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Embracing Nature-based Solutions to promote resilient marine and coastal ecosystems

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ABSTRACT

The world is struggling to limit greenhouse gas emissions and reduce the human footprint on nature. We therefore urgently need to think about how to achieve more with actions to address mounting challenges for human health and wellbeing from biodiversity loss, climate change effects, and unsustainable economic and social development. Nature-based Solutions (NBS) have emerged as a systemic approach and an important component of the response to these challenges. In marine and coastal spaces, NBS can contribute to improved environmental health, climate change mitigation and adaptation, and a more sustainable blue economy, if implemented to a high standard. However, NBS have been largely studied for terrestrial – particularly urban – systems, with limited uptake thus far in marine and coastal areas, despite an abundance of opportunities. Here,

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we provide explanations for this lag and propose the following three research priorities to advance marine and coastal NBS: (1) Improve understanding of marine and coastal biodiversity-ecosystem services relationships to support NBS better designed for rebuilding system resilience and achieving desired ecological outcomes under climate change; (2) Provide scientific guidance on how and where to implement marine and coastal NBS and better coordinate strategies and projects to facilitate their design, effectiveness, and value through innovative synergistic actions; (3) Develop ways to enhance marine and coastal NBS communication, collaboration, ocean literacy and stewardship to raise awareness, co-create solutions with stakeholders, boost public and policy buy-in, and potentially drive a more sustained investment. Research effort in these three areas will help practitioners, policy-makers and society embrace NBS for managing marine and coastal ecosystems for tangible benefits to people and marine life.

1. A changing planet

The world is changing rapidly, threatening the marine and coastal systems of today on which people rely for innumerable ecosystem goods and services. All over the world and across marine, freshwater and terrestrial systems, declines in plant and animal populations and degradation of habitats have been recorded due to increased pressures from human activities exacerbated by climate change [1]. Yet ecosystem goods and services are reliant on healthy ecosystems, which depend on the quantity and quality of the biodiversity they contain [1]. Societal challenges, including the accelerating decline of biodiversity, climate change impacts, unsustainable economic and social development, increased disaster risk, and threats to food security, endanger human health and wellbeing [1–3]. To mitigate the effects of climate change on both the biosphere and society, the most important actions required are to reduce greenhouse gas emissions and to rapidly decarbonise societies [4]. Although this will not prevent further environmental change from past carbon emissions, it will place humanity on the best course for survival [5,6]. If we allow the present ecological and climate crises to continue, they will alter the future of humanity forever – compromising our security and compounding societal challenges through impacts such as reduced protection against more frequent and intense extreme weather events, reduced food security, and increased risk of infectious diseases [6]. In turn, these consequences will affect development pathways, create political instability, and trigger human flight, displacement and migration [e.g. 6,7]. Reducing greenhouse gas emissions alone is not enough to resolve our problems because of time lags and the cumulative impacts embedded within the many separate problems causing the ecological crisis and influencing climate change [8]. Mitigating emissions by conserving and restoring natural habitats and avoiding future emissions from land use change and environmental loss or degradation will also be required [9–11]. Given this and the indisputable value of marine and coastal ecosystems to people [12], we must act without delay to protect and rebuild biodiversity thereby promoting the natural processes that enhance food provision and coastal protection, and mitigate climate change.

2. The emergence of nature-based solutions

The high value of nature and its delivery of ecosystem services that support human and planetary wellbeing is globally recognised [e.g. 1, 2, 13]. Harnessing the power of nature has, therefore, emerged as an important pathway to address societal challenges [14]. Maintaining or recovering nature in a holistic and sustainable way will help support biodiversity and human wellbeing by safeguarding ecosystem service provision. As part of this, Nature-based Solutions (NBS) have been proposed as systemic actions that work with and enhance nature to provide environmental, social and economic benefits that simultaneously address multiple challenges [15–18] (Fig. 1). Hence, they have become a prominent sustainability framework at the forefront of policy dialogues about how we use and look after our environment and why. This reflects an expansion in focus from conserving nature for nature's sake to conserving nature also for its value to people.

Broadly, NBS actions can be categorised into protection, restoration (active and passive) and other sustainable management measures. This term, therefore, provides an umbrella concept for established approaches that use natural, regenerative, inclusive, and adaptive methods to address societal challenges, including biodiversity loss. It brings these approaches together, demanding a broader integrated perspective to achieve more for cross-cutting issues [16-18,21,22]. As such, the additionality of benefits directed at outcomes that are fundamental for nature, climate and society in any scenario have led to NBS being highlighted as "multipurpose, no-regret solutions" [23]. It is important to note, however, that any management intervention can lead to positive, negative and neutral outcomes depending on the viewpoint of those assessing them, particularly when considered from multiple angles. For example, restoring a coastal habitat to enhance biodiversity, mitigate climate change and increase coastal protection, may have negative economic outcomes for some stakeholder groups. In choosing whether or not to implement a NBS, it will therefore be important to set the action within the specific ecological and social context, involve stakeholders, consider potential outcomes and interactions with other interventions, balance trade-offs and prioritise actions and outcomes.

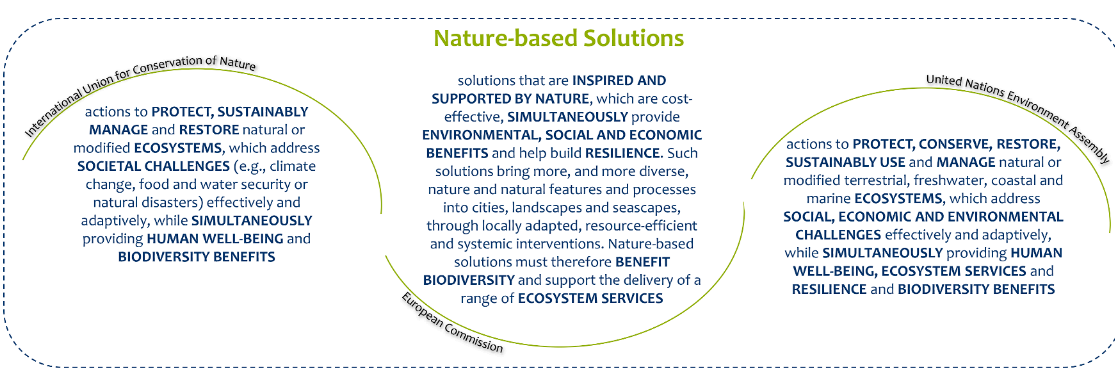

Fig. 1. What are Nature-based Solutions? Existing definitions of NBS from the International Union for Conservation of Nature [19], the European Commission [16], and the United Nations Environment Assembly [20]. Common concepts are capitalised and in bold text. All emphasise the importance of working with nature to tackle societal challenges by producing benefits to biodiversity and human wellbeing.

Well-designed NBS deliver multiple benefits [24]. However, a loosely defined concept is open to ambiguity, and concerns exist that the term could potentially be misused or abused thereby facilitating continued dependence on fossil fuels or promoting actions that harm biodiversity and/or local communities [21,25-28]. As such, the International Union for Conservation of Nature (IUCN), following extensive and continued consultation, has proposed a Global Standard for NBS that provides a set of guidelines and criteria designed to ensure common understanding and consistent application of the term [29]. Within this, eight process-orientated criteria relate to the design of an intervention (Fig. 2), each with a set of indicators, which aim to standardise and improve the design and execution of NBS [29]. Interventions meeting this standard must be designed to enhance biodiversity and simultaneously address additional societal challenge(s). They must meet all criteria, partially or fully (Fig. 2).

3. Research priorities for marine and coastal NBS implementation

Connecting all coastal countries, the oceans provide the largest liveable space on Earth with a huge variety of marine (e.g. seamounts, frontal zones, pelagic habitats) and coastal (e.g. mangrove forests, seagrass beds, saltmarshes) ecosystems and wildlife. From these, just a handful of marine and coastal services (i.e. fishing, aquaculture, tourism, education, coastal and oceanic shipping, carbon sequestration, and biotechnology) were estimated in 2015 to have a value of more than US$2.5 trillion annually [12]. This and other estimates, however, do not include services that are much harder to value, such as spiritual and cultural services, the production of oxygen, planetary temperature stabilisation, and the ocean's role in climate regulation. In short, the oceans and their coasts are undervalued when estimates of economic worth are considered alone. This is especially true for countries with disproportionately large exclusive economic zones compared with their terrestrial space, termed 'large ocean states'. Major international scientific organisations working on biodiversity and climate change now recognise the importance of NBS for delivering transformative change in sustainable management [e.g. 1,3,29-31]. In the past decade, however, the NBS concept has mostly been applied to terrestrial – in particular urban – systems, leading to fewer examples of NBS in marine and coastal ecosystems [Fig. 3; 24], despite an abundance of opportunities [9,32,33].

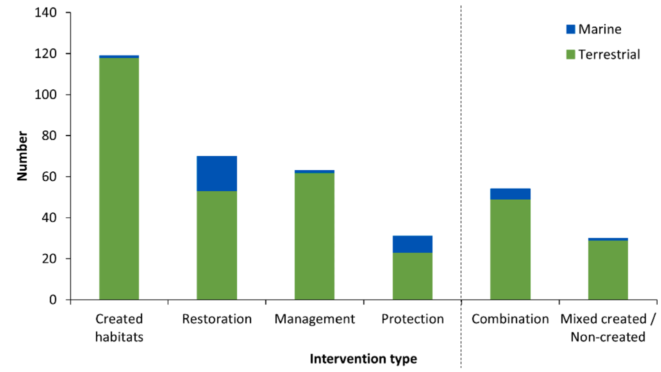

Fig. 3. Number of marine and coastal (blue) or terrestrial, excluding urban systems, (green) NBS identified globally with empirical evidence. "Combination" denotes an intervention that combines two or more intervention types. "Mixed created/non-created" corresponds to an intervention that applies at least one created and one non-created (restoration, management, protection) intervention. Source: The NbS Evidence Platform [34].

Marine and coastal NBS present an opportunity to leverage the world's oceans for global and local societal and biodiversity benefits that includes contribution to a sustainable blue economy [13].

There is a wealth of experience using established approaches to manage marine and coastal ecosystems that can form the basis of NBS, such as marine protected areas, spatial management tools and restoration projects [35–38]. To widely implement effective marine and coastal NBS, we need to learn from these approaches, building NBS that aim to achieve net gains (i.e. more than maintenance or preservation) in biodiversity while addressing other societal challenges for which there is intense ongoing work [e.g. 39]. One option for progressing marine and coastal NBS may be to 'layer up' existing approaches by, for example, conducting active restoration within a marine protected area and/or trialling new approaches, including large-scale and smaller networked NBS, as suggested as part of "climate-smart" marine spatial planning [40]. This would mean short- and long-term interventions with complementary objectives could be combined as an NBS, enabling interventions to achieve more than they otherwise would [e.g. 41].

To date, progress in NBS implementation has been slower in marine

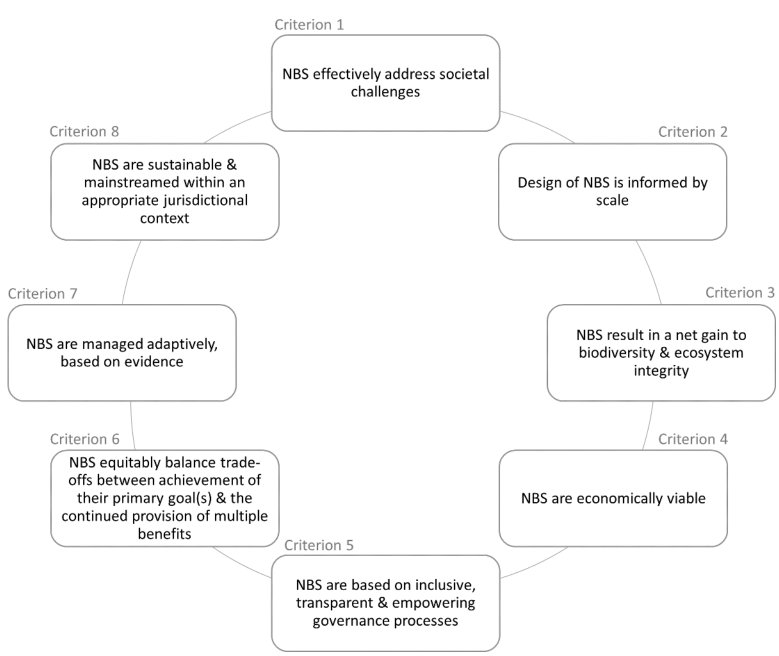

Fig. 2. Criteria of the IUCN Global Standard for Nature-Based Solutions [29].

and coastal ecosystems than on land (Fig. 3) for a number of reasons. First, there is a lack of information and understanding on the mechanisms by which marine biodiversity and ecosystems deliver ecosystem services, how their health and connectivity across seascapes and landscapes affect this delivery, and how to measure ecosystem services and attribute changes in those services to NBS (e.g. IUCN criteria 3 and 7, Fig. 2). Marine and coastal ecosystems are inherently dynamic and often more complex and difficult to access than terrestrial ones. Therefore, specialised expertise and expensive technology to implement and monitor interventions are required. Moreover, the availability of robust long-term data series at high spatial resolution is often scarcer for marine than for terrestrial systems, hindering the analyses needed to elucidate trends away from natural fluctuations [42]. Consequently, it is more challenging to parameterise marine and coastal ecosystem models to assess change and express benefits in economic terms to facilitate cost-benefit analysis. This also results in greater uncertainty, compared to terrestrial systems, on how to best design and implement effective interventions (e.g. criterion 4, Fig. 2). For example, one obstacle in NBS implementation in coastal systems is their very dynamic character, driven by extreme events such as storms. Here, solutions need to be able to survive high-energy events undamaged, or recuperate at sufficiently high rates to endure the next stormy season and provide long-lasting, natural protection and recovery of ecosystem services. The adaptive management of, for instance, the Netherlands' sandy coastlines could provide a good practice example in monitoring, maintaining, upscaling and optimising cost-effective ecosystem services delivery in a dynamic system, providing a wealth of valuable functions on a large scale [43].

Second, because of their interconnected social-ecological nature, marine and coastal NBS must be designed and operated at a seascape scale to be effective, considering the adjacent landscape and the social context of end-users and local populations (e.g. criterion 2, Fig. 2). Although this has been appreciated for a long time and applied via the concept of integrated coastal zone management, it has had varying degrees of success [44]. A major reason is that marine and coastal ecosystems sit within dynamic and diverse societal contexts with a multitude of uses and users which often operate under a complex governance system with indistinct property rights and potentially conflicting interests (e.g. criterion 5, Fig. 2). Moreover, integrated management is hampered by the lack of well-established boundaries for the land-water coastal zone [e.g. 45], meaning that coastal systems are not only prone to jurisdictional conflicts (e.g. between terrestrial and marine planning), but they also face the challenge of managing coexisting public and private activities. This makes it difficult to have the governance systems and policy levers in place to implement integrated management actions such as coastal NBS and to identify the beneficiaries and cost-effectiveness of interventions (e.g. criteria 4–6, Fig. 2). Nonetheless, despite limited data for marine and coastal NBS, enough information does exist to show that actions such as marine protected areas and coastal wetland restoration can be cost-effective [e.g. 46,47]. A paradigm shift in management is therefore required whereby coastal and marine NBS are combined into holistic spatial plans accompanied by moving away from automatically applying traditional solutions to coastal protection, such as grey infrastructure. Where grey infrastructure is required, combining this with coastal vegetated habitats such as mangroves and salt marshes into hybrid solutions could deliver more sustainable and financially attractive coastal protection strategies [48].

Finally, effective implementation of marine and coastal NBS requires greater public and policy awareness of the value of marine and coastal ecosystems, which will require ocean literacy, engagement, collaboration, and understanding of the NBS concept (e.g. criterion 8, Fig. 2). While some coastal wetlands can be seen, subtidal ecosystems (e.g. seagrass beds, kelp forests, oyster reefs, and coral reefs) can suffer from being 'out-of-sight, out-of-mind' and from shifting baselines. The latter makes it hard to understand the degree and scale of past human influence and impact and to develop appropriate and sufficiently ambitious management targets for protection and restoration [e.g. 49]. It also makes it difficult to engage social and economic support for management in marine and coastal areas, particularly without strong evidence to demonstrate clear benefits from NBS. Moreover, engagement with marine issues is different from those on land given the more extensive spatial scale requiring consideration across the sea, coast and land, and the generally greater breadth and diversity of stakeholders with complex interactions [50].

The challenges to working in marine and coastal areas described above are not new, but the NBS concept and associated Global Standard recently highlighted them further. Below, we propose three key interrelated research priorities for advancing NBS understanding and informing implementation in marine and coastal areas (Fig. 4):

- **Priority 1. Biodiversity and ecosystem science: improve understanding of marine and coastal biodiversity-ecosystem services relationship.** NBS address societal challenges while supporting and enhancing biodiversity and reducing vulnerability. It is critical to better understand the links between ecosystem health, extent, and their associated functions and services including how climate change and other human stressors affect these, individually and cumulatively. This will require greater research into the development of cost-effective technologies that are simple to operate, as well as investment and commitment into longer term monitoring programmes to overcome some of the challenges of research in marine and coastal systems. In addition, this research priority should identify safe operating spaces for marine life, tolerance thresholds under anthropogenic stressors and climate change, and reveal how stressors interact. Such information is essential to understand how to reduce pressures, where ecosystem services are delivered and where biodiversity outcomes are obtained. This is also important to understand the spatial distribution of environmental and social-economic conditions that may be favourable to habitats and service provision to support NBS that are better designed to help rebuild system resilience and achieve desired ecological outcomes under climate change.

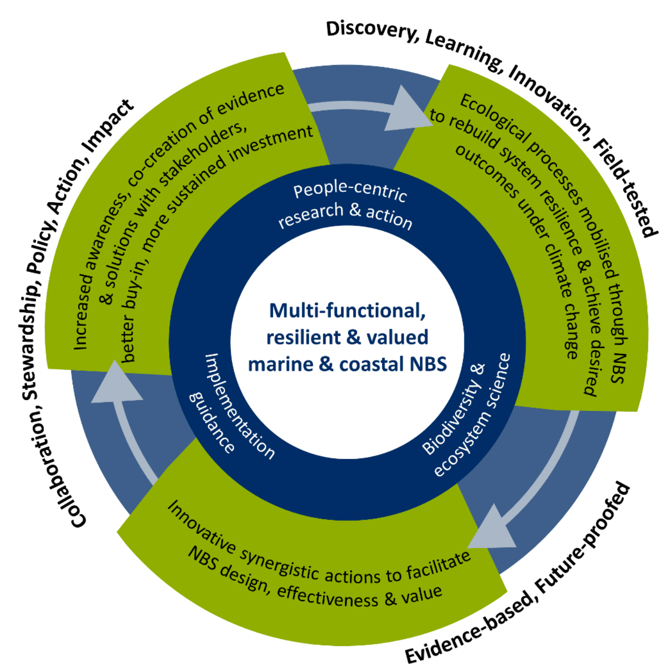

Fig. 4. Research priorities for advancing understanding and informing implementation of multi-functional, resilient and valued marine and coastal NBS. We identified three interrelated research priorities linked to this overall objective (which should be considered in combination). Key expected outcomes from adopting each priority with the others are highlighted in the green segments. Intended translation of actions are shown in the surrounding curved text.

- **Priority 2. Implementation guidance: provide scientific guidance on how and where to implement marine and coastal NBS and better coordinate across NBS strategies and projects.** Building on research priority 1, there is a need for more evidence to support marine and coastal NBS design for effectiveness and sustainability. Existing networks (e.g. https://networknature.eu/, https://oppla.eu/ and www.naturebasedsolutionsinitiative.org/) already help bring together current knowledge around NBS. There remains, however, a need to develop these networks and improve their evidence base, particularly around marine NBS. This includes: developing methods and technologies to implement some NBS (e.g. restoration-based NBS), identifying marine NBS best practices, addressing challenges of how to upscale NBS implementation, and considering the integration of NBS within broader marine spatial planning and strategic visions. As part of this, identifying context-specific barriers to NBS implementation could help leverage incentives to overcome them. Theoretical, inferential and implementation studies can help improve the evidence base around design, monitoring and evaluation. Such a broad approach will help understand factors that explain the gap between desired and observed outcomes of NBS, comparative advantages and cost-effectiveness across different tools including balancing potential trade-offs, and opportunities for 'layering up' existing interventions for greater impact.
- **Priority 3. People-centric research and action: develop ways to enhance marine and coastal NBS communication, collaboration, ocean literacy and stewardship.** Ensuring effective and widespread use of scientific knowledge by multiple stakeholders will be key for successful NBS. Bringing together evidence from research priorities 1 and 2 and providing clear explanation of scientific terminologies, data, and information to all stakeholder groups (including policy-makers, the private sector, local communities, and the general public) will help raise awareness of the NBS concept and its approaches. In turn, this will allow the evidence base for NBS to integrate local ecological-social knowledge, existing scientific knowledge from relevant existing programmes and networks, and practitioner expertise and experiences. It should also help promote the connectedness of people to marine and coastal ecosystems, drawing attention to their value and the need to improve management, including through NBS. Furthermore, engaging better with stakeholders will facilitate NBS co-creation and co-management, boost buy-in, and potentially drive a more sustained investment.

These research priorities are intrinsically linked to each other (Fig. 4) and will always be a work in progress; as methods, knowledge, awareness and goals change, so too will the approach to address these priorities. Moreover, these priorities should be considered in combination. Scientific knowledge produced through research priority 1 should inform implementation guidelines produced through priority 2, while awareness raising, collaboration, co-creation through priority 3 requires constant engagement and should be embedded across all research priorities. Stakeholders (including, for example, community groups, practitioners, policy-makers, industry, and researchers from different disciplines) will be involved across all research priorities, although the groups involved may vary depending on the specific actions adopted.

Implementation of NBS in marine and coastal areas has the potential to address a range of societal challenges while delivering biodiversity benefits. Given the urgency and scale of the challenges the world faces, the time to adopt such ambitious approaches is now. Information needs will always exist for environmental science and management. However, NBS and their associated challenges are areas of active research that aims to build the evidence base, learn from existing approaches and innovatively design new ones. For example, projects such as those we work on (e.g. https://macobios.eu, https://futuremares.eu, and https://rest-coast.eu/) are exploring questions such as: How can NBS help safeguard and increase ecosystem services derived from the marine environment? What can NBS do for coastal communities and marine stakeholders? How can NBS better involve people and be delivered equitably? How can we monitor, evaluate, and assure the quality of marine and coastal NBS across ecological, social, and economic outcomes? Where should NBS be prioritised? How can we design "climate-smart" NBS that can be upscaled? Which NBS approaches work, or not, and why? How can restoration approaches be managed and financed to promote their upscaling? Answering such questions involves a range of research approaches, from mapping past and present habitat distributions to analysing biodiversity, ecosystem health, and ecosystem services via state-of-the-art methods such as eDNA and local systems knowledge, and using models to predict the ecological, social, and economic effects and trade-offs from NBS [e.g. 40,48,51–54].

4. Embracing NBS in marine and coastal areas for transformative change

Life in marine and coastal ecosystems is facing unprecedented risks. For oceans and coasts to continue delivering the ecosystem services on which people depend, it is vital that NBS are deployed wherever possible, enabling system-wide actions to reduce direct and indirect drivers of biodiversity loss and environmental degradation. The evidence to close current knowledge gaps is coming, but in the meantime, lessons need to be applied from established approaches on which NBS are grounded, such as protected areas and coastal restoration projects. We also need to concentrate investment and research efforts now to move forwards with NBS design, implementation, monitoring, and evaluation.

NBS offer the opportunity to transform the management of nature, with the potential for broad and cascading ecological benefits and improvements to the welfare of societies. However, as with all management interventions, desired ecological and social outcomes will not be met if adequate and appropriate measures (e.g. rules, regulations, etc.) and enabling conditions (e.g. resources, community involvement, etc.) are not put in place [37,38,55]. Addressing our research priorities will help build and co-create the marine and coastal NBS evidence base however the translation of evidence into decision-making is rarely linear and decisions are always informed by a variety of sources of which scientific evidence is only one [56,57]. Ensuring NBS are implemented to a high standard is therefore critical and tools such as the IUCN Global Standard for NBS [29] may help. With this in mind, NBS can align societal agendas with complementary actions, simultaneously helping to tackle the twin crises of climate change and biodiversity loss as well as other societal challenges. NBS are, therefore, an essential part of a sustainable blue economy that will embed social and natural resilience into the future. Protected areas, the cornerstone of biodiversity conservation, are fundamental but not enough to save nature and, similarly, ecosystem-based approaches are insufficient to solve long-term societal challenges. Managing ecosystems without NBS through sector-based approaches largely ignores broader ecosystem services, thereby missing opportunities to deliver synergies in management and increasing the risk of unintended or contradictory actions. As the world is struggling to limit greenhouse gas emissions and reduce the human footprint on nature, we urgently need to think about how to achieve more with actions to address mounting societal challenges. As part of this, we need to embrace NBS in the science, policy and practice of managing marine and coastal ecosystems for tangible benefits to people and marine life.

NBS impacts and implications

- Environmental: Nature-based Solutions (NBS) offer powerful opportunities to address societal challenges, including biodiversity loss and climate change, by rebuilding marine and coastal system resilience. To maximise their effectiveness it is critical to advance knowledge on links between marine and coastal biodiversity, ecosystem health, vulnerability, functions, and services.

- Economic: NBS can contribute to a sustainable blue economy by helping to maximise the economic value of marine and coastal ecosystem services. To do so, an improved understanding is required of which marine and coastal NBS offer the greatest value, and how and where to implement and coordinate strategies for them.
- Social: To gain societal benefits and risk reductions from marine and coastal NBS, public and policy buy-in is required for their implementation. Thus, it is vital to improve communication, collaboration, ocean literacy and stewardship to raise awareness, integrate stakeholder knowledge, and potentially drive a more sustained investment.

Declaration of Competing Interest

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

Data availability

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

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