MAS-NBS: a multi-tiered approach to assess suitability for Nature-based Solutions

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MAS-NBS

The multi-tiered approach to assess suitability for Nature-based Solutions (MAS-NBS) is a three-tier decision-support tool that can help identify spatial areas with favourable conditions for a specific marine and coastal ecosystem to exist and persist to help prioritise areas for intervention and support marine and coastal Nature-based Solutions (blue NBS) design and implementation.

MAS-NBS was developed as part of a collaborative programme through the EU funded MaCoBioS project (www.macobios.eu). Tiers 1 and 2 were led by researchers from Centro Euro-Mediterraneo sui Cambiamenti Climatici, University of Portsmouth, and Fundação Gaspar Frutuoso. Tier 3 was led by the Institut Océanographique Paul Ricard, University of Exeter, and Lund University.

KEY INFORMATION

- These guidelines represent a broad overview of the process taken for MAS-NBS. Further information is provided in Furlan *et al.* (2023), Pérez *et al.* (2024), and Espinoza Cordova *et al.* (2023).
- MAS-NBS is a methodological framework designed to integrate environmental, social, economic, and governance dimensions for mapping suitable areas for blue NBS implementation. Choosing the most appropriate areas for intervention will increase the ecosystem's chances of success and MAS-NBS can help inform decision-makers in prioritising strategic actions.
- The output consists of a wide array of spatial data and visualisations for each targeted region, the examined ecosystem and climate change scenarios. MAS-NBS can be applied at different spatial and temporal scales, while considering different ecosystems of interest and climate change scenarios based on the aim of the analysis and available data.
- To use MAS-NBS the following information and data are required:
    - A clear notion of the key environmental variables that determine an ecosystem's distribution;
    - Spatial data at the relevant scale for ecosystem distribution, endogenic and exogenic environmental variables, and projections of these over time under different climate change scenarios;
    - Appropriate environmental suitability mapping and risk assessment modelling tools, and ways to combine these data; and
    - Awareness of the key enabling conditions for successfully implementing interventions and a clear strategy to identify context-specific social, economic, and governance information for priority areas, including a participatory strategy.

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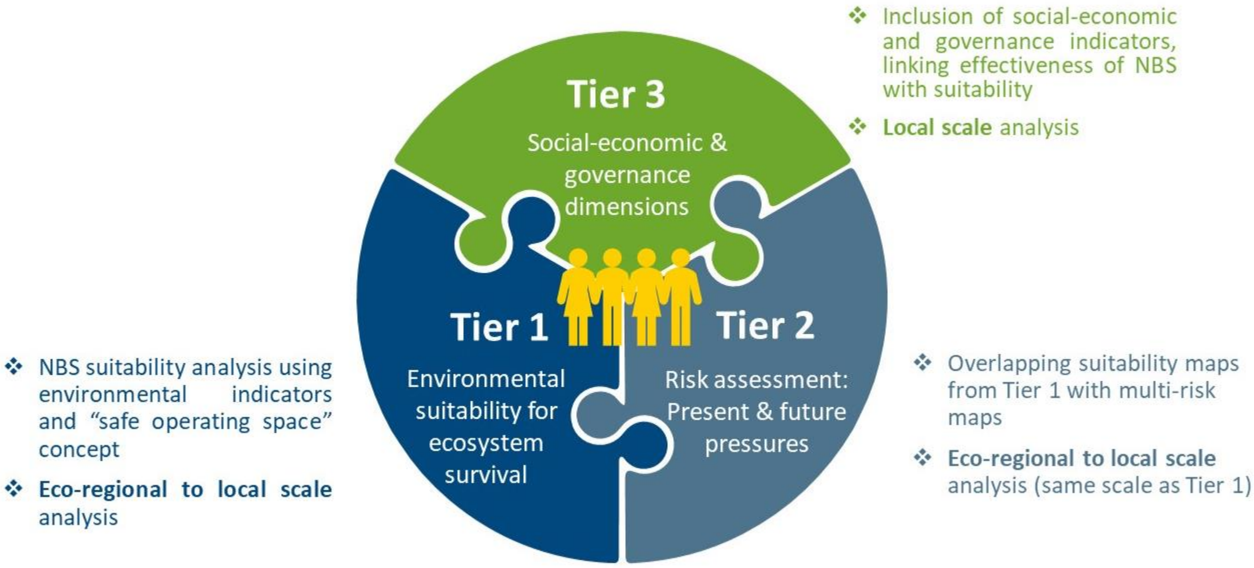
METHODOLOGICAL FRAMEWORK

MAS-NBS integrates environmental suitability mapping (Tier 1) with key outcomes from risk assessment modelling (Tier 2) to identify and predict present and future areas where a specific ecosystem occurs and is likely to persist, the pressures it faces (and could face under mid- and long-term scenarios), and to prioritise areas for intervention. MAS-NBS then combines this information with context-specific social, economic, and governance features (Tier 3) to inform whether areas have the necessary enabling conditions for real-world implementation and successful interventions actions.



- Tier 1 aims to identify areas with suitable environmental conditions for ecosystem persistence. It focusses on the physical, chemical, and biological factors crucial for the sustained existence of the target ecosystem's keystone/foundation species and their environmental tolerance. Based on known environmental requirements, future climate scenarios are used to predict potential shifts in areas suitable for ecosystem existence.
- Tier 2 aims to identify present and predict future areas where a specific ecosystem occurs and is likely to persist considering the pressures it faces (and could face under mid- and long-term scenarios), and to prioritise areas for intervention. It involves overlapping areas where ecosystems face heightened risks from endogenic and exogenic pressures known to affect ecosystem condition with areas that have the most suitable environmental conditions for ecosystem persistence.
- Tier 3 aims to inform local decision-making regarding NBS implementation as to inform whether areas have the necessary enabling conditions for real-world implementation and successful intervention actions. It incorporates social, economic and governance dimensions that influence decisions regarding intervention implementation in a particular area and, if an intervention is implemented, its potential success.

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Tier 1: Environmental Suitability for Ecosystem Survival

Species rely on particular environmental conditions for survival and growth. The existence or absence of these conditions facilitate or inhibit the presence of particular species. As blue NBS implementation relies on the ecosystem(s) present in an area, it is important to understand where keystone or foundation species that form the ecosystem of interest currently exist, and where they may persist in the future. Environmental suitability assessment, in combination with climate scenarios, can be used to identify such areas as long as key information on the environmental conditions that a foundation species needs are known.

Step 1: Identify the scale of assessment.

Environmental suitability assessments can be performed at different scales (e.g., local, regional, national). The spatial scale for the assessment has implications for data availability and processing. For example, finer resolution data is required for local scale assessments compared to regional ones, and data may need to be processed differently to ensure comparability across scales. **The spatial scale of any environmental suitability assessment directly depends on its purpose.**

Step 2: Identify key environmental conditions for an ecosystem and relevant indicators.

To conduct an environmental suitability assessment, **it is critical to identify the key environmental conditions, and indicators that represent these, required by, or that affect, the foundation species forming a particular ecosystem**. Indicators could include aspects such as depth, salinity, or sea surface temperature and these can be identified using existing evidence, expert judgement, and extrapolation methods. Step 2 and Step 3 should be conducted concurrently as data availability and pre-processing is a key determinant of indicator selection.

The spatial scale identified in Step 1 determines the overall focal area of the environmental suitability assessment, however ecosystems typically have specific geomorphological requirements that mean they cannot exist throughout the whole focal area. This can be used to help refine the study area and reduce the processing time of subsequent analyses (Steps 3 to 5). For example, *Posidonia oceanica*, an endemic seagrass species in the Mediterranean Sea, has a maximum depth of approximately 50 m (Tursi *et al.* 2022) which limits its potential spatial extent. The study area can therefore be limited to areas within the focal area with depths less than 60 m.

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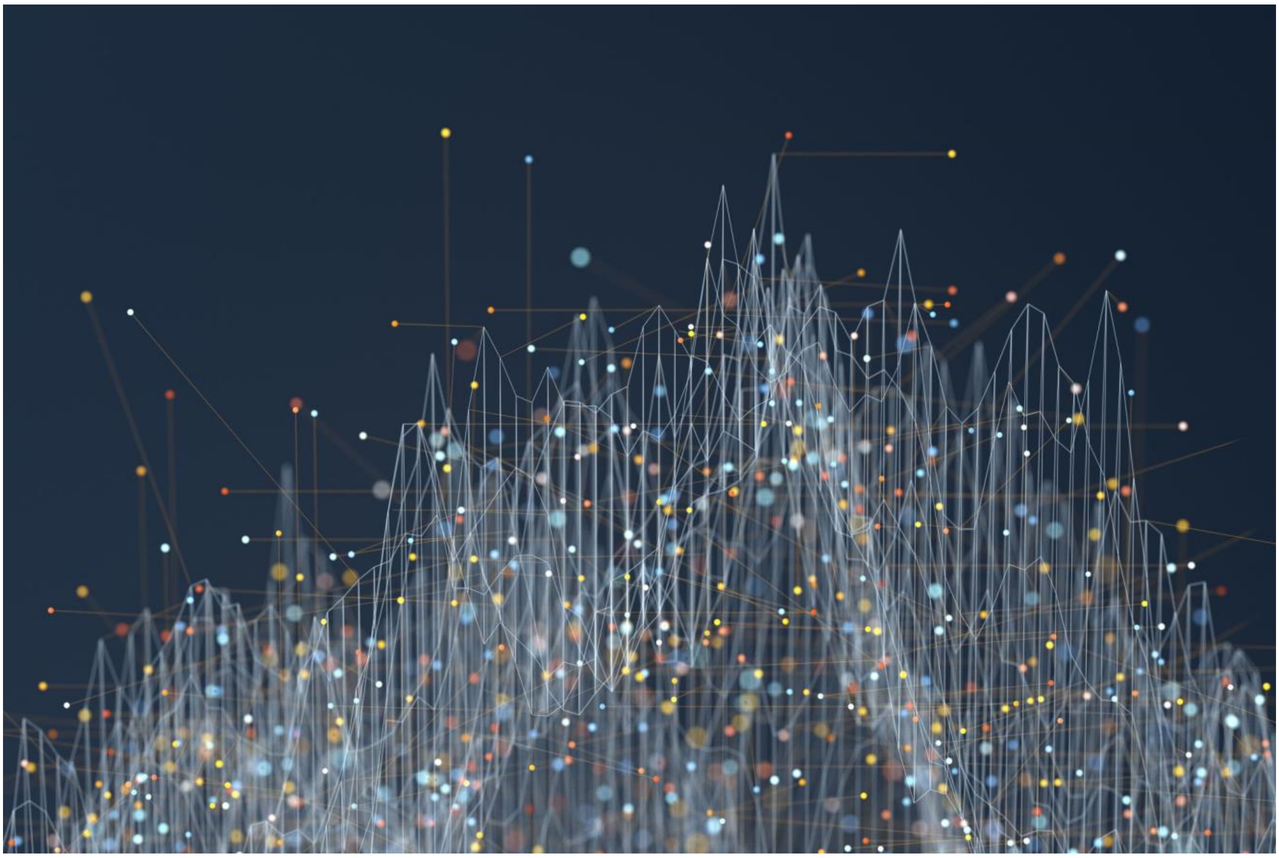
Step 3: Collect and pre-process data.

The merit of an environmental suitability assessment is its ability to spatially evaluate where suitable environmental conditions exist, presently and in the future, for the growth of a target species. Results can be used to predict likely changes in areas where foundation species forming ecosystems can, or could, occur, based on these environmental requirements. Therefore, **comparable data for selected key indicators are required for both baseline (present day) and future (e.g., 2050, 2100) timeframes under different climate scenarios (e.g., RCP4.5 and RCP8.5).** The extent of the ecosystem of interest within the study area is an essential dataset for an environmental suitability assessment if extrapolation methods for indicator values are to be used. Data need to be pre-processed in order to obtain a consistent format to allow comparison and aggregation, e.g., same projection, spatial resolution, etc. Depending on the chosen modelling approach, data might also need to be normalised whereby assigned values are converted to a dimensionless form. No consideration of pressures from direct human activities (e.g., fishing, shipping, etc.) are taken at this stage.



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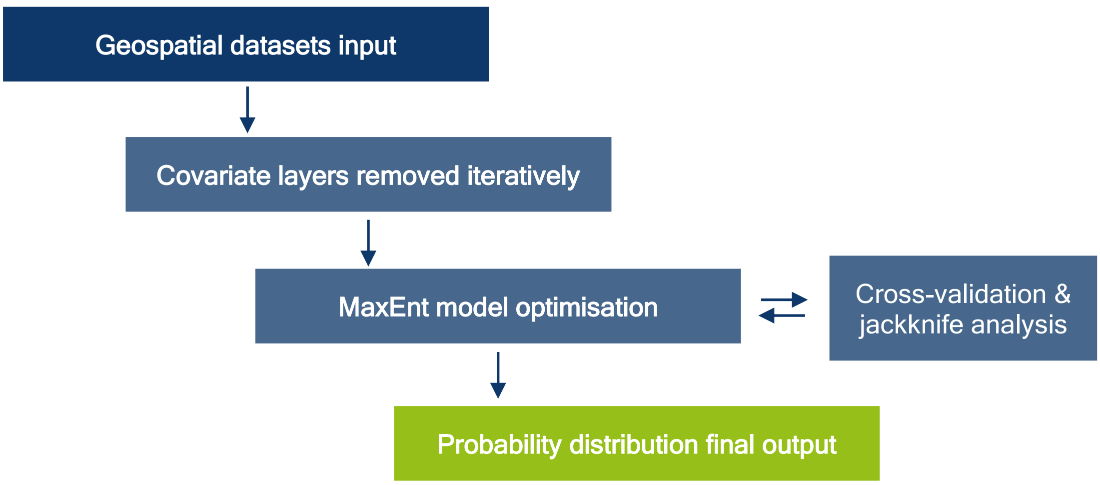
Step 4: Develop a suitability model.

To assess whether an area has suitable environmental conditions for an ecosystem of interest, various methods can be applied. Among the most common are species distribution models such as Maximum Entropy (MaxEnt) and GIS-based Analytic Hierarchy Process (AHP). Different methods may be applied depending on data availability and problem context. For example, MaxEnt is particularly useful when limited data on species occurrences but extensive environmental data exist, while GIS-based AHP is useful for considering the relative importance of multiple criteria in decision-making processes. Steps 1-3 of Tier 1 provide the initial basis for the application of both MaxEnt models and GIS-based AHP through the selection of environmental indicators.

MaxEnt is a probabilistic modelling approach widely used to model species geographic distribution that employs an information theory presence-only approach (Downie *et al.* 2013). Its ability to predict species distribution under future/hypothetical environmental conditions makes it useful for supporting decision-making surrounding blue NBS. After selecting relevant environmental indicators through Steps 1-3, correlated variables are iteratively removed prior to modelling until collinearity is minimised. MaxEnt then compares known environmental conditions of sites where a species has been observed with those in surrounding sites (Downie *et al.* 2013), selecting the statistical model that maximises the entropy of the species probability distribution (Phillips *et al.* 2006). Cross-validation and jackknife analysis assess model performance and indicator contribution, respectively. The model outputs the probability of finding a species at a particular site considering its environmental conditions, enabling predictions under different scenarios. Suitability classes are based on the species presence probability distribution and expert judgement, with the 'very suitable' class corresponding to the highest probabilities of species presence.

Simple representation of the MaxEnt process



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GIS-based AHP, a widely used Multi-Criteria Decision Analysis (MCDA) technique. permits data integration and variable prioritisation of indicator groups through a statistical approach and expert judgement. This enables various indicators to be aggregated into a single index for comprehensive spatial characterisation analyses, aiding complex decision-making involving multiple criteria. This multi-step process involves criteria setup, weighting, aggregation, and geoprocessing tasks (Greene *et al.* 2011). Suitability classes are defined and scored (ranging from 0 to 100) for each environmental indicator through data examination and expert judgement. The 'very suitable' class aligns with optimum conditions (i.e., scored as 100), usually represented by indicator values near the median or extremes, depending on the characteristics of the indicator (e.g., median: salinity; extremes: summer sea surface temperature and dissolved oxygen). Indicator weights are derived through expert consensus using pairwise comparison matrices to decide the relative significance of indicators. Expert scores are combined into a final matrix through geometric mean computation and normalisation. The priority vector, representing final variable weights, is obtained by calculating the arithmetic mean of normalised row values. Consistency of expert scores is assessed to ensure relative consensus and reliability of weightings. This weighting process is repeated for all indicator groups (e.g., water quality), followed by their aggregation with the suitability scores of indicators. This is accomplished using the weighted sum approach for each indicator group and scenario, providing an overall suitability score.

Simple representation of GIS-based AHP

Criteria setup
Indicators selected, geospatial datasets input, and suitability classes defined and scored

↓

Weighting
Pairwise comparison matrices completed by experts to determine relative significance of indicators

⇄ Assess consistency of experts' judgements to ensure reliability of weightings

↓

Aggregation
Weighted criteria combined to create an overall index for each indicator

↓

Geoprocessing tasks
Overall suitability score generated

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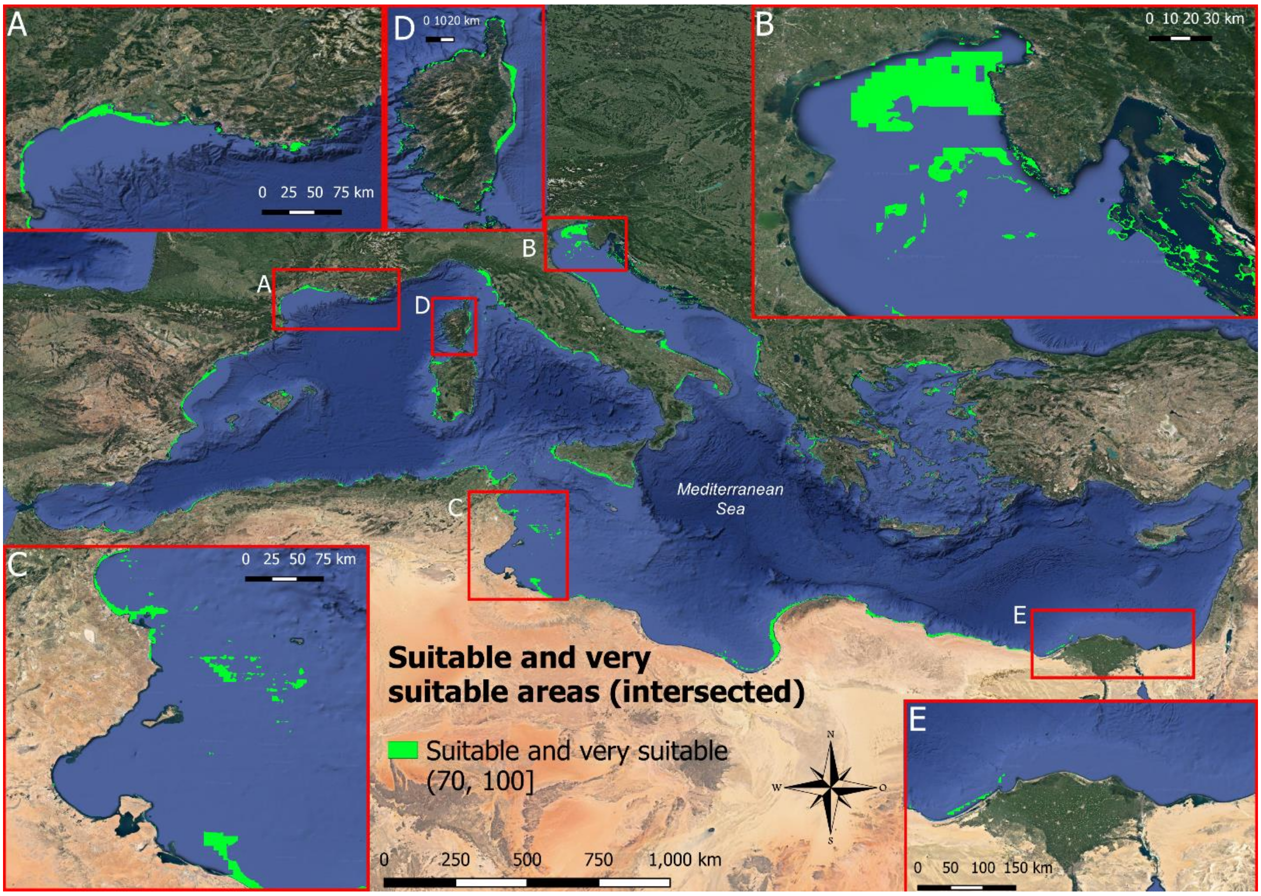
Step 5: Construct baseline and future suitability maps.

For both MaxEnt and GIS-based AHP modelling approaches, the final suitability maps under the baseline and future scenarios can be created by extracting the intersecting suitable and very suitable areas as defined by the models to explore the most suitable areas for the ecosystem of interest and to support decision-making regarding intervention options. As an example, the figure below showcases a suitability map calculated with the GIS-based AHP approach based on data from 2016-2018 for geomorphology, water quality, and climate indicator groups for *Posidonia oceanica* in the Mediterranean Sea (A: western Mediterranean; B: Northern Adriatic; C: Gulf of Gabès; D: western Corsica; E: Egyptian coasts).



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Tier 2: Risk Assessment – Present and Future Pressures

The environmental suitability assessment (Tier 1) informs where favourable conditions exist, and may persist, for a specific ecosystem. However, ecosystem presence or absence, or its condition (health), is affected not only by environmental conditions, but also human activities. Tier 2 therefore adds information about the endogenic (e.g., nutrient input, dissolved oxygen, shipping traffic, coastal development, etc.) and exogenic (e.g., ocean acidification, wave height, water velocity, etc.) pressures that are known to affect ecosystem condition. For data from Tiers 1 and 2 to be combined, the same spatial and temporal scale should be used. By overlapping areas where ecosystems are at greater risk from these pressures and areas with the most suitable environmental conditions for ecosystem persistence, we can identify priority areas for intervention.

To identify areas at greater risk from pressures, both currently and in the future, a risk assessment needs to be conducted. Different methods can be used for risk assessment: within MaCoBioS we developed a multi-risk assessment framework called MARITIME (Furlan *et al.* 2023, Simeoni *et al.* 2024). MARITIME is a machine learning cumulative impact assessment model. It uses a Random Forest based model to explore predicted future ecosystem changes with two main components: i) model predictors with proxy indicators for key endogenic and exogenic environmental variables that determine ecosystem presence (e.g., nutrient input, sea surface temperature, shipping traffic, etc.); and ii) model response as the distribution of the specified ecosystem.

Using the outputs from MARITIME, areas where ecosystems face heightened risks from endogenic and exogenic pressures can be spatially overlapped with areas identified as having the most suitable environmental conditions for ecosystem persistence from the environmental suitability assessment. This enables ‘high-risk’ and ‘low-risk’ zones to be identified to inform prioritisation of areas for blue NBS both presently and under future scenarios. High-risk zones are defined as those with a high probability of species absence considering pressures; conversely low-risk zones are those with a high probability of species presence considering pressures. These maps can then be used to inform decision-making (Tier 3).

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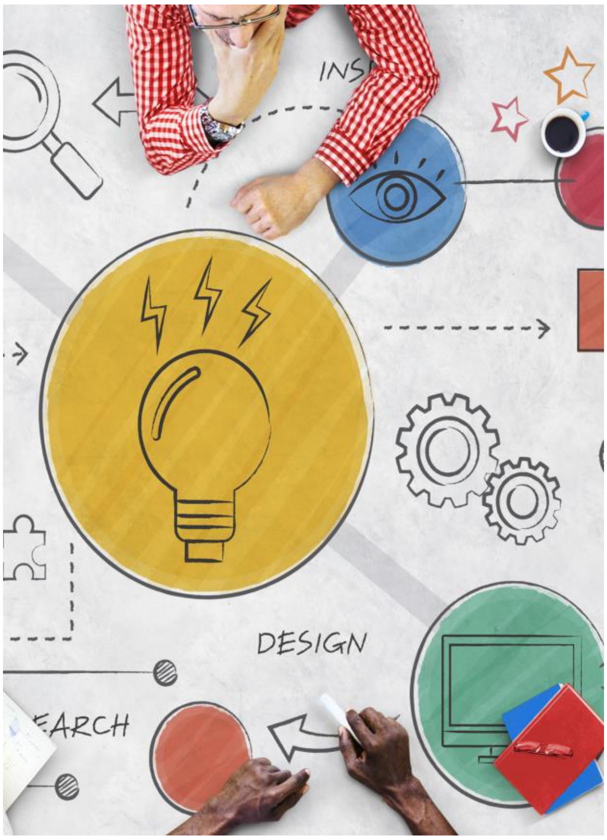
Tier 3: Social-economic and Governance Requirements

Once favourable locations for blue NBS have been identified based on environmental suitability and present and future pressures, the social, economic and governance contexts need to be considered. Effective blue NBS implementation requires social and institutional support and local decision-making. Apart from an ecological need to implement a particular blue NBS, social desirability and the benefits, or trade-offs, for society are important factors to understand and foster. The context-specific nature of blue NBS means that local knowledge and social-economic, as well as environmental, conditions are important for their design, operation, and effectiveness (Pascual *et al*. 2023). Application of Tier 3 requires integration of stakeholders to inform understanding of both policy and local community concerns, ecological knowledge, and social pressures, to help create interventions that yield positive outcomes for people, nature, and society.

Tier 3 incorporates the social, economic, and governance dimensions that determine whether an intervention can be implemented in a particular area, what the intervention could be, and how successful it might be. Coast-Adapt (Espinoza Cordova *et al*. 2023) and PBI-Support (Pérez *et al*. 2024) have been designed to help integrate these dimensions with the local environmental context to identify appropriate adaptation strategies and potential blue NBS options. This tier requires a more detailed scale of analysis and site-specific information.

Tier 1 and Tier 2 of MAS-NBS can help direct decision-makers to places where NBS interventions may be appropriate now and into the future. However, once areas potentially suitable for management have been identified, local context should be reviewed to inform selection of the most appropriate blue NBS, if any, to be implemented. This is to understand what is needed to improve ecological conditions, protect and restore ecosystems, support society, and, if necessary, influence human behaviours. It will, therefore, be important to understand the problem that needs to be addressed, the vulnerability of the social-ecological-economic system to biodiversity loss and climate change, the drivers of change, the stakeholders involved, and the potential trade-offs different interventions and approaches may involve.



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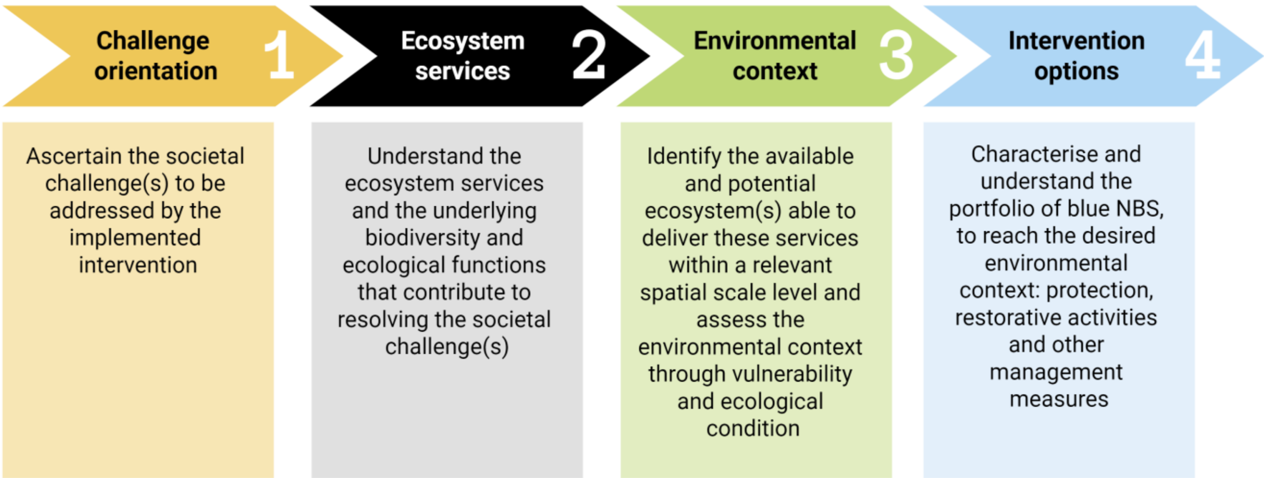
In deciding whether or not a blue NBS is appropriate, the following questions will be important to consider:

- Who are the relevant stakeholders to involve, from local communities and indigenous people to industries?
- What societal challenges are prioritised by national policy, and which do different stakeholder groups perceive as most relevant at the local level?
- What spatial scale can the intervention be implemented at?
- What marine and coastal ecosystems are present in the area that could contribute to addressing the identified societal challenge(s)?
- What is the ecological condition of the marine and coastal ecosystem(s) and, if appropriate, what are the main drivers of decline?
- How vulnerable are marine and coastal ecosystems to likely hazards (e.g., storm surges, hurricanes, human pollution, fishing pressure, etc.)?
- Can a blue NBS help address the societal challenge(s) and, if so, what action(s) could be taken?

The Potential Blue Interventions Support (PBI-Support) tool developed by MaCoBioS (Pérez *et al.* 2024) may help those leading the NBS process to integrate relationships among societal challenges, ecosystem services, environmental context, and ecosystem-based management approaches (protection, restorative action, and other management measures) to identify appropriate blue NBS. PBI-Support takes the following step-by-step approach:



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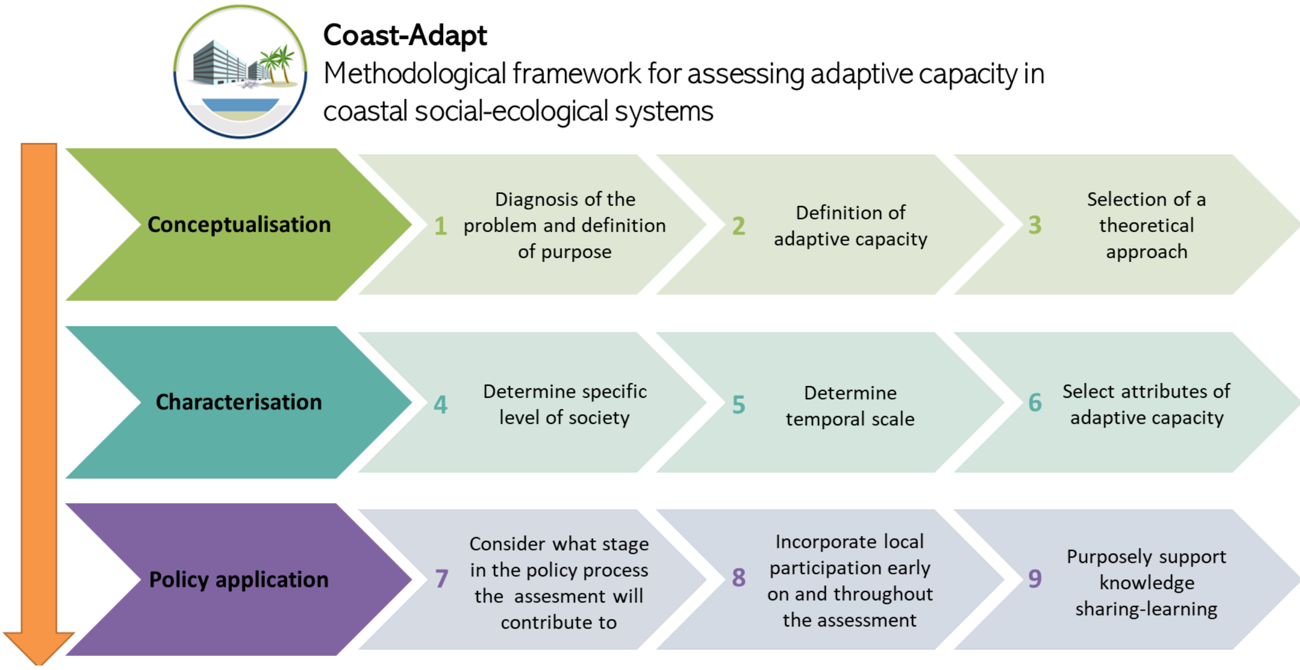
PBI-Support presents a new approach to facilitate the identification of potential blue NBS by orienting intervention-selection around specific societal challenges and contextual environments. Blue NBS interventions considered by PBI-Support include marine protection (i.e., fully, highly, lightly, and minimally protected areas), restorative action (i.e., active, passive, and partial restoration; rehabilitation of ecological function(s) and ecosystem creation), and other management measures (i.e., implementation and enforcement of regulations).

When designing an intervention, it is critical to appreciate local social-ecological context. This includes understanding: which communities are more vulnerable to the impacts of climate change or ecosystem loss; what conditions enable them to anticipate, respond, and adapt to these changes; how these change over time; and how we can enhance this capacity. The Coastal Adaptive Capacity Assessment Guidelines (Coast-Adapt) produced by MaCoBioS (Espinoza Cordova *et al.* 2023) can help to design, implement, and apply index-based adaptive capacity assessments that can effectively support adaptation strategies in coastal social-ecological systems. Coast-Adapt aims to provide practical guidance for the development and implementation of adaptive capacity assessments to support future management decisions aimed at reducing social vulnerability and increasing adaptive capacity in the context of climate change adaption in coastal social-ecological systems.



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Implementing blue NBS will require collaboration across multiple sectors and actors to catalyse and integrate locally appropriate and innovative solutions that advance environmental and social outcomes beyond those already achieved by established approaches for environmental management. The success of any intervention therefore depends on the participation and support of local communities and stakeholders (Pascual *et al.* 2023). Strong partnerships among public and private entities and local communities will therefore be required for blue NBS implementation. Taking the results of Tiers 1 and 2 will help inform conversations with stakeholders to identify shared objectives and design locally-appropriate NBS through Tier 3. These conversations and engagement activities should be led by three key principles:

Following these principles should help develop robust, transparent, and inclusive participation in decisions surrounding blue NBS. It should also help stakeholders come together to codesign interventions with effective regulations and legislation that focus on reducing and mitigating relevant local stressors and that work with existing management actions.

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CONCLUSIONS

Nature-based Solutions (NBS) comprise various ecosystem-based approaches that work with and enhance nature to address multiple challenges, including biodiversity loss and climate change impacts. To maximise the success of blue (marine and coastal) NBS in helping us face those challenges, we need to carefully consider how to design and where to implement them. While there are very few absolutes for how best to design and implement locally appropriate blue NBS, MAS-NBS can help inform spatial strategic prioritisation, conversations with stakeholders, and ensure local social, economic, and governance dimensions are considered during planning of interventions.

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Marine Coastal Ecosystems Biodiversity and Services in a Changing World (MaCoBioS) was a four year research project running between 2020 and 2024 funded by the European Union's Horizon 2020 research and innovation programme. Its objective was to inform efficient and integrated management and conservation strategies for European marine and coastal ecosystems to face climate change by: (a) advancing the scientific evidence base on ecosystem functioning, and (b) developing tools to assess vulnerability and advancing understanding of potential management options.

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