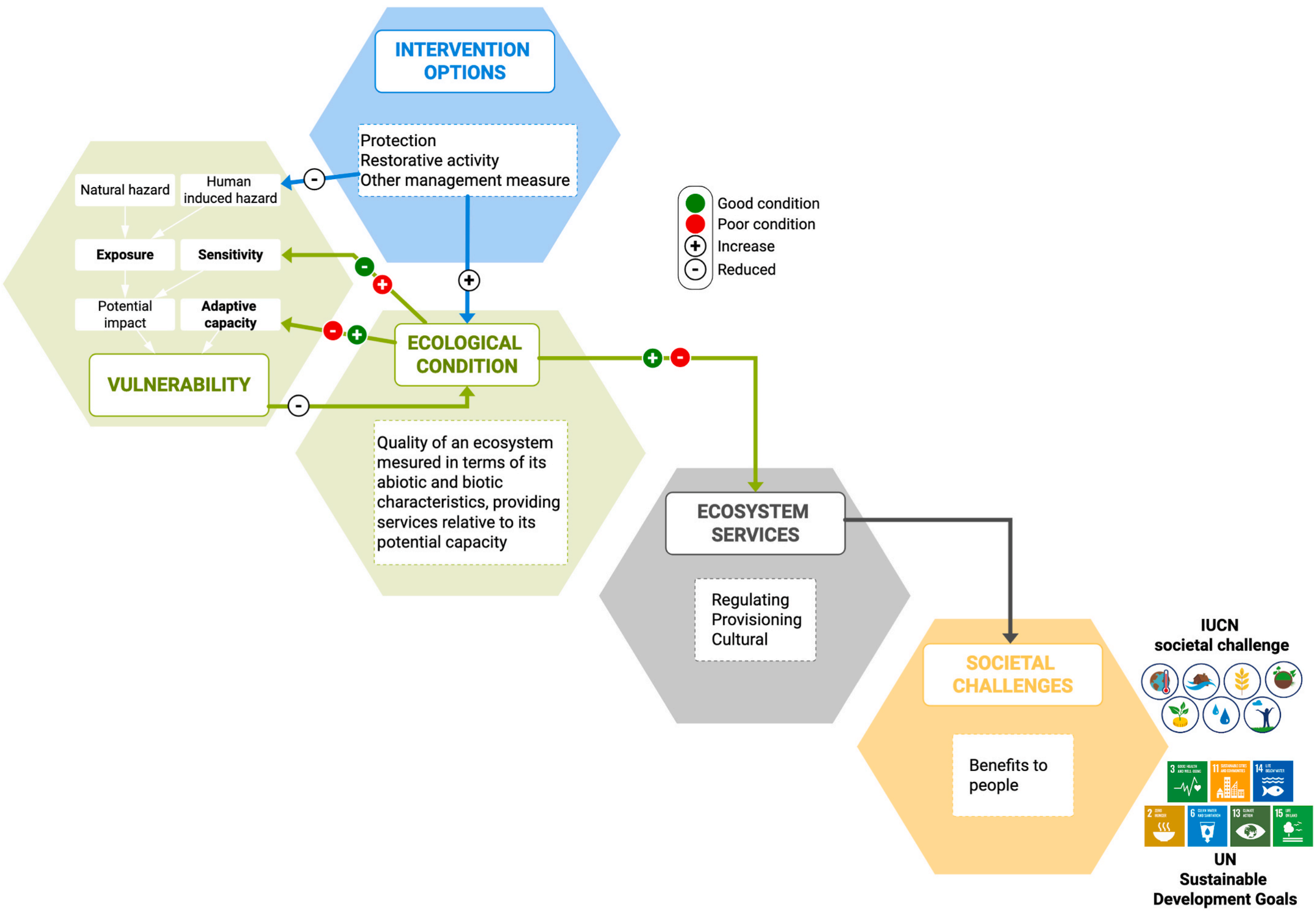

Fig. 2. Relationship between intervention options (protection, restorative activities, and other management measures) and ecological system's capacity to deliver ecosystem services based on vulnerability and ecosystem condition.

Question 1. What could be the potential "spatial scale" of the measure you want to design?

We defined three levels of spatial scale (i.e., micro, meso, and macro) that encompass our dual ecological and governance component. Each level corresponds to an environmental unit, considering the system's social and political organization (Fig. 3).

The ecological "micro" scale corresponds to a 'scape level ('scape being shorthand for landscape and/or seascapes [IPBES, & IPCC, 2021]). The 'scape terminology has been acknowledged and adopted for multiple purposes (Arts et al., 2017; Dudley, 2008; IPBES, & IPCC, 2021; Pittman, 2017). Here we use it to "describe a mosaic of habitats connected by the movement and dispersal of organisms and other biological, physical, and chemical processes" (Murphy et al., 2021), "often within which a particular 'focal' or 'target' habitat patch is embedded" (Boström et al., 2011). For the governance aspect, the "micro" level denotes a community, with people living in one particular area and considered as a unit through the governance that brings them together.

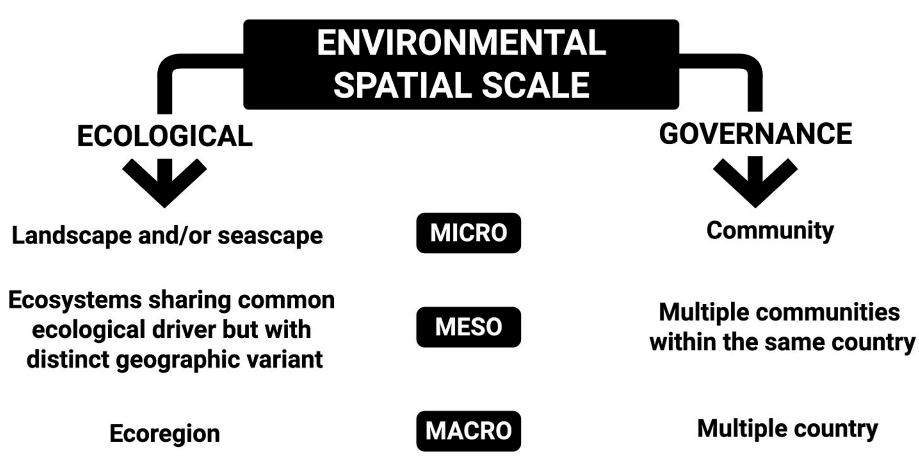

Fig. 3. The three spatial scales with their ecological and governance components.

The ecological “meso” scale corresponds to an area with common ecological drivers presenting distinctive geographic characteristics. Ecological drivers encompass abiotic (e.g., type of substrate, wave energy) and biotic (e.g., key species density or diversity) parameters and all their interactions, as well as human perturbations and natural hazards that influence resource availability (Keith et al., 2020). The governance “meso” level denotes an area within the same country encompassing multiple communities.

Finally, the ecological “macro” scale corresponds to an ecoregion defined as an “area of relatively homogeneous species composition, clearly distinct from adjacent systems. The species composition is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the ecoregions vary from location to location but may include isolation, upwelling, nutrient inputs, freshwater influx, temperature regimes, ice regimes, exposure, sediments, currents, and bathymetric or coastal complexity” (Spalding et al., 2007). The governance “macro” level encompasses multiple countries and thus requires a collaborative approach across geo-political boundaries.

Consequently, the spatial scale of any NbS project directly depends on where it will be implemented and by whom it will be led. Moreover, the ecological and governance levels are interrelated. Indeed, users can design a project within a ‘scape level (“micro” ecological level) that involves multiple countries (“macro” governance level) or at an ecoregion (“macro” ecological level) while considering the multiple communities encompassing in the same country within this ecoregion (“meso” governance level). The spatial scale depends also on the intervention objectives. For instance, restoration is currently mainly implemented at a “micro” scale (Saunders et al., 2020). Scaling-up those interventions would allow to address global threats, like climate change, at a relevant scale (Saunders et al., 2020).

Question 2. Which ecosystem(s) is(are) or could be available at your spatial scale?

While global patterns of species richness and habitat extent exist (Rogers et al., 2022), local environmental conditions (i.e., social, economic, and ecological factors) will drive the presence or absence of different habitats and associated biodiversity. In this context, the options for blue NbS implementation depend on which ecosystem(s) is (are) present in the potential intervention area or whether an ecosystem was once present and the environmental conditions still exist for it to return and persist. Ultimately, the ecosystem(s) of interest should provide the ecosystem services (Step 2) necessary to address the identified societal challenge(s) (Step 1), considering that each marine and coastal ecosystem provides a different mix of services. In the absence of an ecosystem able to address the identified societal challenge(s) within the targeted area, one could be created (European Commission, 2021; Gann et al., 2019). The choice of this alternative native ecosystem, based solely on local species, needs to fit the physicochemical characteristics of the area and must be implemented in an unproductive area to avoid biodiversity loss (Temmerman et al., 2013). For example, creating an ecosystem can be the solution in areas with high and unmodifiable structural perturbation (e.g., coastal cities) and thus be a great alternative to ‘hard’ engineering (Temmerman et al., 2013; Turner et al., 2007). Although an ecosystem can deliver a multitude of services required to address societal challenge(s), the amount and quality of services are affected by the ecological condition of the ecosystem (Maes et al., 2020; Gann et al., 2019). Moreover, not all services are necessarily affected in the same way following ecosystem degradation. For example, the degradation of a coral reef habitat would only slightly reduce the service of coastal protection in the short term because the physical structure of the reef remains, while in the long term, due to erosion, dead coral reefs will break, causing the loss of this service (Trégarot et al., 2017). However, the overgrowth of macroalgae, which is often concomitant with the loss of live coral cover in eutrophic conditions, would substantially improve the service of water purification due to their elevated growth rate and nutrient uptake rate (Lapointe, 1999; Den Haan et al., 2016), but this gain of service cannot be seen as an offset for the loss of the coastal protection service’. Therefore, in analyses of trade-offs to inform management strategies in the design of NbS, it is essential to consider not only the different services provided by an ecosystem but the overall mixes of services rendered by one or multiple ecosystems and its (their) ecological condition.

Question 3. What is the “ecological condition” of the present ecosystem(s)?

Ecological condition corresponds thus to “the quality of an ecosystem measured in terms of its abiotic and biotic characteristics” (United Nations, 2021). The abiotic characteristics correspond to the ecosystem’s physical descriptor and chemical composition. The biotic characteristics denote its compositional (e.g., presence or abundance of key species), structural (e.g., total biomass, seagrass shoot density), and functional (e.g., primary productivity, disturbance frequency) state characteristics (United Nations, 2021). Therefore, the ecological condition of an ecosystem is specific to the spatial scale users focus on (Fig. 2), as an ecosystem’s biotic and abiotic characteristics depend directly on the area size and the ecosystems around it (United Nations, 2021).

This notion of “ecological condition” is broadly used in ecology but is often poorly or not defined and inconsistently interpreted. Terms such as “health”, “state”, “quality”, and “integrity” are used interchangeably to refer to the ecological condition of ecosystems (Wicklum and Davies, 1995; Roche and Campagne, 2017). In this regard, the Marine Strategy Framework Directive (MSFD) (EU directive 2008/56/EC) refers to environmental status in their definition of condition. The implementation of the MSFD has started by defining the criteria/indicators of the eleven qualitative descriptors for assessing good environmental status (GEnS), which includes the structure and functioning of marine ecosystems and considers physical, chemical, biological, and geological factors as well as anthropogenic impacts.

The idea of such assessment is thus that an ecosystem in good ecological condition will deliver a better quantity and quality of services than one in poor ecological condition (Gann et al., 2019; MOVE project, 2021; Roche and Campagne, 2017; Standish et al., 2014; United Nations, 2021). For instance, in the archipelago outside Vikna (Norway), a trawled area showed a 67% reduction of epiphytes, an 89% reduction of invertebrates, and altered fish populations in comparison to a non-trawled area of the same size, thus affecting the quantity and quality of resources available (Norderhaug et al., 2020). Consequently, assessing ecological condition will provide users with crucial information to choose the right intervention option(s), giving the highest quantity and quality of ecosystem services to best respond to their societal challenge(s).

Determining the ecological condition of the present ecosystem requires the identification of a set of relevant ecological indicators that should meet the following criteria (Dale and Beyeler, 2001): i) be easily measured, ii) be sensitive to stresses on the system, iii) respond to stress in a predictable manner, iv) be anticipatory, v) predict changes that can be averted by management actions, vi) be integrative, vii) have a known response to disturbances, anthropogenic stresses, and changes over time, vii) have low variability in response. By measuring those indicators, one should be able to detect signs of changes in the ecosystem, whether it is in its structure or functioning. In order to detect these changes (negative, positive, neutral), it is also required that ecological indicators values must be comparable with ones describing a pre-existent or referent condition. The statistical comparison (deviation) with a reference baseline then informs on the ecosystem’s condition and its trajectory.

While users can develop their own ecological condition assessment framework, different frameworks exist in the literature that may be of use (e.g., Borja et al., 2013; de Juan et al., 2018; Jakobsson et al., 2021; Maes et al., 2020; United Nations, 2021). However, the necessary data to properly assess the ecological condition of an ecosystem may not be available. In that case, users can relate to expert and/or Local Community knowledge.

Question 4. What is the "vulnerability" of the present ecosystem(s)?

The vulnerability of an ecosystem is determined by its exposure to stresses, associated sensitivity, and related adaptive capacity to cope with pressure (Fig. 2; Adger, 2006; Ellison, 2015; IPCC, 2007, 2014). The level of exposure corresponds to the Nature and degree of extrinsic pressures that the system is likely to experience. These pressures can be natural (e.g., specific geomorphic settings of the system or natural hazard), climate change driven (e.g., sea level rise or temperature warming), or directly human induced (e.g., human pollution or management measures) (Adger, 2006). Sensitivity is the degree to which a system is affected by such exposure (Adger, 2006; Turner et al., 2003), such as damages caused by an increase in the frequency of coastal flooding due to sea level rise (IPCC, 2014). Finally, adaptive capacity is the ability of a system to cope with or accommodate environmental hazards or policy change with minimal disruption (Adger, 2006; Ellison, 2015).

The assessment of a system's vulnerability is a non-measurable dimensionless property (Ellison, 2015), as it is a composite of qualitative and quantitative factors. Different vulnerability frameworks exist in the literature (Ellison, 2015; Mafi-Gholami et al., 2019; Mamauag et al., 2013; Turner et al., 2003), which may be of use to adopt or adapt to the specific needs of the user. However, if all aspects of the vulnerability assessment cannot be covered, users may limit their focus on the exposure to stresses of their targeted ecosystem. For example, data on natural hazards like storms or flood intensity, land cover, and land use, as well as the likely impact of human activities on the ecosystem(s) (e.g., terrestrial run-off; nutrient enrichment), from existing databases or expert knowledge can be easily measured or assessed.

Ecosystem vulnerability is specific to each ecosystem at a particular scale. It relies, therefore, on understanding the ecosystem's response against likely hazards (e.g., storm surges, hurricanes, human pollution, fishing pressure) (e.g., Auber et al., 2022; Kelly and Adger, 2000). When the system's adaptive capacity cannot compensate for its level of exposure and sensitivity, its vulnerability is high, and vice-versa. A high vulnerability implies that in the presence of stressors, the ecological condition of the ecosystem is likely to be impacted. Therefore, the ecosystem's vulnerability assessment will give users crucial information on what type of intervention would be the most appropriate to minimize impacts on the ecosystem's condition. Conversely, a low vulnerability will be associated with better ecological conditions, ultimately ensuring the delivery of ecosystem goods and services and, consequently, a positive output to address identified societal challenge(s). For instance, within the French overseas territories, mangrove forests could remove more than 10 million kgN per year (based on the average denitrification rate); however, given the vulnerability of mangrove forests in the different territories, the loss of water purification service represents about 2 million kgN less per year (Trégarot et al., 2021b).

2.4. Step 4: intervention options

Based on the options selected in Steps 1 and 2 and the context-specific links among spatial scales, ecosystem(s) presence, ecological condition, and vulnerability (Step 3, Figs. 1 and 2), our conceptual framework provides a portfolio of protection, restorative activities, and/or other management measures to support the desired objectives, and that could be considered a NbS.

2.4.1. Protection

For marine and coastal areas, protection is typically achieved through Marine Protected Areas (MPAs). MPAs are "conservation tools intended to protect biodiversity, promote healthy and resilient marine ecosystems, and provide societal benefits" and should be designated by law (Grorud-Colvert et al., 2021). The expected outcomes from MPAs are directly linked to the level of protection from direct human activities. Indeed, the recent COVID pandemic has shown that a halt in human activities has a positive impact on biodiversity even in the short term (Jiang et al., 2022; Khan et al., 2021; Kumar Verma and Prakash, 2020; Somchuea et al., 2022. Those levels of protection can be classified into four protection categories: Fully, Highly, Lightly, and Minimally protected (Fig. 4). These categories represent a gradient of protection levels, with fully protected areas being the most restrictive to human activities, thereby offering the top level of protection, and minimally protected areas being the least restrictive, allowing many human activities, some of which may even be incompatible with management objectives, thus offering the lowest level of protection (Grorud-Colvert et al., 2021, Fig. 4). Within a fully protected MPA, no extractive or destructive activities are allowed, and all impacts are minimized. For instance, mining and fishing activities are prohibited, while diving or anchoring are reduced to have a minimal impact. A highly protected MPA only allows light extractive activities and other impacts are minimized to the extent possible. Mining and fishing activities are still prohibited in that case, but more impacts from activities like aquaculture or other maritime infrastructure are allowed. Within lightly protected MPAs, moderate to significant extraction and impacts are allowed. For example, fishing, dredging, and dumping activities or anchoring are allowed but within the limits of a moderate impact. Finally, a minimally protected MPA allows extensive extraction and other impacts while still providing some conservation benefit to the area. This benefit could come directly from the regulation of available resources or from the MPA administration being represented in the urban development of the coastline. Furthermore, the MPA stage of establishment among only committed (project made public), designated (legal recognition), implemented (operational on water), or actively managed (enforceable rules, monitoring, evaluation, adaptive management, and conservation outcomes) have a direct impact on the state of the biodiversity in those MPAs (Grorud-Colvert et al., 2021) in addition to their size, age or level of enforcement (Edgar et al., 2014).

The selection of the level of protection depends on the ecosystem's ecological condition and vulnerability to existing and future stressors, as well as the management-based objectives and the level of stakeholders' and local community consent. While it has been shown that only fully and highly protected MPAs with active management measures provide tangible positive outcomes in terms of biodiversity (Claudet et al., 2020), these levels of protection can be difficult to achieve (cf. acceptance) and might not be the most appropriate options. For instance, an ecosystem with a good ecological condition and low vulnerability to stressors does not require such a high level of protection. Instead, a lightly protected MPA would maintain the full provision of ecosystem services required to address the societal challenges whilst supporting already existing human activities that are not harmful to the environment. Only when the vulnerability increases should active management measures be implemented along with a higher level of protection.

2.4.2. Restorative activities

Restorative activities can be generally defined as "all deliberate interventions for recovering ecosystem attributes that have been lost or degraded" (Gann et al., 2019). One of the main principles behind restoration is to seek the highest level of recovery possible (Gann et al., 2019). Based on the framework Gann et al. (2019), CBD (2019), Intergovernmental Science-Policy Platfore on Biodiversity and Ecosystem (IPBES, 2018), and EC (2021), we can define five categories of restorative activities (Fig. 4): (1) Passive ecosystem restoration denotes management measures intentionally implemented to halt pressure(s) that cause an ecosystem's degradation or hinder its recovery (e.g., Lefcheck et al., 2018); (2) Active ecosystem restoration corresponds to activities aiming at the full recovery of the native ecosystem's functions in order to provide the full range of ecosystem services (e.g., Burden et al., 2019); (3) Partial restoration corresponds to activities that may

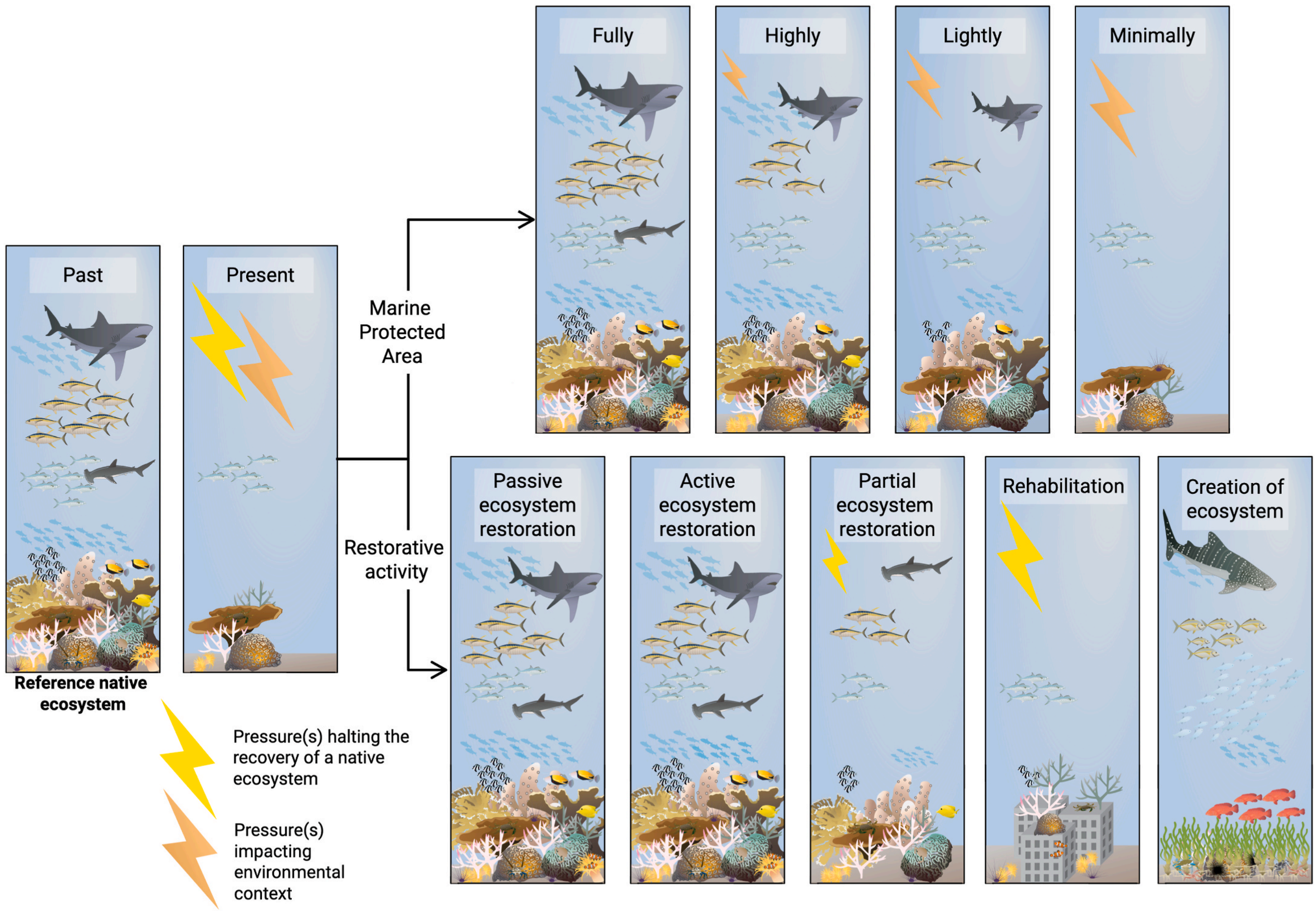

Fig. 4. Continuum of ecosystem recovery based on MPA protection levels and restorative activities. (Figure adapted from Grorud-Colvert et al., 2021 for the continuum of MPA protection levels and built on to include restorative activities).

fall short of fully restoring the ecological communities of the native reference ecosystem due to resource, technical, environmental, or social constraints (e.g., Ahammad et al., 2013); (4) Rehabilitation corresponds to ecological repair activities that aim to gain ecological function(s) rather than biodiversity and integrity of the native reference ecosystem (e.g., Tanner et al., 2014); and (5) Ecosystem creation corresponds to activities implementing an alternative native ecosystem (based on locally native species), subject to biodiversity gain without replacing a productive ecosystem. This definition gathers two approaches. The first is used when critical and insurmountable environmental or societal changes hinder the recovery of the reference native ecosystem. The second is used to recover (or gain) key ecosystem function(s) in an area where the native ecosystem is no longer delivering these services (e.g., Dawe et al., 2000).

The choice of a specific restorative activity depends on the degradation level in the reference native ecosystem, the level of human pressures, the willingness or possibility to halt them, and the technical feasibility of implementing an effective restorative measure for a specific ecosystem.

2.4.3. Other management measures

Other management actions gather all the ecosystem-based practices that are not directed toward MPAs and restorative activities but still contribute to reducing and halting pressures on ecosystems (Borja A. et al., 2010; Piet et al., 2015). They are very diverse in terms of implementation and can lead to different ecological, social, and/or economic outcomes (Reimer et al., 2021). For instance, by implementing temporary fisheries closures and/or banning particular types of fishing gear, these measures can increase organisms' size, abundance, and/or species diversity, which can lead to improved harvest (e.g., professional and recreational fisheries) or non-harvest (e.g., diving, boat tourism, ecotourism) incomes (Carvalho et al., 2019). Another management measure could materialize through the adoption of a regulation law that bans a specific practice in a particular ecosystem (e.g., anchoring in an area of protected marine plant species, see French prefectural decree n°123/2019 - Article 6) in order to maintain ecosystem integrity, function, and/or resilience, whilst maintaining traditional practices and/or access to resources. Other management measures can focus on reducing pollution, addressing specific threats to species, or providing equitable access to resources and/or alternative livelihood activities to everybody. For instance, developing less destructive economic activities within mangrove forests like ecotourism, oyster harvest, or honey production instead of relying solely on destructive charcoal harvesting (Debrot et al., 2020).

The implementation of other management measures depends on the socio-economic characteristics of the area, as well as the willingness of decision-makers, practitioners, Local Communities, and Indigenous People to implement such limitations of activities and/or develop other types of activities.

2.4.4. Suitable intervention selection

Ambitious international objectives for conservation and restoration have been agreed (e.g., EU's biodiversity strategy for 2030; Protect 30% of marine space by 2030: IUCN, SDG14, CBD target; UN Decade on

Ecosystem Restoration, 2021–2030). However, among the many intervention options, selecting the most appropriate one(s) at the relevant spatial scale to address societal challenges effectively is important and critical for mobilizing action. In the marine biome, positive outcomes can be expected from each specific protection, restorative activity, or other management measure depending on their implementation (Fig. 5) (Grorud-Colvert et al., 2021; Jacquemont et al., 2022; Saunders et al., 2020). Consequently, the choice of the most appropriate intervention or portfolio of interventions that would optimize the ecosystem services provision depends on the ecological condition and vulnerability (Step 3). For example, a protection measure is highly efficient on its own at maintaining or enhancing an ecosystem's ecological condition, when it is already relatively good (Fig. 5 - "Protection" blue triangle). Such protection measures may be less relevant or require additional supportive measures (e.g., restorative activities or other management measures) to deliver the same objectives within a highly degraded or destroyed ecosystem (Fig. 5 - "Protection" blue triangle, crossing "Restorative activity" blue triangle and "Other management measure" blue rectangle). Following that idea, restorative activities are highly effective at recovering a degraded to destroyed ecosystem, or at least some ecosystem functions, and so these may be less relevant for ecosystems in good ecological condition (Fig. 5 - "Restorative activity" blue triangle). By using ecosystem creation or rehabilitation in degraded or destroyed ecosystems, it may be possible to regain or establish new ecological functions (Fig. 5 - dark orange arrow). As protection and restorative activities tend to be spatially defined, other management measures are particularly useful for their ability to apply consistent regulation on human activities over large areas to reduce their environmental impacts and can be applied across the spectrum of ecological conditions (Fig. 5 - blue rectangle).

To provide an example of how relevant intervention(s) may be selected, consider a mangrove forest at an ecological and governance "micro" scale. This mangrove forest is in good ecological condition and has low vulnerability to pressures. It thus delivers an effective coastal protection service to nearby local communities, addressing the societal challenge of disaster risk reduction. The objective for a NbS intervention is, therefore, to maintain what already exists and, using the framework presented in Fig. 5, the community may choose to implement protection and/or other management measures. Conversely, if the mangrove forest was in poor ecological condition and highly vulnerable to existing pressures, its ability to provide coastal protection would be reduced and require strengthening. Blue NbS objectives would, therefore, need to focus on ecosystem rehabilitation and enhancement, improving ecological condition and reducing ecosystem vulnerability, while stopping or limiting human pressures.

3. Discussion

Our conceptual framework presents a new approach, filling a gap in guidance (O'Leary et al. 2023) to facilitate the identification of blue NbS by orienting intervention selection around specific societal challenges and contextual environments. This drives a holistic approach that ultimately offers a selection of potential interventions that can support the delivery of marine and coastal ecosystem services. It also places the ecological foundations on which ecosystem services are derived at the center stage in decision-making. Therefore, our conceptual framework highlights the importance of cross-cutting (e.g., social, economic, ecological) and multi-disciplinary (e.g., social survey, ecosystem monitoring) engagement and collaboration in environmental management.

Existing international reports presenting frameworks or standards already encompassed many of the different aspects on which our conceptual framework builds. The standard for NbS, developed by the IUCN (IUCN, 2020), and the NbS handbook for practitioners, developed by the European Commission (EC, 2021), better define the concept of NbS, how to design one, the need for good effectiveness and the importance of monitoring. However, they do not link monitoring results with intervention effectiveness. The Marine Strategy Framework Directive (MFSD - Directive, 2008/56/EC) lists the qualitative descriptors for determining good environmental status, but it does not link it with the quality and quantity of ecosystem services delivered. Additionally, some reports propose ways to address challenges faced by societies (e.g., SDGs, IUCN societal challenges), but only for one type of intervention, using area-based management (Kettunen et al., 2021) or restorative activities (Gann et al., 2019; Hallett et al., 2023), for instance. Consequently, it was necessary to makes the link between ecological conditions, vulnerability, ecosystem services, and societal challenges for protection, restorative activities, and other management measures within marine and coastal ecosystems. For this reason, although we know conservation is a complex field, our focus was on how to think and grasp the subject of protecting, restoring, and managing ecosystems considering both People

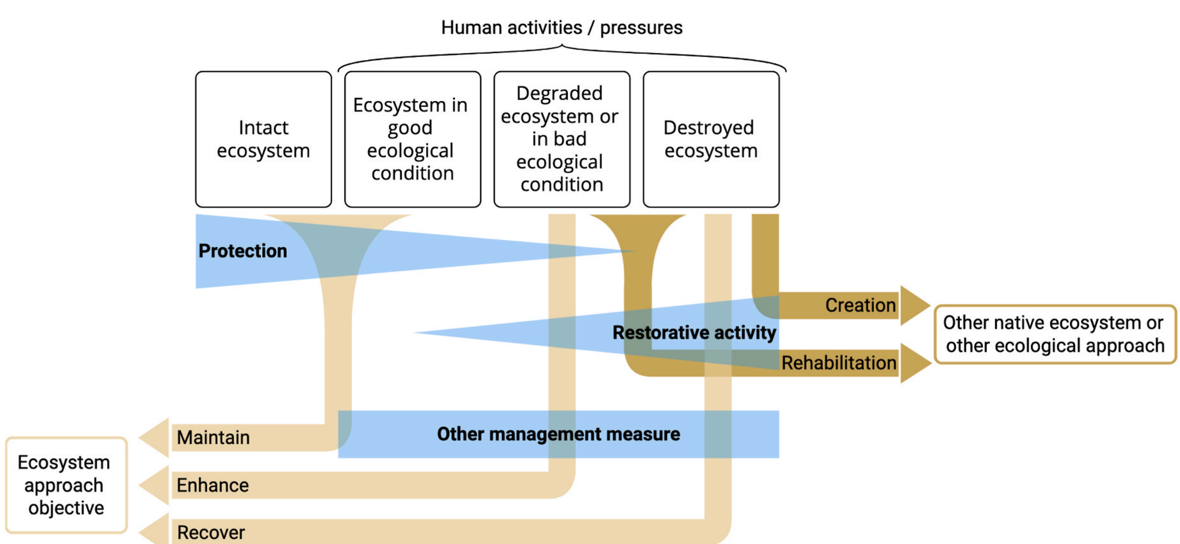

Fig. 5. Summary of ecosystem conservation objectives based on an ecosystem's ecological condition and available blue NbS intervention options to achieve them. Arrows represent the intervention objectives. NbS intervention options are classified as protection, restoration, and management (blue shapes). Management refers to those measures that exist outside protection or restorative activities: management actions can apply to ecosystems in any ecological condition equally. Triangles represent protection and restorative activities and highlight the dominant approach that should be taken for ecosystems according to their ecological condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and Nature, to better inform decision-makers, practitioners, and other stakeholders about the choice of the most suitable intervention(s) through a simple and easy to use framework.

Frameworks such as that presented here offer useful tools to help decision-makers intentionally bring together complex elements in the development and implementation of actions. However, they should not be seen as fixed and definitive, and they do not provide specific guidance because they can only take into account those factors for which they are designed. The decision-making process provided by our framework is not meant to be the only set of possibilities. The users can investigate all alternatives to explore the right fit for their specific location. Indeed, the particular advantage of such frameworks is their ability to help users identify and clarify what is known, desired, and valued and then connect these with other aspects that influence possibilities.

Environmental management decisions should be context-dependent, informed not only by ecological conditions but also by the social (including cultural), economic, and institutional elements of a marine and coastal system (Esmail et al., 2023). Although our conceptual framework mostly focuses on the ecological components of the system, we emphasize the importance of early and genuine stakeholder engagement in all stages of decision-making, from challenge orientation to intervention selection and beyond. It helps ensure: i) the most pressing and relevant societal challenge(s) to the Local Community and other stakeholders are identified (IUCN, 2020); ii) Local Ecological Knowledge is integrated into assessments of the environmental context (IPCC, 2023); iii) support for the selected intervention(s) by embedding transparency in the decision-making process (IUCN, 2020); iv) co-design of the spatial extent and regulations of the desired intervention through time; and, v) co-management of the newly implemented intervention(s) through time.

Blue NbS appears to be a key component of the response to address societal challenges in marine and coastal systems. However, it is essential to recognize that effective protection, restorative activities, and other management measures, which, on their own, take a narrower approach to problem-solving, can still be applied outside the NbS framework. Given the breadth of challenges that humanity is facing, decision-makers and practitioners should remain open to a broad range of actions to tackle biodiversity loss, climate change, as well as other societal challenges, for which our conceptual framework would provide guidance. Similarly, while our framework focuses on protection, restorative activities, and other management measures, it does not exclude the possibility of merging such interventions with "hard" engineering. For example, in shared spaces between Nature and People, decision-makers may choose to layer up NbS with traditional interventions, such as grey infrastructure, to achieve objectives (IUCN, 2016). Indeed, the high connectivity between marine and coastal ecosystems (e.g., O'Leary and Roberts, 2018) means that there is no 'one size fits all' approach to address societal challenges. Instead, an appropriate selection from a portfolio of approaches will be required. For example, the different potential ways of managing a seascape composed of an assembly of mangrove forests, seagrass meadows, and coral reefs will affect the provision of storm protection, water quality, fishery resources, and ecotourism-related income, bringing similarly a different variety of benefits, and costs, to different stakeholders. This emphasizes the importance of stakeholder engagement in the prioritization of objectives and management objectives throughout the application of our conceptual framework and into intervention design and implementation. Nonetheless, our conceptual framework helps decision-makers define the problem that needs to be addressed, the vulnerability of an ecosystem to human pressures, and the drivers of change while providing potential intervention options that can then be evaluated for useability and feasibility. This approach provides an overview of NbS approaches best suited to addressing specific societal challenges within a particular context to inform the more optimal allocation of limited environmental conservation and management resources.

The field of NbS is still young, particularly in marine and coastal systems. As such, criteria for NbS (e.g., IUCN, 2020) will develop over time, and new interventions might be considered NbS in the future. For example, in marine and coastal management, Other Effective Conservation Measures (OECMs) are gaining traction as complementary tools for marine protection (Kettunen et al., 2021; Gurney et al., 2021, 2023). An OECM is "a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in-situ* conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values" (CBD, 2018). OECMs are not legally designated but are an area-based conservation tool that recognizes places and practices that occur outside MPA boundaries and that contribute to addressing biodiversity loss and degradation. They can offer recognition for biodiversity conservation value where a legal MPA designation may not be appropriate or desired. OECMs accommodate the ways people use 'scapes and can recognize and support Indigenous People and Local Communities in managing their lands and seas in line with their own concerns and values while conserving Nature (Gurney et al., 2021). As blue NbS are embraced, OECMs, which have biodiversity conservation as a primary objective and enhance human health and well-being as an outcome of co-addressing another societal challenge, could be considered NbS. Similarly, other management interventions and approaches may emerge in the future. It will, therefore, be important to continually assess the availability and appropriateness of potentially suitable interventions presented by our conceptual framework to ensure it remains up-to-date.

To remain relevant, the information underpinning conceptual frameworks requires constant development to ensure the integration of the most up-to-date scientific knowledge (local and global) and to ensure relevant factors that influence decision-making are taken into account, where possible. In the case of our conceptual framework, deepening our understanding of the interaction between the ecosystem's condition and services delivery would improve our ability to apprehend potential trade-offs in services provision within and among ecosystems, which is essential to tailor the list of interventions to address societal challenge(s), and adapt the interventions with future coastal changes. Indeed, doing so will be all the more challenging considering the current climate change context (Mooney et al., 2009). Furthermore, practitioners need precise information on the actual services provided by the ecosystems present within their area of interest to estimate the expected outcomes regarding maintaining, enhancing, recovering, or producing new service(s) provided by an ecosystem approach developed under a NbS context. Further work should, therefore, aim to integrate expert knowledge with existing scientific evidence to link ecosystem service delivery with ecological conditions and vulnerability for each specific coastal and marine ecosystem at each spatial scale. This will require, amongst others, improving our ability to assess marine and coastal ecosystem health by developing new methodological tools and monitoring methods (Auber et al., 2022; Simeoni et al., 2023). The nexus between biodiversity and ecosystem services flow needs to be better addressed in marine and coastal areas to bring forward ready-to-use knowledge for the robust development of blue NbS. Together, this work would help operationalize our conceptual framework into a decision-support tool that applies evidence in a standardized manner to facilitate consistent, evidence-based recommendations, providing a portfolio of potential interventions specific to each user's needs.

Finally, the success of any environmental management intervention in achieving desired goals depends on taking appropriate and adequate measures and creating favorable conditions, including resources, the ability to alleviate threats, and stakeholder engagement (Gill et al., 2017; Grorud-Colvert et al., 2021; Hölting et al., 2020; Sánchez-Arcilla et al., 2022). As such, while our conceptual framework can help inform the selection of a potential blue NbS approach, it needs to be balanced with the level of resources and support available for mobilizing and managing any NbS. Indeed, to achieve their expected outcomes, blue NbS must be implemented as effective and holistic interventions

(European Commission, 2021; IUCN, 2020), balancing the solutions between environmental and societal needs and being both cost-effective and supported by stakeholders, practitioners, Local Communities, and Indigenous People. This is because the presence and condition of Nature are essential across a wide variety of human activities and uses, which in turn have corresponding impacts on Nature. As such, this conceptual framework has been developed to act as a decision-support system to guide the selection of NbS by bringing together a variety of factors that will need to be considered. It, therefore, offers a basis for strategic discussions and better alignment of blue NbS with respect to societal challenges.

4. Conclusion

In conclusion, various established conceptual frameworks, such as the MSFD (Directive, 2008/56/EC), the Restorative continuum (Gann et al., 2019), and NbS (IUCN, 2020), provide indispensable tools for guiding interventions in marine and coastal ecosystems. However, our overarching goal was to create a versatile portfolio of potential interventions that cater to the specific needs of each ecosystem rather than imposing a rigid, one-size-fits-all model. These should serve as invaluable resources for decision-makers as they help align what's known, desired, and valued with the factors influencing decisions, making the actions more effective. Moving forward, we should keep updating these frameworks to stay relevant and include the latest scientific information in their application. In the meantime, combining expert knowledge with scientific facts will help us link what ecosystems provide, their ecological condition, and their vulnerability at different locations. Additionally, we should try to cover all the important factors that affect decision-making to fill the knowledge gaps that remain. Finally, we will need a more comprehensive integration of socio-economic considerations within our framework to have a fully rounded plan that better considers both Nature and People.

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CRediT authorship contribution statement

Géraldine Pérez: Conceptualization, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing, Project administration. **Bethan C. O'Leary:** Conceptualization, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. **Elena Allegri:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Gema Casal:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Cindy C. Cornet:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Silvia de Juan:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Pierre Failler:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Stein Fredriksen:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Catarina Fonseca:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Elisa Furlan:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Artur Gil:** Funding acquisition, Writing – review & editing. **Julie P. Hawkins:** Funding acquisition, Writing – review & editing. **Jean-Philippe Maréchal:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Tim McCarthy:** Funding acquisition, Writing – review & editing. **Callum M. Roberts:** Funding acquisition, Writing – review & editing. **Ewan Trégarot:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Matthijs van der Geest:** Conceptualization, Funding acquisition, Methodology, Writing – review & editing. **Rémy Simide:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

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

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

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