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Short Communication

Informing implementation of Nature-based Solutions in marine and coastal environments: the MaCoBioS Blue NBS Toolbox

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Abstract

Interconnected societal challenges such as climate change, biodiversity loss and food security demand immediate and coordinated action across local to global scales, guided by coherent policies and management mechanisms. Reflecting on the critical need to address societal challenges, Nature-based Solutions in marine and coastal environments, known as blue NBS, have emerged as an important part of the response strategy. Blue NBS integrate actions to protect and restore marine and coastal ecosystems while managing human impacts, embedding nature and people into decision-making through multifaceted approaches. However, blue NBS implementation trails terrestrial NBS. To effectively inform blue NBS implementation, research must produce actionable science that is relevant, timely and usable, requiring collaboration and active knowledge exchange across the science-policy-practitioner interface. Working with stakeholders, we developed the MaCoBioS Blue NBS Toolbox to begin addressing some of the barriers facing blue NBS implementation. Containing a collection of multi-disciplinary, scientifically-grounded and stakeholder-informed tools and products, the toolbox guides practitioners through different stages of blue NBS implementation. This toolbox provides an important initial set of resources to support the design and implementation of effective blue NBS and pave the way for further collaborative work to operationalise these tools in different social-ecological contexts.

Keywords

Introduction

Marine and coastal ecosystems provide a wide range of goods and services which are essential for economic development and social wellbeing (Costanza et al. 1997, Lefcheck et al. 2019, Wedding et al. 2022). Determining the economic value of marine and coastal ecosystems is challenging, but global ocean ecosystem services have been valued at trillions of euros per year (Hoegh-Guldberg 2015, Buckley et al. 2019). Due to their ecological, economic and social importance, it is no coincidence that one-third of the world's population lives within 100 km of the coast (Reimann et al. 2023) and 40% of large cities (> 1 million inhabitants) are located near the coastal zone (Kummu et al. 2016). However, the ecosystem services that biodiversity supports are being compromised in the context of biodiversity degradation from anthropogenic pressures and climate change (Cardinale et al. 2012, Trégarot et al. 2024). Urgent and effective actions are needed to reduce biodiversity loss and mitigate climate change (IPCC 2023).

Nature-based Solutions (NBS) have emerged as a practical approach to tackling diverse societal challenges, including biodiversity loss and the impacts of climate change. Marine and coastal (blue) NBS interventions include protection, restorative actions and other

sustainable management measures meeting specific criteria (IUCN 2020). In a given social-ecological system, understanding which intervention (or set of interventions) is appropriate and can be implemented to deliver the desired outcomes for people and nature is important. The advantage and challenge of blue NBS in comparison with other ecosystem-based approaches lies in their ability to integrate diverse actors and processes; however, enhanced standards are necessary for their application to fully realise their potential (O'Leary et al. 2024).

While NBS hold great potential for marine and coastal environments, their application has lagged behind terrestrial and urban systems (Pérez et al. 2024), in part due the absence of tools and resources that can support practitioners and decision-makers in planning interventions (Pérez et al. 2024). Overcoming the barriers currently hindering blue NBS implementation will require coordinated action, uniting researchers, practitioners, policy-makers, industries and local communities (O'Leary et al. 2023, O'Leary et al. 2024). Practitioner knowledge and experience is essential for advancing blue NBS implementation at international (e.g. The Kunming-Montreal Global Biodiversity Framework) and national levels. However, stakeholder engagement is also crucial, as management interventions can have different outcomes (positive, neutral or negative) depending on stakeholder perspectives and context (O'Leary et al. 2023).

To reach their full potential, blue NBS must be grounded in evidence and embedded in social networks, legitimacy and contexts. This requires blue NBS research and practice to be conducted collaboratively, taking a people-centric approach to facilitate cohesive actions towards a more sustainable future (O'Leary et al. 2023). The implementation of effective blue NBS should, therefore, consider and understand their local social, economic and ecological context, be built on effective partnerships, based on strong stakeholder engagement and participation and establish clear objectives to provide information for design and enable their evaluation. The MaCoBioS blue NBS toolbox, developed within the H2020 project "Marine Coastal Ecosystems Biodiversity and Services in a Changing World", was built to support-decision and management by bringing together multidisciplinary (ecology, social and policy), scientifically grounded and stakeholder-informed tools and products. Here, introduce the MaCoBioS blue NBS toolbox to raise awareness and encourage its use and future collaborations for tool development.

The MaCoBioS Blue NBS Toolbox structure and audience

The MaCoBioS Blue NBS Toolbox can be accessed directly at: https://macobios.eu/toolbox/. It is composed of a main landing page that describes the aim of the toolbox and introduces key concepts to understand the relevance and purpose of the different tools and how they relate. This main page also summarises the context of the MaCoBioS project and provides six StoryMaps that offer information on multiple marine and coastal ecosystems (mangrove forests, coral reefs, kelp forests, maërl beds, seagrass beds and salt marshes) and some of the work undertaken within the project. It then introduces the

blue NBS concept and the tools through short descriptive questions using an infographic figure that drives the user to the intended use of each tool (Fig. 1).

Figure 1.

Infographic describing the tools included in the MaCoBioS Blue NBS Toolbox.
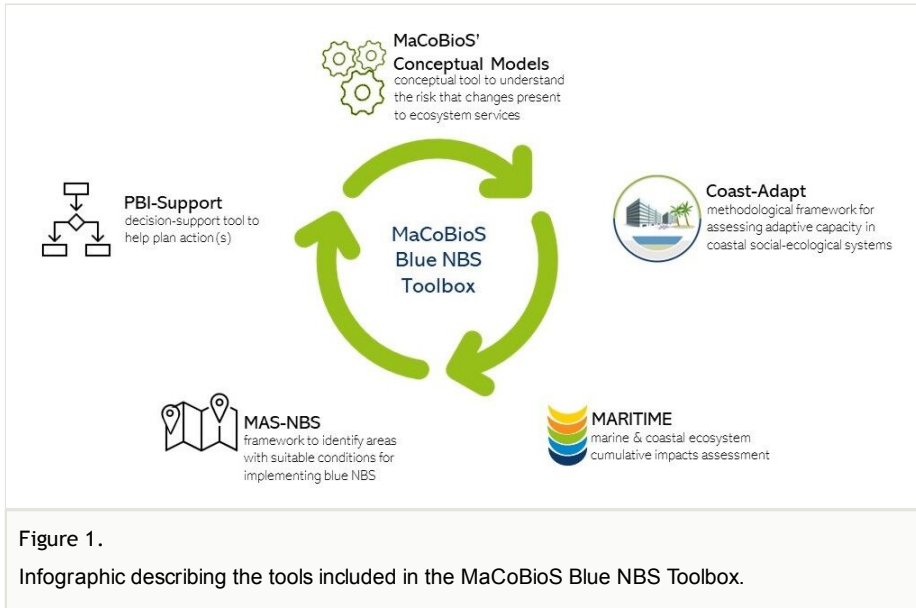
More detailed information for each tool can be found in each specific subpage of the toolbox, but a brief introduction is presented here:

- *Conceptual models.* *What happens to the ecosystem and its services if …?* Through fuzzy cognitive mapping, these conceptual models aim to help managers understand and visualise the complexity of marine and coastal ecosystems to provide information on system changes - cascading effects - following an increase or a reduction of pressure(s), therefore simulating the potential effects of intended management measures.
- *Coast-Adapt.* *Will a community be able to adapt to changes? How can we enhance their adaptive capacity*? This tool provides guidance for the development and application of an index-based adaptive capacity assessment in coastal socio-ecological systems to support future management decisions aimed at reducing social vulnerability and increasing adaptive capacity.
- *MARITIME.* *Where is the management to reduce local pressures most needed*? To help understand the response of marine and coastal ecosystems to the cumulative impacts caused by the interplay between climate change and human activities and to support the design of blue NBS, MaCoBioS developed a Machine Learning-Cumulative Impact Assessment model. This tool aims to support the design of blue NBS by modelling the response of marine and coastal ecosystems to cumulative impacts.
- *MAS-NBS.* *Where can we find the most favourable conditions for intervention*? For this purpose, MaCoBioS developed a Multi-tiered Approach to assess Suitability for NBS. MAS-NBS provides a framework to identify suitable areas in

which to implement blue NBS by combining environmental, social, economic and governance dimensions. This tool aims to support the identification of areas with suitable conditions for implementing blue NBS.

- **PBI-Support.** *What are the potential interventions that could be applied*? The Potential Blue Interventions Support tool aims to provide a clear and structured framework to guide decision-makers and practitioners through the initial stages of planning blue NBS.

Additionally, on the main page, further information is provided on the methods employed by MaCoBioS to collect biodiversity data that can help inform monitoring strategies for blue NBS. Finally, the main page presents a series of short, policy-relevant thematic briefings with accompanying guidelines on:

1. Innovating with nature and people: insights and recommendations for integrated design of blue Nature-based Solutions;
2. Enhancing uptake of blue Nature-based Solutions in European marine and coastal-related policies;
3. Implementing blue Nature-based Solutions to tackle climate change and biodiversity loss and improve human health and wellbeing; and
4. Research orientations for blue Nature-based Solutions.

The Policy Briefs section is followed by links to all project outputs and a WebGIS interface. The WebGIS consists of an Interactive Visualisation Tool to provide evidence-based products developed at an ecoregional level (Fig. 2). It provides spatial decision support in an accessible and user-friendly way to present ecoregional-level data collected and processed over the life of the project to a wide range of users, from practitioners to researchers and the public (Uchôa et al. 2024).

The MaCoBioS Blue NBS Toolbox is primarily intended for practitioners working to implement blue NBS with some information for lay audiences and researchers. The toolbox intends to provide tailored tools for blue NBS, in a user-friendly and usable format, to support the implementation of blue NBS and stakeholder engagement. The toolbox structure leverages interdependencies and complementary approaches taken between tools. Yet, each tool can be easily identified and applied as a standalone procedure. Throughout the MaCoBioS project, active communication channels have been maintained between toolbox developers and different stakeholders to identify and produce tools and resources that can support the earliest stages of blue NBS implementation.

Discussion

The protection and restoration of marine and coastal environments, as well as the conservation of natural habitats and species, is a key priority for the European Union, as acknowledged by the European Commission (European Commission 2020) and the Council of the European Union (Council of the European Union 2020). The importance of

safeguarding marine ecosystems and their services is underscored by international bodies such as the United Nations and the European Union. Key initiatives like the Sustainable Development Goals (e.g. SDG 13: Climate Action and SDG 14: Life Below Water) and the EU Biodiversity Strategy 2030 emphasise the need to halt biodiversity loss and ecosystem degradation by integrating environmental considerations into policy-making to combat climate change.

Figure 2.

WebGIS interface showing the seagrass distribution in the Mediterranean Sea under a climate change scenario (RCP8.5, 2100), taking into account all the pressures considered.

Blue NBS could be a powerful tool for mobilising policy-makers, practitioners and stakeholder communities towards multidisciplinary decision-making and leveraging sustainable funding for long-term solutions (O'Leary et al. 2023, O'Leary et al. 2024). However, marine and coastal areas present significant challenges for improved environmental management due to numerous human activities, diverse stakeholder interests and governance levels combined with the high heterogeneity and dynamism of coastal environments (UNEP 2006, O'Hagan et al. 2020, O'Leary et al. 2023). Addressing these requires multidisciplinary collaboration to effectively manage and protect marine and coastal ecosystems (Yates et al. 2024) and address complex issues inherent in coastal zones (McKinley et al. 2020, Casal and McCarthy 2023).

Translating scientific findings into practical real-world applications is a primary objective for conservation scientists and an essential component of evidence-based policy development and decision-making (Singh et al. 2014). However, more effort is required to ensure that scientific evidence is effectively transformed into actions to protect marine and coastal biodiversity (Noble and Fulton 2020, Casal and McCarthy 2023, O'Leary et al. 2023). In the case of NBS, a novel and evolving field, practitioners play a crucial role in developing policy and actions for their effective implementation (O'Leary et al. 2024), but meaningful and sustained collaboration between researchers and practitioners is necessary for research to support decision-making effectively. Additionally, the creation

of adaptive policies for managing dynamic and complex marine and coastal ecosystems requires flexible and innovative tools that address multifaceted issues, uncertainties and a wide range of future conditions (Furlan et al. 2018).

The MaCoBioS Blue NBS Toolbox introduces a novel set of multidisciplinary (ecology, social and policy), scientifically-grounded and stakeholder-informed tools and products to support the implementation of blue NBS at different stages. It aims to provide practical tools that equip practitioners with some of the necessary information to make better-informed decisions for blue NBS design that protects and restores the marine environment, while supporting local communities and invested stakeholders. Although several tools and methods have previously been developed to support the design and implementation of adaptive policies, specific tools for implementing blue NBS remain scarce (Pérez et al. 2024). The MaCoBioS Blue NBS Toolbox marks a significant advancement in operationalising blue NBS. Ongoing collaboration between researchers, practitioners and policy-makers will be essential to refine and adapt these tools to diverse social-ecological contexts. This continuous co-development of knowledge and tools will enhance the resilience and sustainability of marine and coastal ecosystems, ultimately benefitting the communities that depend on them. The MaCoBioS Blue NBS Toolbox exemplifies how collaborative, interdisciplinary efforts can generate actionable science to support coastal management and sets the stage for more effective and widespread application of blue NBS. Continued efforts to integrate, operationalise, and iteratively review and refine these tools will be crucial for improving our ability to sustain the resilience of these vital ecosystems and the people who depend on them.

Conclusions

As societies increasingly recognise the vital role of marine and coastal ecosystems in mitigating and adapting climate change impacts and supporting biodiversity, there is a growing urgency to design and deploy blue NBS effectively. The implementation of emerging blue NBS underscores a pressing need for tools and resources to guide decision-making and management processes. Accessible and usable tools are crucial to support stakeholders in identifying suitable interventions in the evolving blue NBS landscape. This toolbox provides an initial set of resources that can help address all these steps.

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Conflicts of interest

The authors have declared that no competing interests exist.

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