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Deliverable D3.3 – *Portfolio of optimized spatially defined ecology-based tools, and associated supporting information technologies, to support the consolidation and assessment of MPAs and MPA networks in Living Labs*

WP3 – Work Package 3

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Document History

Deliverable Title	Portfolio of optimized spatially defined ecology-based tools, and associated supporting information technologies, to support the consolidation and assessment of MPAs and MPA networks in Living Labs
Brief Description	This deliverable documents the implementation, optimisation, and co-development of a portfolio of ecological and environmental decision-support tools and associated information technologies in six Blue4all Living Labs. It demonstrates how these tools can be applied to address concrete management needs in individual MPAs and MPA networks and provides practical guidance for their effective use and integration into ongoing MPA and MPA-network processes.
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Abbreviations

CIA: Cumulative impact assessment

CP: Contact Point

DST: Decision-Support Tool

EA: Ecosystem Approach

EUNIS: The European Nature Information System

EU: European Union

LL: Living Lab

NA: Needs Assessment

NEAT: Non-indigenous Species Effects Assessment Tool

NIS: Non-Indigenous Species

MPA: Marine Protected Areas

SEG: Stakeholder Engagement Groups

WP: Work Package

MSFD: Marine Strategy Framework Directive

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1. Executive Summary

Work package 3 aims to provide science-based solutions that strengthen the use of ecological and environmental information in the design and adaptive management of marine protected areas (MPAs) and MPA networks. This deliverable documents the co-development, implementation, and optimisation of a portfolio of ecology-based, spatially explicit decision-support tools (DSTs) in six Blue4All Living Labs across the Baltic Sea, North Sea, and Irish Sea. Building on the conceptual framework in deliverable 3.1, the tool inventory and assessment in deliverable 3.2, and the needs assessment carried out in work package 4. Selected DSTs were tailored to address concrete management needs related to the assessment of the cumulative effects of human activities and pressures, the analysis of the distribution and potential impacts of non-indigenous species, and ecosystem service potential supply and the sensitivity to pressures in individual MPAs and MPA networks. Through a common process focused on defining decision contexts, gathering and harmonising data, and iterative testing with Living Lab contact points and stakeholder engagement groups, the Non-Indigenous Species Effects Assessment Tool (NEAT), the PlanWise4Blue Cumulative Impact Assessment Tool, and an ecosystem-service sensitivity analysis with interactive Sankey visualizations were implemented and substantially improved in terms of usability, transparency, and decision-making relevance. The work led to new and enhanced outputs, including spatially explicit assessments and interactive visualisations, and identified key data gaps, technical limitations, and enabling conditions for wider uptake. The deliverable translates these experiences into a practical implementation guide and defines priorities for further development and integration of these tools into the Blue4All MPA Solutions Hub, thus supporting more consistent, science-based, and user-oriented decision-making in the design and management of MPAs across European seas.

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2. Introduction

Conservation and restoration efforts are gaining momentum across global and European seas. This trend is being driven by recently adopted, high-profile commitments under the Kunming-Montreal Global Biodiversity Framework (GBF), notably Target 3 (widely known as the "30×30" target), which calls for the effective conservation of at least 30% of terrestrial and marine areas by 2030 (CBD, 2022). In Europe, the ambition is even higher, with the EU Biodiversity Strategy for 2030 aiming not only to protect 30% of EU seas, but also to place 10% under strict protection, thereby raising expectations not just about the extent of designated areas, but also about the level of protection that implemented measures should deliver (EC, 2020).

Marine protected areas (MPAs) are among the most widely used and long-established area-based instruments for marine conservation. They are globally recognized as strategic tools for translating biodiversity ambitions into concrete actions. A substantial body of evidence generated in the last two decades indicates that, when MPAs are carefully planned and effectively implemented, they can safeguard habitats and species, improve biodiversity across levels of biological organization, facilitate ecosystem recovery, strengthen resilience to human activities and pressures (including climate-related ones), and provide an enduring governance framework for managing human uses in ecologically sensitive areas (e.g., Kerwath et al., 2013; Mellin et al., 2016; Topor et al., 2019; Sala et al., 2021; Schmidt et al. 2025). Realizing these benefits, however, depends on MPAs being underpinned by robust ecological and environmental information, strategically located and appropriately designed, and sustained through monitoring, adaptive management, and effective compliance (Grorud-Colvert et al., 2021; Hoppit et al., 2025).

In the EU, the marine area designated as MPAs has increased over the past decade, rising from around 4% in 2012 to over 13% in 2023 (EEA, 2025). This expansion has been driven primarily by the growth of the Natura 2000 network, complemented by nationally designated MPAs and further supported by the coordination established within the framework of the Regional Sea Conventions (Aminian-Biquet et al., 2024; EEA, 2025). Despite this progress, the current trajectory remains insufficient to meet the EU's 30% by 2030 target. According to the European Environmental Agency, meeting the target will require more than a twofold increase in the current rate of designation (EEA, 2025). However, a more fundamental concern is that designation is a weak proxy for real protection. Recent assessments indicate that over 80% of EU MPAs provide low levels of protection, often because allowed human activities remain misaligned with stated conservation objectives and because key components of implementation, clear regulations, sufficient management capacity, monitoring, and enforcement, are absent or inconsistently applied (Aminian-Biquet et al., 2024). In this context, the central challenge is not only to expand MPA coverage, but also to ensure that MPAs are planned and managed considering the ecological realities and dynamics of the systems they are intended to safeguard, and to explicitly account for the activities and

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pressures, currently or in the future, acting upon them. This is certainly not the situation across Europe, where MPA processes still draw on ecological, environmental, and human-use knowledge in an uneven and often limited way, as shown by a Blue4all Deliverable 3.1 (Hoppit et al., 2024).

To improve the current situation and deliver agreed protection commitments, Europe needs to plan and manage MPAs through a comprehensive, science-informed ecosystem approach (EA), rather than treating MPAs primarily as boundary-setting exercises. At its core, an EA is grounded in a robust understanding of the condition, dynamics, and interactions of key habitats, species, and ecological processes, and combines this ecological evidence with information on human uses to identify the pressures and pathways through which activities affect ecosystem components (EC, 2016). Crucially, this understanding is used to minimize harmful interactions, by reducing, redirecting, or preventing the most damaging pressures, so that conservation objectives are achieved while compatible activities can continue. In practice, this requires assessing drivers and pressures within and beyond the managed area using the best available evidence, accounting for cumulative and interacting effects across activities, and implementing measures that target the pressures most relevant to the stated conservation objectives. Framed this way, MPAs are far more likely to deliver tangible conservation and restoration outcomes rather than become “paper parks” relevant only in policy documents.

A major challenge in operationalizing an EA perspective for MPAs` design and management is integrating and analysing, across space and time, multiple sources of ecological, environmental, and human-use information. However, as has been shown in the Blue4all Deliverable 3.2, doing so is increasingly feasible (Barboza et al., 2025). A growing suite of science-based digital tools can now integrate multiple data streams and translate them into spatially explicit outputs (maps), indicators, and scenarios, designed to inform marine planning and decision-making (Pınarbaşı et al., 2019; Depellegrin et al., 2021; Barboza et al., 2025). Yet, such tools are often applied narrowly to their original purpose and geographic context, even when their underlying methods and data structures would allow broader transfer. A clear example is the range of decision-support tools (DSTs) developed for implementing cumulative impact assessment (CIA) (e.g., Kotta et al., 2020; Menegon et al., 2018). Although these tools have been used primarily to support MSP and strategic environmental assessment (SEA), they can be repurposed to inform MPA processes. CIA tools can be used to assess the distribution of human activities and pressures, their effects on ecosystem components and processes, and how these effects may shift under alternative management and human-use development scenarios. In doing so, they can support the strategic design and placement of MPAs and the development of fit-for-purpose monitoring and assessment programs to maximize their long-lasting effectiveness. The limited uptake of these tools in MPA processes across Europe is also often compounded by insufficient co-development with end-users, meaning that tools may not align with established planning and decision-making workflows, the technical capacities of intended users, or the practical

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questions that managers and practitioners need to address. Additional barriers include persistent data gaps, limited awareness of where relevant datasets can be accessed even when they exist, and a lack of skills and resources to integrate and harmonize heterogeneous data streams, all factors that collectively constrain the wider uptake and upscaling (Barboza et al., 2025).

This deliverable describes and details the work carried out under Task 3.3 to implement, upscale, and improve a set of tools that provide tailored solutions to the ecological and environmental information needs identified by the Blue4all Living Labs (LLs), supporting concrete actions for the design and management of individual MPAs as well as national and transnational MPA networks across Europe. To do so, WP3 in the frame of Task 3.3 has extensively worked in collaboration with the LLs' Contact Point representatives (CPs) and established stakeholder engagement groups (SEG) to:

(i) Identify digital decision support tools (DSTs) with strong potential to provide the ecological and environmental information needed to support ongoing MPA processes and the practical implementation of an ecosystem-based approach within the LLs. Building on the tool inventory and assessment presented in Deliverable 3.2, the selection considered the characteristics of the identified tools, the specific needs of the LLs, the availability and suitability of relevant data, and the feasibility of implementing or adapting the tools within the project timeframe.

(ii) Apply the selected DSTs in the LLs, documenting and critically assessing key development needs, and strengthening tool performance through the integration of global and European data infrastructures (e.g., GBIF, OBIS, Copernicus, EMODnet), national databases, and participatory monitoring initiatives.

(iii) Improve and optimise the tested DSTs in response to the needs identified during the testing phase, ensuring that digital applications, underlying algorithms, and data workflows align with the operational requirements and decision processes of MPA managers and decision-makers.

(iv) Deliver a clear, step-by-step implementation guide for applying the DSTs in practice, incorporating the latest advances and lessons learned, and preparing the tools for integration into the Blue4all MPA Solutions Hub developed in WP5.

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3. Tool testing process

3.1 General approach

The work carried out under Task 3.3 and reported in this deliverable was guided by four core principles, intended to ensure that the outputs are science-based, practical, and directly usable by the LLs:

1. ***Living Lab needs as a starting point***: All activities begin from the needs identified across the different LLs. These needs provided the foundation for prioritizing actions, selecting methods and tools, and shaping the solutions delivered through Task 3.3.

2. ***Build on existing tools and methods ("avoid reinventing the wheel")***: Rather than developing new tools from scratch, we focused on delivering solutions through the tools identified in Task 3.2 and presented in Deliverable 3.2. This involved: (i) repurposing tools for uses beyond those for which they were originally developed, (ii) extending their application beyond their initial geographic scope, and (iii) improving and expanding them to better reflect the requirements of MPA decision-makers and practitioners.

3. ***Maximise the use of available data and address persisting gaps***: The implementation of identified tools relied primarily on established European and global data infrastructures (e.g., GBIF, OBIS, Copernicus, EMODnet, HELCOM Map and Data Services), complemented by national repositories, outputs from relevant projects, participatory mapping initiatives, and other locally available information. Where critical data gaps persisted, targeted modelling and mapping efforts were developed within Blue4all to support tool deployment in different LLs.

4. ***Iterative implementation with end-users (test, learn, improve)***: Tools were implemented in close collaboration with the LLs and established SEGs, and their functionality and outputs were evaluated from an end-user perspective. This served two complementary purposes: (i) addressing LL needs related to ecological and environmental aspects, and (ii) identifying and implementing improvements through iterative refinement, guided by end-user feedback.

Taken together, these principles ensured that Task 3.3 moved beyond pure academic exercises to deliver actionable, scalable, and user-informed tools and outputs, aligned with the needs of MPA managers and practitioners.

3.2 Identifying Living Labs' needs and the data and tools required

During the comprehensive Needs Assessment (NA) carried out across all 14 Blue4all LLs under WP4, in close collaboration with WP2 and WP3 (see Deliverable 4.4 for a detailed description of the process and results), a set of priority needs was identified that called for the targeted implementation of science-based ecological and environmental tools. These needs reflect the operational challenges and information demands expressed by managers, practitioners, and researchers involved in the SEGs established in each LL. They emerged in response to real-

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world decision contexts at local, national, and transnational levels, particularly those related to the design, management, and revision of individual MPAs, national MPA networks, and transnational MPA networks.

Building on the needs identified, follow-up meetings were held with representatives from each LL to discuss priorities and assess the feasibility of addressing them through science-based ecological and environmental DSTs. Deliverable 3.2 identified and assessed a broad set of tools with promising characteristics that could be considered within Blue4all, thereby providing the foundation for the selection of tools to be further tested and developed under Task 3.3. However, the final selection was not based solely on the information gathered and the assessment carried out in Deliverable 3.2; it was also guided by the specific needs of the LLs, the availability and suitability of relevant data for tool implementation, and the feasibility of implementing or adapting the tools within the project timeframe. Therefore, depending on the LL's needs and practical considerations, tools were selected from the Deliverable 3.2 inventory, including tools embedded within broader tool platforms. In addition, tools that were not yet available at the time of Deliverable 3.2 submission were also considered when directly relevant to LL needs, particularly when they built on promising tools and tool platforms included in Deliverable 3.2. As a result, within Task 3.3, ecological and environmental tools were tested across six LLs in the Baltic Sea, North Sea, and Irish Sea, where needs that could be addressed within the timeframe of the project by implementing science-based ecological and environmental DSTs were identified (see Deliverable 4.4 for details about the matchmaking process). In each of these LLs, the tool implementation and further development proceeded in parallel through an iterative, continuous improvement cycle informed by SEG feedback. This process enabled the tools to be refined and adapted to better fit stakeholder needs. Overall, the improvements delivered under T3.3 are intended to ensure that MPA managers, decision-makers, and their technical teams can use the tools more easily and effectively in the future, thereby strengthening the integration of scientific knowledge into MPA and MPA network design and management processes.

Implementing ecological and environmental DSTs in the project LLs required a case-study specific approach. To do so, WP3 developed the "*Protocol for the preparation and execution of the tool testing phase in WP3"* (Annex A), describing a set of guiding steps:

Step 1: Definition of a clear aim and the relevant context for achieving it

Step 2: Data gathering and expected representation of outputs

Step 3: Tool selection, formal testing, and feedback analysis

Based on all the information provided by each LL CP (in collaboration with SEG members) in the aforementioned protocol, consultation meetings between the CPs, SEG members, and WP3 representatives helped to better understand their specific needs, data availability and suitability, and to suggest and decide upon a tool to be used (Table 1).

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Table 1. Detailed needs analysis, geographic scope, and the tool chosen for implementation.

Living Lab	Need	Scope	Tool
French Natura 2000 network	Assessing non-indigenous species distribution and potential effects in the MPA network	French Natura 2000 network and associated areas	NEAT (Non-indigenous species Effects Assessment Tool)
Danish Wadden Sea	• Cumulative impact assessment of human activities and pressures on seagrasses (*Zostera noltii* and *Zostera marina*)	• Danish part of the Wadden Sea, with the potential to upscale to the entire Wadden Sea as data for other countries become available.	PlanWise4Blue
	• Demonstrating the true cost of nature loss by assessing ecosystem services and evaluating how human pressures affect key ecosystem components	• Northern Danish Wadden Sea	Sankey diagram
Väinameri and Väike Väin (Joint SEG and tool implementation process for both areas)	Cumulative impact assessment of human activities and pressures on protected habitats	Väinameri and Väike Väin areas in Estonia	PlanWise4Blue
Irish MPA network	Cumulative impact assessment of human activities and pressures for reef habitats	Western Irish Sea	PlanWise4Blue
Baltic Sea MPA network	Enhancing DSTs to strengthen decision-making in transnational MPA networks addressing identified needs (e.g., cumulative impact assessment)	Baltic Sea	PlanWise4Blue

The **French Natura 2000 network** identified a critical and previously unaddressed need: assessing the distribution and potential impacts of non-indigenous species (NIS) within MPAs. While the inclusion of NIS in environmental assessments is required under relevant EU directives (e.g., Marine Strategy Framework Directive, MSFD), progress has been constrained by limited data availability and the absence of fit-for-purpose assessment tools. Following several exchanges between WP3 and the French Biodiversity Agency (OFB), it was agreed that a recently published invasive-species impact assessment framework (Kotta et al., 2025b) could be adapted for its application in the French Natura 2000 network. Subsequent discussions with other LLs, and with MPA managers beyond the project area, confirmed that this need is widespread and shared across multiple contexts. In response to the identified need, WP3 committed to advancing the development of NEAT, an online tool based on the framework proposed by Kotta et al. (2025b), which had previously been applied only in the Baltic Sea and Oslofjord. This development aimed to extend NEAT's geographic applicability beyond its original regional focus and adapt it for use across a broader range of northern European marine areas. Although NEAT was not included in Deliverable 3.2 because it had not yet been released, its selection was closely linked to the Deliverable 3.2 assessment of the BlueBioSites platform and its integrated cumulative impact assessment tool, PlanWise4Blue. Both were identified as technically promising, user-friendly, and relevant for supporting MPA managers and practitioners. Since NEAT is integrated within BlueBioSites and builds on the same underlying architecture, its further implementation and development within Blue4all was a logical response to the needs expressed by the LL. Section 3.5.1 provides further details on the specific developments and improvements made to the tool in this context.

In the **Danish Wadden Sea**, two needs were addressed. The first need highlighted by the stakeholders was the importance of conducting a CIA for the Wadden Sea as a whole. As the spatial coverage of the data remains uneven across the full transboundary area, the implementation focused only on the Danish Wadden Sea using PlanWise4Blue (Kotta et al., 2025a, Kotta et al., 2020). This approach provides a practical pathway for upscaling the CIA once the necessary spatial data layers from neighbouring countries become available. PlanWise4Blue was selected because Deliverable 3.2 identified it as a CIA tool with promising technical and user-friendly characteristics within the BlueBioSites platform. Its selection was further supported by the possibility of integrating tailored improvements in response to SEG feedback within the project framework, and by the fact that it already contained effects data relevant to the LL, which were subsequently expanded within Blue4all. The second need highlighted was a chronic underfunding for research and conservation, which the SEG identified as a major barrier to effective management. The SEG stressed the importance of making a stronger evidence-based case for investment by demonstrating the cost of nature loss through a comprehensive assessment of ecosystem services and the impacts of human pressures on key ecosystem components. Stakeholders agreed that clearly communicating the costs of nature loss to decision-makers could help shift investment priorities. To support this goal, the WP3 research team, together with the SEG, developed a structured expert-based ecosystem service assessment method, visually presented through a Sankey diagram. The approach builds on the method developed by Armoškaitė et al. (2020) and extends it by incorporating the effects of human activities and pressures. This approach was developed because the systematic search conducted in Deliverable 3.2 did not identify an existing tool that met the specific requirements of the LL, in particular, the need for a simplified, visually informative output capable of communicating the relationships between ecosystem components and services and the effects of human pressures in an accessible way.

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In the **Väinameri and Väike Väin MPAs**, the main objective of the tool-testing phase was to apply a CIA to habitats and species of conservation concern. During the NA, a key barrier to the use of DSTs in the areas was identified: the required data inputs are fragmented across multiple national databases. This includes spatial boundaries for specific conservation features within the region, as well as the most recent, officially validated nature value layers approved by competent authorities. Thus, PlanWise4Blue was selected because it already contained several relevant datasets for the area, enabled the integration of automatically updated national data layers produced in Estonia, and had been identified in Deliverable 3.2 as a relevant tool for supporting spatially explicit CIA.

For the **Irish MPA network**, tool testing was focused on the Western Irish Sea, which has access to comprehensive, high-quality, and validated datasets. This focus was agreed based on input from key stakeholders involved in the MPA network expansion process, as well as recommendations from previous reports prepared by Irish MPA practitioners. The Western Irish Sea was also selected because Irish MPA practitioners conducted a similar exercise in 2021, providing a helpful reference point. The objective was to test the PlanWise4Blue tool to examine trade-offs associated with expanding the current MPA coverage to better consider underrepresented habitats (e.g., biogenic reefs). In addition to the set of characteristics assessed in Deliverable 3.2, PlanWise4Blue was selected because it enabled, in the frame of Blue4all, the development of tabular outputs tailored to the needs of the LL, quantifying the percentage contribution of each human activity and pressure to the overall estimated effects and providing direct input for the planned trade-off analysis.

In the transnational MPA network considered in the project, the **Baltic Sea MPA network**, the tool testing approach was adapted to focus on: (i) the key challenges and barriers to using DSTs in a transnational setting, and (ii) the tool enhancements required to better support cross-border decision-making and respond to SEG priorities (e.g., mapping the distribution of human activities and pressure hotspots, and assessing their cumulative effects across the MPA network). In transnational MPA networks, governance and administrative complexity, including the need to coordinate with representatives from multiple countries, makes it particularly difficult to run hands-on, iterative tool-testing processes that rely on sustained and continuous participation within the project timeframe (as was the case for all other LLs). For this reason, WP3 adopted a more proactive and flexible approach, assessing the applicability and usefulness of selected DSTs and their outputs through structured questionnaires addressed to network representatives. In this context, the HELCOM Expert Group on Marine Protected Areas (MPAs), given the expertise and diverse backgrounds of its members, provided an ideal forum for evaluating the relevance and potential added value of available DSTs in addressing the regional needs identified for the Baltic Sea MPA network.

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3.3 Data gathering, harmonization, and integration process for the implementation of selected tools

The datasets identified in the tool-testing protocols were first carefully reviewed to assess their suitability for implementing the selected tools. For most of the LLs, this revealed a need for substantial additional work, including new data searches and the creation or modelling of new spatial layers.

3.3.1 French Natura 2000 network

To enable the Non-indigenous species Effects Assessment Tool (NEAT) to function effectively within the French Natura 2000 network, extensive data collection efforts and species distribution modelling were required.

The OFB first generated a list of 362 NIS, of which 125 are known to be established or invasive in the French sector of the English Channel and North Sea. An initial search for occurrence records was conducted using global open-access databases (GBIF and OBIS) and national data sources, with a focus on the French Natura 2000 network. Because most species had few or no records within this initial domain, the search area was subsequently expanded to include the Greater North Sea, the Celtic Seas, and the Baltic Sea. This broader geographic scope enabled the development of more robust models by incorporating occurrence records across key environmental gradients, improving their ability to characterise species–environment relationships and to predict potential distributions in regions where observations are currently absent or sparse.

After removing temporal and spatial duplicates, preliminary species distribution models were developed for all species with more than 20 occurrence records (25 species in total; Table 2). Because only presence data was available, we used the Maxent modelling framework. Models were fitted using a custom script based on the R package *maxnet*. To improve ecological realism, species-specific environmental tolerance limits were incorporated, constraining predictions to environmentally suitable conditions for the species. Additional data provided by OFB and collected through participatory mapping were incorporated to enhance the predictive performance of the models, particularly within the LL area. The distribution maps for 25 species were validated in two rounds by local experts, and the models were further improved based on their feedback. Following the feedback from local experts during the map validation process, the environmental tolerance limits were also refined to better reflect local environmental conditions and expert observations (Table 2).

Table 2. Non-indigenous species for which distribution models were developed for the French Natura 2000 network, and the environmental tolerance limits applied. The inclusion or exclusion of the species in the Non-indigenous Species Effects Assessment Tool (NEAT).

Species	Final map validation decision	Salinity (min)	Salinity (max)	Depth (min, m)	Substrate type (to include)
Acartia tonsa	Include in NEAT	2	35		

Gracilaria vermiculophylla	Include in NEAT	5		-6	
Amphibalanus improvisus	Include in NEAT	3	40		
Asparagopsis armata	Include in NEAT	20		-40	
Bonnemaisonia hamifera	Include in NEAT			-10	hard or mixed
Caprella mutica	Include in NEAT	6			
Codium fragile	Include in NEAT	12		-10	hard or mixed
Cordylophora caspia	Include in NEAT		35		
Crepidula fornicata	Include in NEAT	15			
Dasysiphonia japonica	Include in NEAT	10		-10	hard or mixed
Ensis leei	Include in NEAT	15			soft or mixed
Ficopomatus enigmaticus	Include in NEAT	1		-3	hard or mixed
Grateloupia turuturu	Include in NEAT	12		-14	hard or mixed
Hemigrapsus spp. *(H. takanoi and H. sangineus)*	Include in NEAT	8			
Magallana gigas	Include in NEAT	4		-20	hard or mixed
Mnemiopsis leidyi	Include in NEAT	7			
Mya arenaria	Include in NEAT	5	35		
Ruditapes philippinarum	Include in NEAT	12			soft or mixed
Sargassum muticum	Include in NEAT			-10	hard or mixed
Styela clava	Include in NEAT	20			
Undaria pinnatifida	Include in NEAT	20			
Eriocheir sinensis	Exclude (experts noted that, as reproduction does not occur in marine environments, it should not be considered)		25		
Potamopyrgus antipodarum	Exclude (experts noted that, as reproduction does not occur in marine environments, it should not be considered)		15		
Hemimysis anomala	Exclude (low predictive capacity of the models for the area of interest)				
Mytilopsis leucophaeata	Exclude (low predictive capacity of the models for the area of interest)				

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Environmental and anthropogenic datasets used in the modelling were obtained from several open-access sources: Copernicus (nitrate and phosphate concentrations, net primary production, salinity, temperature), EMODnet (bathymetry, EUNIS 2023 seabed habitat maps, vessel density), and AVISO (tidal amplitude).

Following the first round of map validation with local experts, the EUNIS seabed habitat maps were further improved by integrating habitat information validated within the French Natura 2000 network (provided by the OFB). Although artificial substrates are known to support NIS and can act as stepping stones for their spread, neither the EUNIS classification nor the OFB habitat data included information on artificial substrates within the modelling area; therefore, they were not included in the modelling. This should be addressed in future iterations as relevant artificial substrate data become available.

Based on the best available information, all habitat polygons were classified into three substrate types: i) soft sediment (e.g., sand, mud, clay), ii) mixed sediment (e.g., sand with gravel and/or shells, debris, small stones), and ii) hard substrate (e.g., large boulders, mussel reefs, stone-dominated or gravel beds). The created substrate classification spatial data layer (Figure 1) was subsequently used as a predictor variable in the species distribution models.

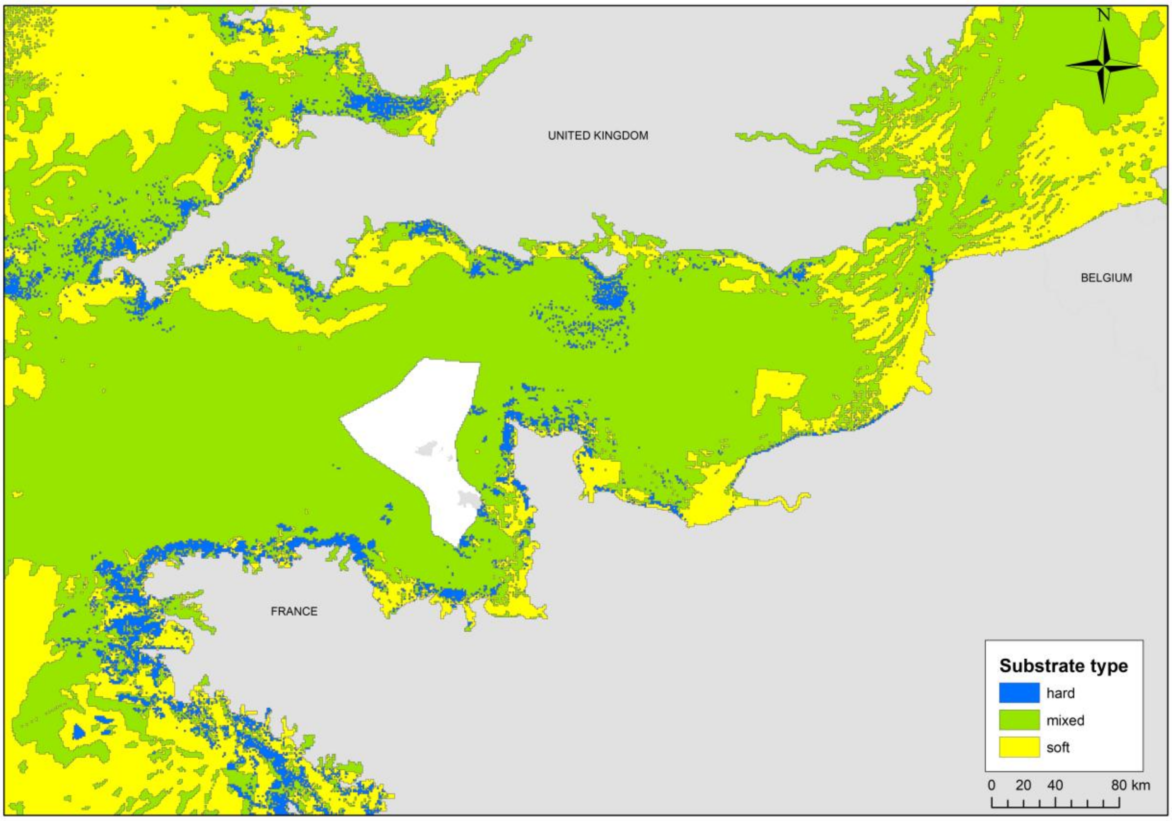

Figure 1. Substrate type layer produced for the French Natura 2000 network and the surrounding areas.

Following the second validation round with local experts, distribution maps for 21 species were identified as suitable for the study area and subsequently integrated into the NEAT web tool (Figure 2). Four species were excluded due to insufficient model performance or low

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confidence in predictions (Table 2). Details on the final NIS models, along with examples of the validated mean probability of occurrence and the respective prediction uncertainty maps (e.g., *Magallana gigas and Sargassum muticum*) for the French Natura 2000 network area are provided in Annex B. Species maps were provided to the LL and are also available for consultation in the input layers section of the NEAT tool (Figure 2).

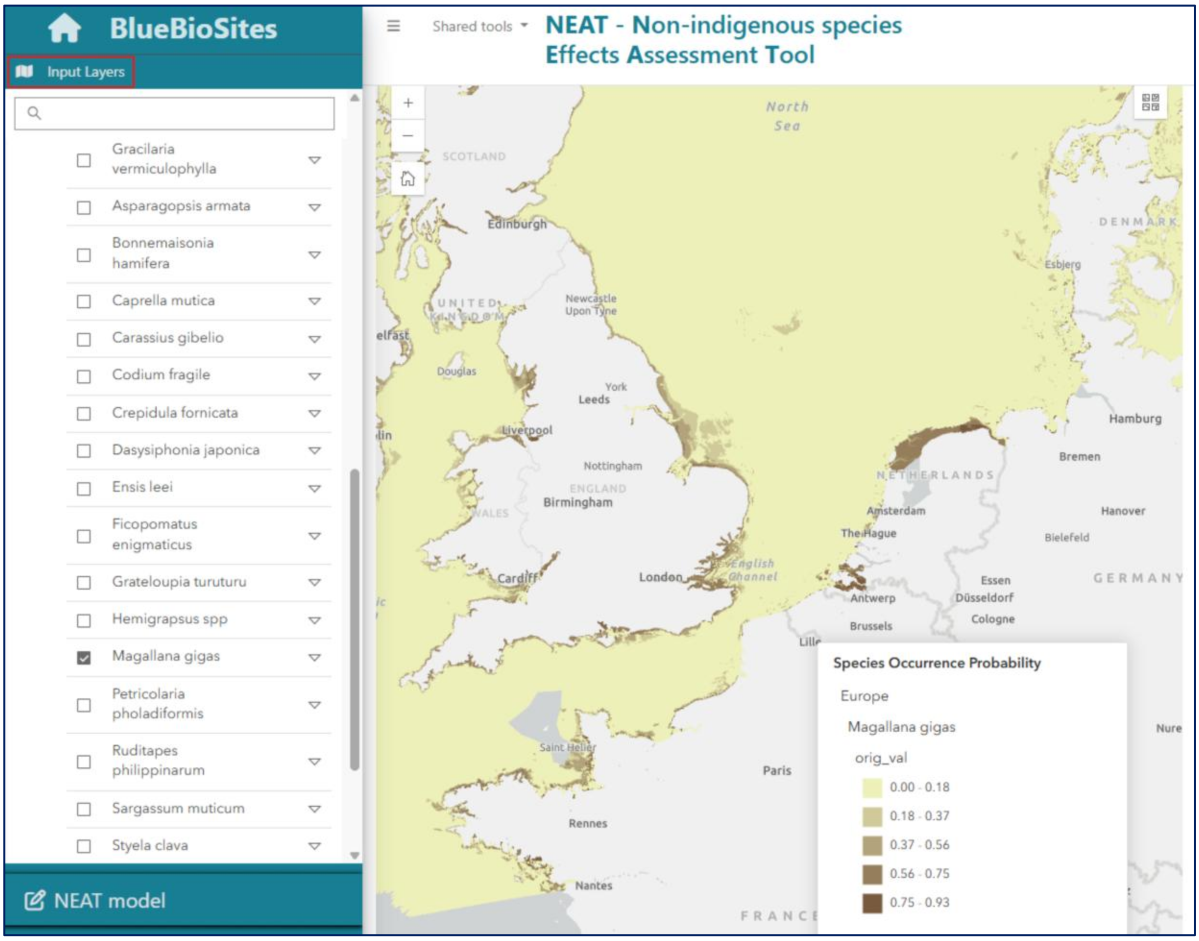

Figure 2. Species probability of occurrence maps included in the Non-indigenous Species Effects Assessment Tool (NEAT).

In addition to species' spatial distributions, the NEAT algorithm requires information on the magnitude of ecological effects exerted by each NIS. The tool integrates both scientific evidence and expert judgement to quantify these effects. A comprehensive literature review was conducted to identify science-based evidence of NIS effects. A total of 1,637 publications were screened, resulting in the extraction of 102 effect sizes for five species: *Gracilaria vermiculophylla* (46), *Magallana gigas* (15), *Sargassum muticum* (18), *Mnemiopsis leidyi* (8), and *Hemigrapsus* spp. (15). This evidence base is continuously updated as new research and results from ongoing projects become available and should therefore be regarded as a living resource. For species with more than two independent data points, per capita effect sizes are calculated within the tool. The method proposed by Kotta et al., (2025b) was adapted in NEAT to integrate effect sizes with probability-of-occurrence maps and abundance.

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For species with insufficient empirical data, effect sizes were derived from expert assessments. Experts evaluated the potential positive or negative impacts of each species across three biotic and two abiotic categories, as well as habitat provision. Each category was scored on a scale from –3 (strong negative effect) to +3 (strong positive effect). The overall effect size represents the mean of all categories applicable to the species, and variability is expressed as the standard error among evaluators. These assessments were provided by marine ecology experts from the North and Baltic Sea regions. Further details on effect size calculations are available in the tool user manual (https://gis.sea.ee/bluebiosites/files/NEAT_manual.pdf).

3.3.2 Danish Wadden Sea

Cumulative impact assessment

To assess the cumulative impact of human activities and pressures in the Danish Wadden Sea, several in-person and online meetings were held between stakeholders and WP3 representatives. These discussions focused on identifying ecologically relevant nature values, supported by available spatially gridded information, to serve as the basis for CIA. An updated habitat suitability model for seagrasses (*Zostera noltii* and *Zostera marina*) was selected for the analysis (Timmermann et al., 2021). Seagrass beds in the region have experienced substantial historical decline over the past half-century, largely driven by human activities and disease outbreaks (Reise & Kohlus 2008 and references therein). Given the high ecological value of seagrass habitats and the growing number of planned restoration initiatives, habitat suitability maps, rather than present-day occurrence maps, provide a more reliable basis for identifying areas with the potential to support successful restoration.

Extensive searches were conducted to compile spatially gridded datasets describing the human activities and pressures identified as relevant and overlapping with seagrass distribution in the Danish Wadden Sea. Approximately 20 national and international data portals and databases were reviewed (e.g., odaforalle.au.dk, www.northseaenvironmentportal.eu, danmarksarealinformation.miljoeportal.dk, data.geus.dk/geusmapm, havplan.dk, https://ono.dtuaqua.dk/DDFAM/, EMODnet, Copernicus, and a range of Danish national databases and reports).

The final CIA model incorporated one nature value and five human activity and pressure layers available for the area (Table 3). All datasets were harmonized to a common 1 km² grid resolution, and all layers were standardized to represent relative intensities on a continuous scale from 0 to 1.

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Table 3. Spatial data used for the cumulative impact assessment in the Danish Wadden Sea.

Data Layer	Source	Description	Year included
Recreational activity hotspots	https://havplan.dk/en/page/service-layers	The map is a model output (kernel density surface) based on data from two national PPGIS survey (one representative survey with the public and one crowdsources survey with dedicated marine recreation users). Mapped places to visit (points) and routes (polylines), are included. Visit frequency (number of visits per year) is the unit of analysis. More than 16000 mapped places and routes by 6500 people are included in the model. The respondents according to the population in the five regions of DK, and by gender and age. See further details about the data layer in the ECOMAR report (Andersen et al., 2020).	2015-2016
Benthic fishing	DTU Aqua	Sub-surface swept area ratio (SAR) is used as an indicator of the number of times an area is swept by mobile bottom contacting gears. See further details about the data layer in the ECOMAR report (Andersen et al., 2020).	2015-2017
Dredging and dumping	EMODnet	Dredging and dumping vessels annual average is used as a proxy for seabed disturbance caused by material dredging or dumping.	2023
Nutrients	NIVA	The average surface winter concentration of dissolved inorganic nitrogen was used as a proxy for eutrophication pressure in the area. See further details about the data layer in the ECOMAR report (Andersen et al., 2020).	2013-2018
Anchoring activity	EMODnet	Pleasure craft vessel activity is used as a proxy for potential anchoring activity, as its activity hotpots overlap with point data from Global Fish Watch and a EMODnet	2023

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		"Europe Seas habitats potentially affected by anchoring" data layer.	
Eelgrass habitat suitability	Aarhus University	An advanced model for eelgrass habitat suitability model is used (Timmermann et al., 2021). The original model (Staehr et al., 2019) has been updated and recalibrated with new nationwide data layers for bottom water temperature, physical exposure and salinity for the period 2012-2016 provided by DHI. These data were produced by running 11 hydrodynamic models to ensure physical background data for calculating the climate's significance for eelgrass depth limits. In addition, bottom oxygen concentration from corresponding ecological models is also included in the calibration of the updated model. Data layers for sediment conditions, light attenuation, and water depth are unchanged compared to the original GIS model (Staehr et al., 2019).	2021

While PlanWise4Blue already includes a substantial amount of scientific information on effect sizes, the information was further enriched with available effect size data for the eelgrass species *Zostera noltii* and *Zostera marina* in the North Sea. A systematic literature review was conducted using the Web of Science and Scopus databases, during which 483 scientific publications were screened, and 73 effect size estimates were extracted and incorporated into PlanWise4Blue. Details about the calculation of the sensitivity scores (i.e., effect sizes for each human activity or pressure and their combinations) can be found in the tools´ user manual (https://gis.sea.ee/bluebiosites/files/NEAT_manual.pdf).

Structured Ecosystem Service Sensitivity Assessment with Interactive Sankey Visualization

To demonstrate the true cost of losing nature and visualize the inherent complexity of the interconnected ecological and social systems, Sankey flow diagrams were used. The database for the diagrams was derived from a structured ecosystem service assessment using expert elicitation, following Armoskaite et al., (2020). In contrast to earlier diagrams that primarily mapped links between ecosystem components, functions, and services, the team further developed the approach to explicitly incorporate pressures to better illustrate the consequences of biodiversity decline and ecosystem degradation. Two locally focused diagrams were planned for species of high relevance and their associated services: the dark-

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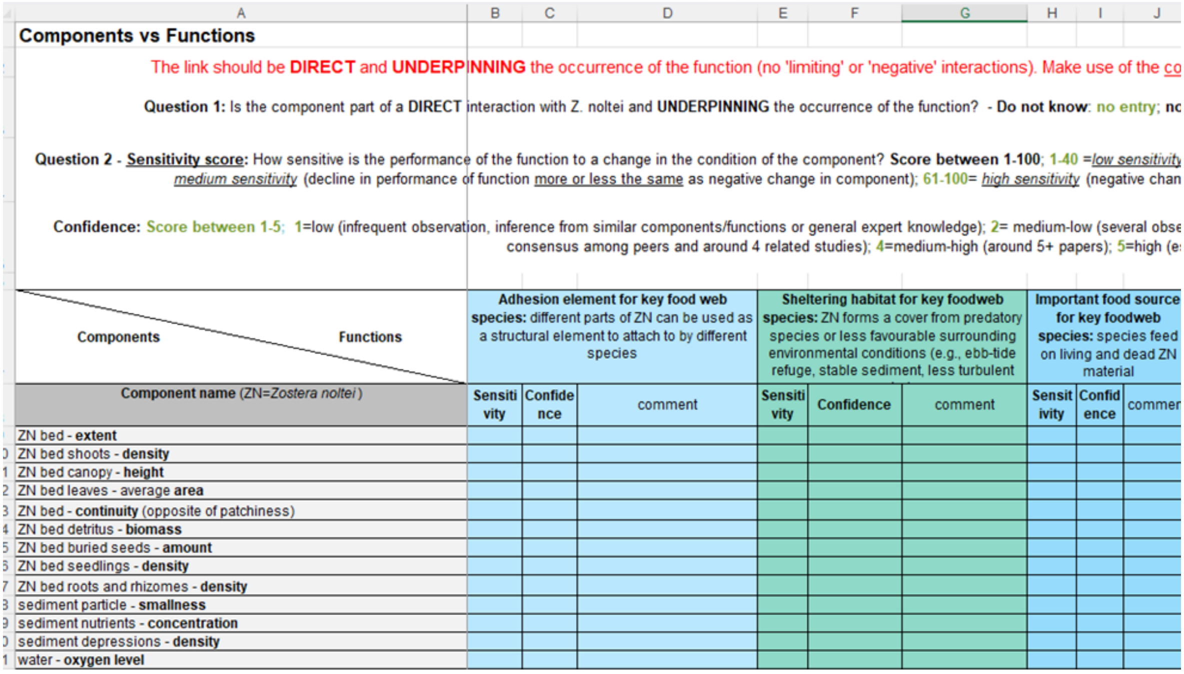
bellied brent goose (*Branta bernicla bernicla*) and dwarf eelgrass (*Zostera noltii*). Both diagrams focus on the Northern Danish Wadden Sea, where human pressures are highest and declines in *Z. noltii* have been observed.

The expert-based data collection followed five steps:

1. Preliminary lists: A semi-structured literature review on the two study species informed lists of ecosystem services, functions, components, and relevant human pressures.
2. Verification of lists: National and international Wadden Sea experts were contacted via snowball sampling. Interested experts joined semi-structured interviews to validate these lists.
3. Interlinkages and scoring: The 2-hour one-on-one scoring sessions started off with a 20 min recorded introduction to the exercise. At least one team member was constantly present to guide through the scoring sheets and answer immediate questions (Figure 3). Experts (*Z. noltii*: n=5; *B. bernicla bernicla*: n=7) were asked to individually link components to functions and functions to services, assuming a naturally functioning ecosystem in good ecological condition in the context of the Northern Danish Wadden Sea. They only linked those components and functions that play a direct underpinning role. They scored sensitivity (0–100) for functions to moderate component changes, services to moderate function changes. They also scored the impact (0–100) of pressures on components, considering intensity, extent, duration, recovery time, indirect effects, and feedback loops. Each link received a confidence score (1–5).



Components vs Functions

The link should be **DIRECT** and **UNDERPINNING** the occurrence of the function (no 'limiting' or 'negative' interactions). Make use of the co

Question 1: Is the component part of a DIRECT interaction with Z. noltei and **UNDERPINNING** the occurrence of the function? - **Do not know**: no entry; nc

Question 2 - **Sensitivity score**: How sensitive is the performance of the function to a change in the condition of the component? **Score between 1-100**; 1-40 =*low sensitivity* *medium sensitivity* (decline in performance of function more or less the same as negative change in component); 61-100= *high sensitivity* (negative chan

Confidence: Score between 1-5; 1=low (infrequent observation, inference from similar components/functions or general expert knowledge); 2= medium-low (several obse consensus among peers and around 4 related studies); 4=medium-high (around 5+ papers); 5=high (e:

Components / Functions	**Adhesion element for key food web species:** different parts of ZN can be used as a structural element to attach to by different species			**Sheltering habitat for key foodweb species:** ZN forms a cover from predatory species or less favourable surrounding environmental conditions (e.g., ebb-tide refuge, stable sediment, less turbulent			**Important food source for key foodweb species:** species feed on living and dead ZN material		
Component name (ZN=*Zostera noltei*)	**Sensitivity**	**Confidence**	comment	**Sensitivity**	**Confidence**	comment	**Sensitivity**	**Confidence**	commer
ZN bed - **extent**									
ZN bed shoots - **density**									
ZN bed canopy - **height**									
ZN bed leaves - average **area**									
ZN bed - **continuity** (opposite of patchiness)									
ZN bed detritus - **biomass**									
ZN bed buried seeds - **amount**									
ZN bed seedlings - **density**									
ZN bed roots and rhizomes - **density**									
sediment particle - **smallness**									
sediment nutrients - **concentration**									
sediment depressions - **density**									
water - **oxygen level**									

Figure 3. Part of the scoring sheet the dwarf eelgrass experts used in the 2 h one-on-one online scoring sessions to create the database for the pressures-component-function-service network. The top rows contained important background

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information to ensure a standardized scoring approach. Column A contains a list of biotic and abiotic ecosystem components that had to be linked to the relevant ecological functions connected to dwarf eelgrass beds in the context of the Northern part of the Danish Wadden Sea using sensitivity (1-100) and confidence scores (1-5).

4. Score aggregation: The data was checked for gaps, extremes, and contradictions, and resolved using, where available, expert comments. Confidence-weighted averages were calculated. Uncertainty of each link and score was expressed based on 1) standard error; 2) number of experts; 3) average confidence; 4) and level of expert agreement on link vs no link. Preliminary sensitivity networks were created.
5. Result verification: In 2-3h online sessions, experts reviewed inconsistencies, revised impactful links, and confirmed reasoning. Remaining discrepancies were resolved, where possible, through a conceptual review and remaining score gaps were imputed from similar network elements and/or flagged. Final networks will be verified by the experts via email in January 2026.

A multiplicative model translated the network into a Sankey diagram. Average sensitivity scores determined whether a source node (e.g., component) influenced a target node (e.g., function) faster or slower than proportionally. Mathematically, this means that the scores determined exponents of multiplicative factors in the model, where an exponent of 1 indicated proportional influence (average score of 50). The multiplicative structure captures critical links—collapse of one source node cascades through connected functions—and accounts for indirect and cumulative effects of pressures. The model output was then normalized per layer to represent flow. This flow can be interpreted as a measure of support of components for functions, and of functions for services, and forms the basis of the Sankey diagram: Node height shows total outgoing and/or receiving support flow, and links trace how this support flow propagates through the network. Initially, pressures were set to 0% and services to 100%; as pressures rise, components, functions, and services respond at rates based on the multiplicative model. The diagram was created in R.

Based on the multiplicative model and the Sankey diagram, an interactive app was developed in R, which shows how service delivery and the Sankey diagram itself change with different pressure intensities. This interface is hosted on a 'Posit' cloud server and will be accessible via a weblink. By manipulating pressure intensity, interested tool users will be able to use the interface to illustrate the consequences of human activities in the area on ecological functions and ecosystem services related to dwarf eelgrass and the dark-bellied brent goose in support of local decision-making and science communication (see section 3.4.2 for more details).

3.3.3 Väinameri and Väike Väin

To gather information on the specific needs and data needed for the CIA to be incorporated into the PlanWise4Blue tool, a series of in-person workshops (October 2024, May 2025) with local stakeholders and MPA managers was organised to capture decision-makers' requirements and ensure the tool aligns with existing design and management processes. Based on these inputs, the developers worked closely with MPA managers to integrate or

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update the required ecological, environmental, and management-relevant datasets into the web tool, with several layers now configured to update automatically from national databases (Table 4).

Table 4. Data layers, with their units and sources, integrated into the PlanWise4Blue web tool for Väinameri and Väike Väin.

Data layer name	Source
1110 HD - Sandbanks	Tartu Ülikooli Eesti Mereinstituut, 2024. Loodusdirektiivi mereelupaikade seisundi hindamine ja EL Looduse taastamise määruse mereelupaikade piiritlemine (Translation: University of Tartu, Estonian Marine Institute, 2024. Assessment of the conservation status of marine habitats under the Habitats Directive and delineation of marine habitats under the EU Nature Restoration Regulation).
1130 HD - Estuaries	
1140 HD - Mudflats and sandflats	
1150 HD - Coastal lagoons	
1160 HD - Large shallow inlets and bays	
1170 HD - Reefs	
Bird – Benthic feeders (ind*km^{-2})	Eesti Ornitoloogiaühing, 2019. Lindude peatumisalade analüüs (Translation: Estonian Ornithological Society, 2019. Analysis of bird stopover sites).
Bird – Herbivores (ind*km^{-2})	
Bird – Migration routes	
Bird – Piscivores (ind*km^{-2})	Eesti Ornitoloogiaühing, 2022. Mereliste rahvusvahelise tähtsusega linnualade uuendamine (Translation: Estonian Ornithological Society, 2022. Updating internationally important marine bird areas).
Loons' density (ind*km^{-2})	
Cormorant density (ind*km^{-2})	
Cormorant density in winter (ind*km^{-2})	
Cormorant density in spring (ind*km^{-2})	
Cormorant density in summer (ind*km^{-2})	
Cormorant density in autumn (ind*km^{-2})	
Loons' density in winter (ind*km^{-2})	
Loons' density in spring (ind*km^{-2})	
Loons' density in autumn (ind*km^{-2})	
Auk density in autumn (ind*km^{-2})	
Benthos feeders' density in winter (ind*km^{-2})	
Benthos feeders' density in spring (ind*km^{-2})	
Benthos feeders' density in summer (ind*km^{-2})	
Benthos feeders' density in autumn (ind*km^{-2})	
Bird – Wintering areas	Leho Luigujõe & Ainārs Auniņš. 2016. Talvituvate lindude rahvusvaheline lennuloendus (Translation: Leho Luigujõe & Ainārs Auniņš, 2016. International mid-winter waterbird census).
ER Limited-conservation area	Estonian Ministry of Climate
ER Protected areas	

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ER Protected animals, cat III	
ER Protected plants, cat III	
ER Natura 2000 bird protection areas	
ER Natura 2000 habitat protection areas	
Natura habitats (Annex I habitats of the EU Habitats Directive)	

Once the new and updated information had been integrated, stakeholders formulated test scenarios for the LLs to implement the tool and give further feedback on needed tool improvements.

3.3.4 Irish MPA network

Previous reports produced by an expert advisory group of Irish marine practitioners, researchers, government officials, and other key stakeholder groups were led by the statutory body responsible for MPA designation in Ireland (formerly the Department of Housing, Local Government and Heritage). These reports described the current status of Irish MPAs, the key species and habitats currently protected, and recommended pathways forward.

For the purpose of this analysis, following recommendations made by those previous reports, conversations with a senior civil servant who is taking a leading role in the current Irish MPA network expansion, and a central academic involved with the previous reports, it was decided to focus the tool testing on a set of key benthic habitats. This is because benthic habitats are currently underrepresented in existing Irish MPAs (Marine Protected Area Advisory Group, 2020) and it reflects a wider desire to move away from designating MPAs just for individual marine species.

The specific nature values chosen were biogenic reef habitats. This is because of the reef habitat's vital role in providing ecosystem services including biodiversity, fishery nursery areas, support carbon sequestration, and disperse wave energy that can damage coastal areas. These nature values are also highly sensitive to human activities, including commercial fishing, the development of offshore renewable energy (specifically wind), and coastal development. Thus, biogenic reef habitats require strong formal protection mechanisms to continue delivering wider ecosystem services.

The human pressures identified as most likely to impact biogenic benthic reef habitats in the Irish sea were offshore renewable energy development (windfarms), bottom contact fishing activities (e.g. bottom trawling), and vessel density from commercial shipping activities in the important economic zone of the Irish sea. Both windfarm development and bottom contact fishing activities can cause direct damage to benthic habitats through habitat destruction, disturbance, removal of key habitat, removal of associated species like fishes, sediment disturbance, and changes to local hydrological conditions. Commercial vessel density can mainly cause issues via chemical pollution or acoustic disturbance.

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The final CIA model incorporated one nature value and five human activity and pressure layers available for the area (Table 5). All datasets were harmonized to a common 1 km² grid resolution, and all layers were standardized to represent relative intensities on a continuous scale from 0 to 1. The models for each nature value were implemented in the desktop version of PlanWise4Blue.

Table 5. Human activities, pressures and nature values included in the CIA models.

Data Layer	Source	Description	Year included
Wind Farms	https://opendata.housing.gov.ie/dataset/foreshore-offshore-renewable-energy-data	Potential wind farm locations, submitted to the Irish Government. Not built yet.	2022
Bottom contact fishing	https://data.gov.ie/dataset?q=fishing	Fishing effort from Bottom Otter Trawls, International Dredges and Beam Trawls was summed to represent the intensity of bottom trawling in the area.	2025
Shipping	EMODnet	To represent the pressures of shipping, the average density of all vessels (excluding fishing vessels) was used.	2023
Offshore Circalittoral rock and biogenic reef	https://www.npws.ie/maps-and-data/habitat-and-species-data	Dataset curated by the National Parks and Wildlife Service (of Ireland)	2023
Circalittoral rock and biogenic reef	https://www.npws.ie/maps-and-data/habitat-and-species-data	Dataset curated by the National Parks and Wildlife Service (of Ireland)	2023
Infralittoral rock and biogenic reef	https://www.npws.ie/maps-and-data/habitat-and-species-data	Dataset curated by the National Parks and Wildlife Service (of Ireland)	2023

3.3.5 Baltic Sea MPA network

To collect information on the challenges and needs associated with using DSTs in a transnational MPA network, an online anonymous questionnaire was developed and distributed to the HELCOM Expert Group on Marine Protected Areas (under the HELCOM Working Group on Biodiversity, Protection and Restoration). This approach captured the perspectives of national decision-makers and MPA planning experts across the Baltic Sea region, with a particular focus on: (i) the opportunities and barriers to implementing and using DSTs in a cross-border governance setting, and (ii) the priorities of the Baltic Sea MPA network, especially improving the understanding of the spatial distribution of human activities and pressures across the network, and assessing their cumulative impacts. As an

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example of one of the available too for performing CIA, PlanWise4Blue with potential modifications for MPA incorporation was used.

The questionnaire contained 10 questions (Table 6). The questionnaire included a mix of free-text questions and predefined response options, with an additional "Other" field for respondents to provide any additional relevant information for each question (Table 6).

Table 6. Questions and associated answers included in the questionnaire shared with the HELCOM Expert Group on Marine Protected Areas. Depending on the nature of the questions and answers, the percentage of respondents that selected a given option or the average score across respondents are presented. Highest percentage of respondents or average scores are highlighted in bold.

No	Questions	Options	%	Average score
1	Are you aware, been in contact or actively using digital decision-support tools (DSTs) for developing your activities in relation to spatial planning and conservation measures design and management?	I am not aware of any digital DSTs	**40**	
		I am aware, but have not been in direct contact or tried to use any digital DSTs	**60**	
		I have some experience with the use of digital DSTs	0	
		I actively and continuously use digital DSTs to develop and inform my activities	0	
2	Which dimensions should decision support tools address to support the design and management of transnational MPA networks?	Cumulative effects assessment of human activities and pressures	**100**	
		Zoning and spatial optimization of area-based conservation measures	60	
		Ecological connectivity analysis and assessment	**80**	
		Ecosystem functioning and services assessment	20	
		Climate change vulnerability assessment	60	
		Identification and prioritization of ecological and biological significant areas for conservation	60	
		OTHER: Species and habitats important for ecosystem functioning (for the sake of nature)	20	
3	In your view, how important are the following characteristics of digital DSTs for their effective use in designing and managing transnational MPA networks? (0-4)	Tool type (web or desktop-based)		1.8
		Ease of use for a wide range of users		3
		Open access availability		**3.4**
		User-friendly interface with intuitive navigation		**3.8**
		Multi-language options		2.2

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	OTHER: In your opinion, are there any additional characteristics that are important for ensuring the effective use of DSTs in the design and management of transnational MPA networks?	Low technical skills requirements		**3.4**
		Low time demands (learning and implementation)		**3.4**
		Methodological transparency (clear description of calculations and processes used)		3.2
		Interoperability with other tools and/or data platforms		3
		Long-term technical support and maintenance		**3.4**
		Built-in data availability		2.4
		Data upload capability		2.6
		Low technical infrastructure requirements (e.g., high-speed internet or high-performance computer not needed)		2.4
		OTHER: Ability to export results in different formats to use elsewhere (Office formats), or meaningful graphs as well as very easy to understand results overviews to be used with more policy focused decision-makers		
4	What limitations and barriers prevent, or could prevent, the effective implementation of digital DSTs in designing and managing transnational MPA networks? (0-4)	Limited knowledge or awareness of existing DSTs		**3.2**
		Absence of DSTs tailored to the needs of transnational MPA networks		3
		Limited technical capacity or tool training opportunities		2.8
		Inadequate financial resources to implement tools (including staffing and operational costs)		**3.2**
		Lack of usable, standardized, and openly accessible data		2.8
		Concerns regarding data confidentiality, security, or sovereignty		2.8
		Weak coordination and decision-making mechanisms between countries		3
		Divergent national priorities, policies, and conservation objectives		**3.2**
		Use of different DSTs for the same purpose across countries		2.2
		Limited collaboration between DST developers across countries		2.6

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5	How would you like to improve the “extent” option?	It is useful as it is		0
		I would like to upload my own predefined area of interest (e.g., shapefile)	**100**	
		I would like to select from a list of predefined sea areas (e.g., basins, sub-basins, administrative units such as MPAs)	20	
		I would like to define multiple areas within the same assessment	60	
		I would like to define different sub-areas within a given extent (e.g., core protection areas, buffer zones)	40	
6	What additional options would you find useful when selecting human activities, pressures, and nature values?	The current options are suitable as they are	0	
		Option to upload new data layers of human activities, pressures, or nature values	40	
		Option to adjust the intensity (% change) of selected human activity layers to explore alternative management scenarios, either across the entire area or within specific sub-areas	**80**	
		Option to include within PlanWise4Blue an environment for participatory mapping of human activities, pressures, and nature values, with the possibility to directly integrate the results into the cumulative impact assessment.	40	
7	Are the output options (in the list on the above figure) of the tool easy to understand? OTHER: (please specify what is unclear)	Yes, easy to understand	**60**	
		OTHER: Define better what the output options	40	
8	Which characteristics of DSTs outputs are most relevant for you? (0-3)	Generates detailed spatial maps that illustrate the distribution and intensity of impacts.		**3**
		Provides aggregated quantitative indicators that combine data into overall numerical results (e.g., total impact scores, percentage change in biomass, or average pressure intensity).		2
		Provides synthesized qualitative assessments (e.g., descriptive evaluations).		1.6
		Includes confidence or uncertainty levels to indicate the robustness of the results.		2

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		Enables downloading of outputs (maps, tables, and supporting data) for further use.		2.4
		Ensures clear, intuitive visual presentation for easier communication with diverse audiences.		**2.6**
		Offers interpretation and explanation of results, helping users understand implications.		2.2
		Provides comprehensive metadata for data layers, including sources, methods, and limitations.		2.2
9	Is this type of result (see above example) relevant for decision-making at the transnational MPA network level and why? (Free text box)	no, it's too general		
		Not sure, I don't fully understand the legend of the map; what does the standardized change relate to?		
		Yes, for scientific personnel, but it needs clearer labels for policy-makers to understand what this means		
		Yes, so we together can discuss and address the human impacts and necessary measures for the network of MPA and OECMs		
		yes		
10	Regarding the incorporation of MPAs into the tool's outputs, what additional functions or analyses would you like to see?	Tabular presentation of results – provides clear tables summarizing outputs for each MPA included within the analysis extent.	**100**	
		Separate calculations for inside vs. outside MPAs – distinguishes results within MPA boundaries from surrounding areas.	60	
		Highlighting priority MPAs – for example, automatically flags MPAs that exceed defined thresholds of impact.	60	
		OTHER: Calculation of coherence, i.e., representativity (how much of different species and habitats are included in the current network), nature values (identify areas of high nature values not yet protected to be included in the MPA network) and connectivity.		

Alongside the questions, respondents were provided with screenshots illustrating the operational steps in PlanWise4Blue for selecting the geographic extent, human pressures, and

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nature values (see the pictures in the PlanWise4Blue step-by-step guide in ANNEX E) and an example scenario on how MPAs could be incorporated into the tool (Figure 4).

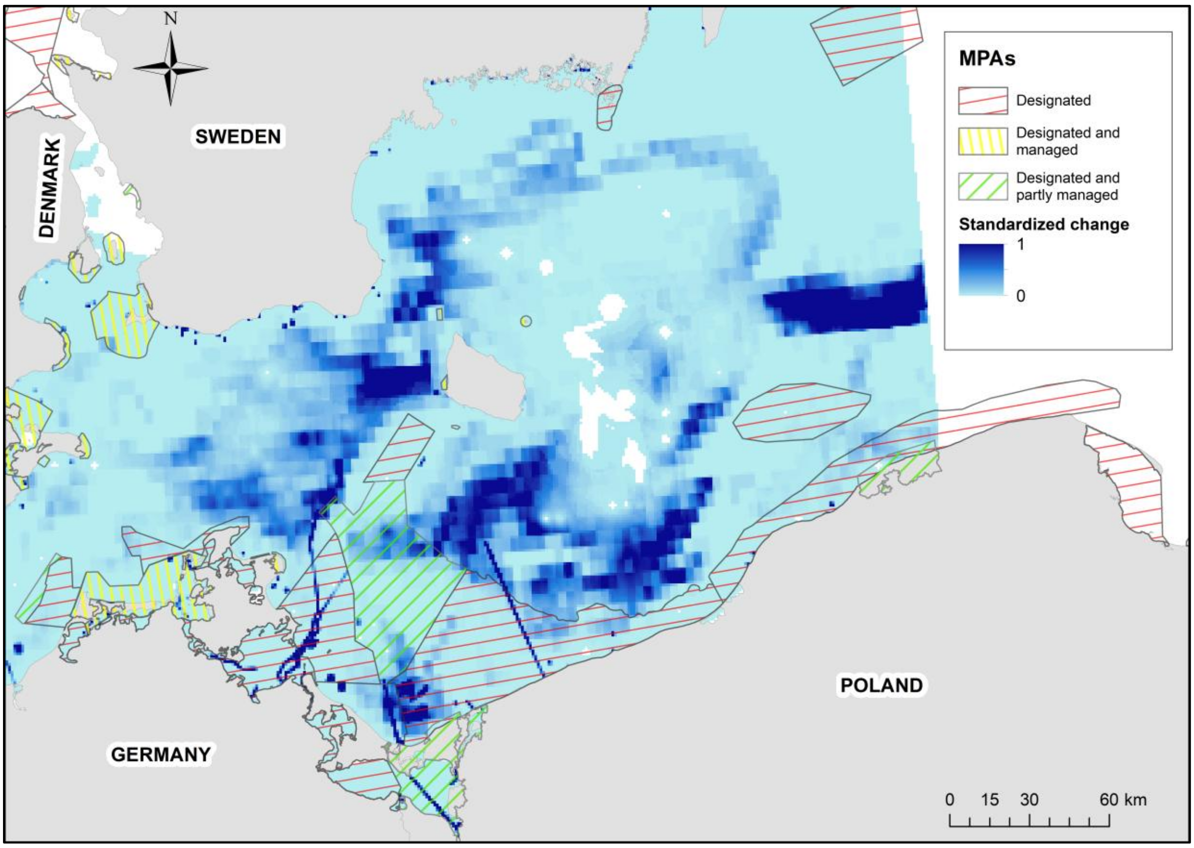

Figure 4. An example of the potential incorporation of MPAs into PlanWise4Blue presented to representative of the HELCOM Expert Group on Marine Protected Areas indicating the potential change of a nature value (change in biomass, standardized from 0 to 1) caused by the cumulative pressure of human activities and pressures.

The primary result from the survey showed that the respondents had not actively used DSTs. Although most found the outputs useful, several important improvements need to be done to increase their use in decision-making. As an output, the respondents feedback was used to improve the output options and general characteristics of PlanWise4Blue. Based on this feedback we encourage other tool developers to apply the suggested improvements to environmental and ecological tools so to strengthen the uptake of ecological and environmental data in decision-making processes. A more detailed overview of the tool developments is explained in Section 3.5.2.

3.4 Implementation of selected tools and Living Labs' feedback

3.4.1 French Natura 2000 network

During the tool implementation phase, preliminary outputs were presented to the SEG in September 2025 to gather feedback on the relevance, clarity, and suitability of the proposed output options. The adjustments and refinements to the tools undertaken in response to SEG comments are described in detail in Section 3.5.

Following incorporation of SEG feedback and the integration of the validated input data, a scenario was executed in the NEAT web tool for the French Natura 2000 network, including all 21 species with validated distribution maps for the study area. Results indicate that the projected effect of each individual species is generally low across the area. However, when aggregated, the combined (additive) effect suggests that locations with a high magnitude of potential NIS impacts (values > 3) may occur within the network (Figure 5).

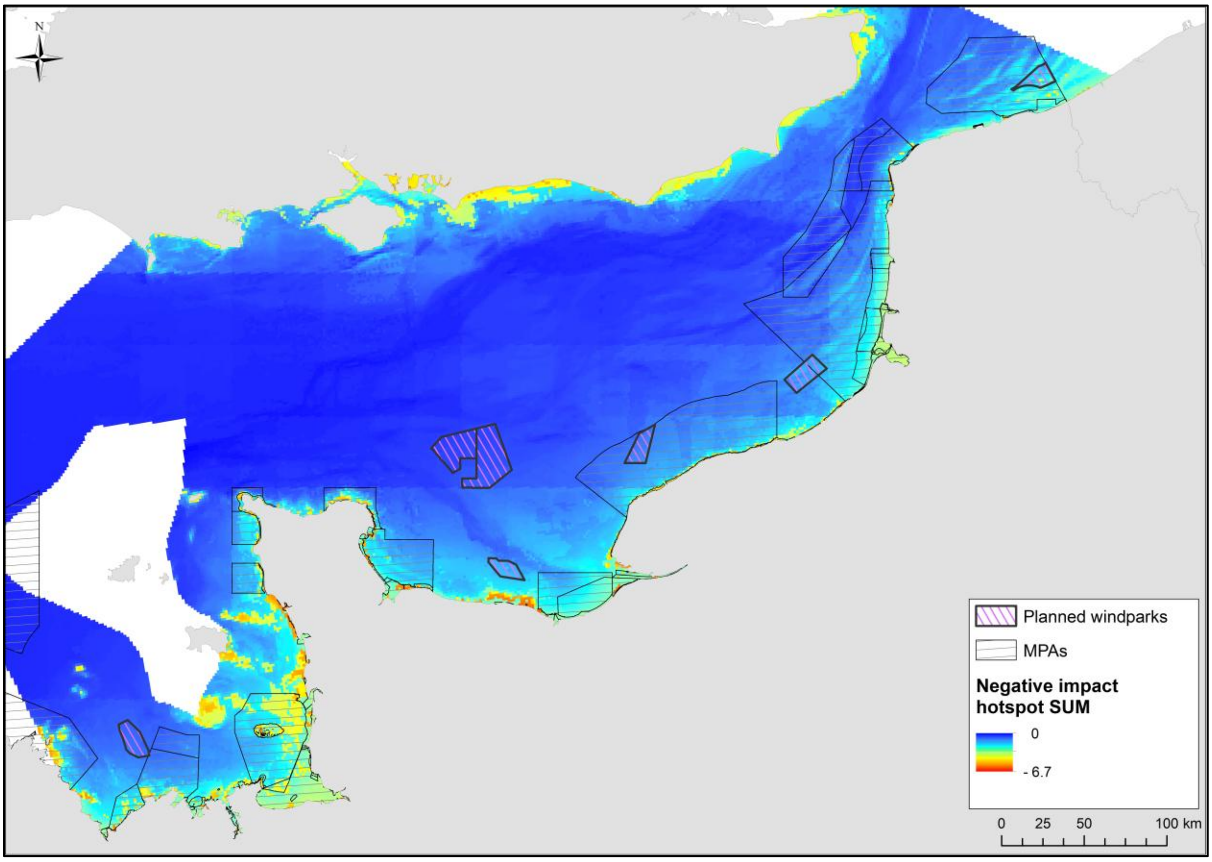

Figure 5. Additive negative impact of all NIS in the model in the French Natura 2000 network area.

The tool also provides a tabular summary of results (downloadable as .csv, .xlsx, or .pdf), reporting for each species the mean estimated effect, associated standard error, and occupancy within the selected area (Annex C).

An online seminar was held in September 2025 to present the results to the SEG and to gather feedback. The feedback received during the seminar was subsequently used to guide the development and refinement of the NEAT tool, as described in Section 3.5.1.

Overall, the tool was regarded as highly valuable, with plans already in place to use both the tool and its outputs to support forthcoming actions. In particular, the tool will be applied to inform citizen science monitoring related to NIS management actions, as well as to guide and support activities among industrial stakeholders, including the nuclear and wind energy sectors.

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3.4.2 Danish Wadden Sea

Tool 1: Cumulative impact assessment

Assessing the cumulative impacts of human activities and associated pressures on seagrass habitat suitability in the Danish Wadden Sea revealed several hotspots where suitability declined markedly. These spatial patterns provide a practical basis for management as they can guide the selection of priority restoration areas to increase the likelihood of successful interventions and can also support targeted conservation measures to safeguard high-value seagrass habitats.

Overall, the Danish Wadden Sea is characterized by comparatively low reported intensities of most human activities, and the associated loss of suitable seagrass habitat is therefore moderate. When defining “suitable” habitat as having a suitability value > 0.5, 15.6% of the area shifts below this threshold, although more than half of the study area shows some degree of influence from human activities (Table 7).

Recreational activities emerge as the dominant pressure, accounting for more than half of the observed reduction in habitat suitability (Table 8). This pronounced contribution is partly explained by the wide spatial coverage of recreational activity data, which spans large portions of the area, particularly shallow waters, where other pressures are absent or underreported. Importantly, recreational activities also include pressures that are not captured by AIS-based vessel tracking, such as seabed disturbance from anchoring by small leisure and fishing boats and from motorized water sports. In contrast, bottom trawling contributes 25.1% of the observed impact in the Danish Wadden Sea and is primarily associated with larger vessels operating in deeper areas, mainly around harbours, while nutrient inputs play a secondary role.

*Table 7. Extent of suitable areas for eelgrass habitats with and without of human activities effects in the Danish Wadden Sea. * Habitat suitability over 0.5; ** Over 1% change caused by human activity*

Nature value	Unit	Seagrass habitat
Original habitat area*	km^2	791
Original suitable area*	km^2	199
Expected suitable area*	km^2	168
Loss of suitable habitat*	%	15.6
Area affected**	%	57.90

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Table 8. Human activities and pressures contributions to the decrease of eelgrass habitat suitability.

Human activity	Contribution (%)
Dredging and dumping	0.3
Bottom trawling	25.1
Nutrient loading	19.2
Recreational activity	55.5
Pleasure crafts	0

The shallow tidal zone remains largely unaffected, with the most pronounced changes concentrated around the larger harbours, particularly in the northern Danish Wadden Sea (Figure 6).

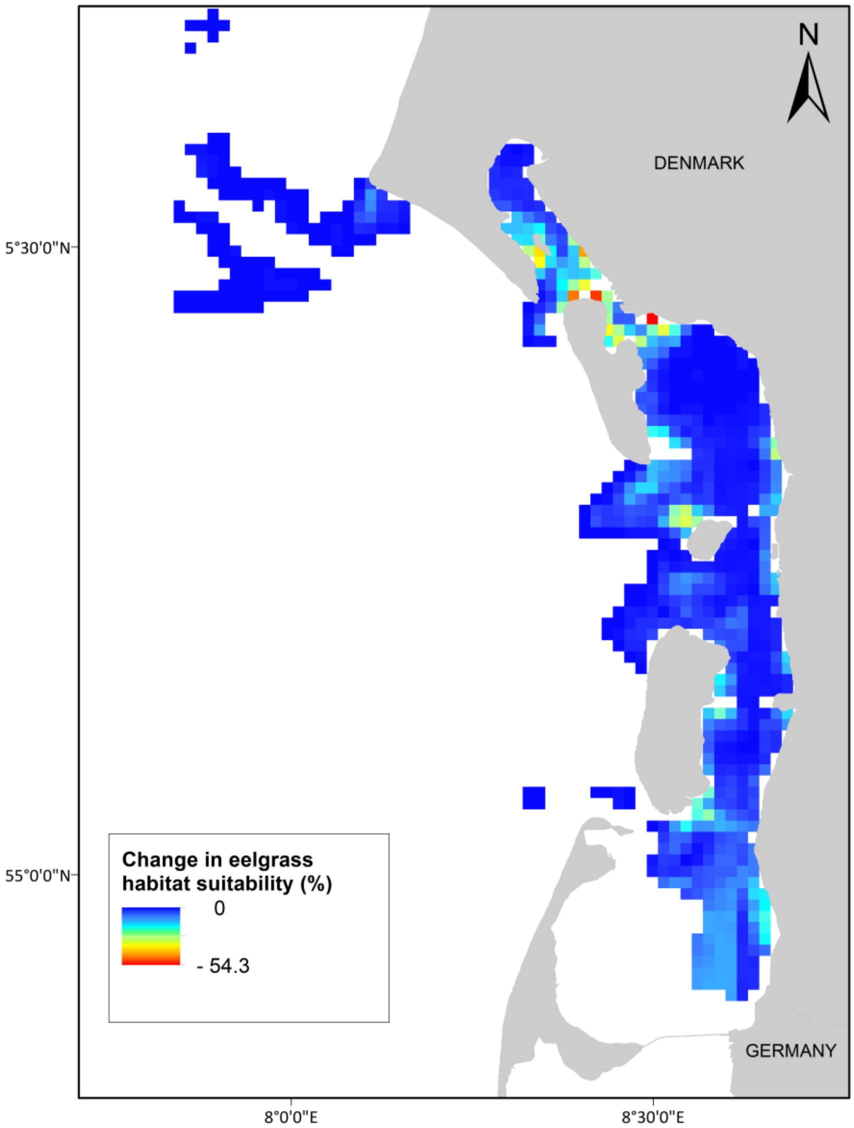

Figure 6. Expected change in habitat suitability of seagrasses in the Danish Wadden Sea.

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The main hotspots of suitable eelgrass habitat, when human activities and associated pressures are considered, are located in the southern Danish Wadden Sea, with several additional potentially suitable sites in the central part of the area (Figure 7).

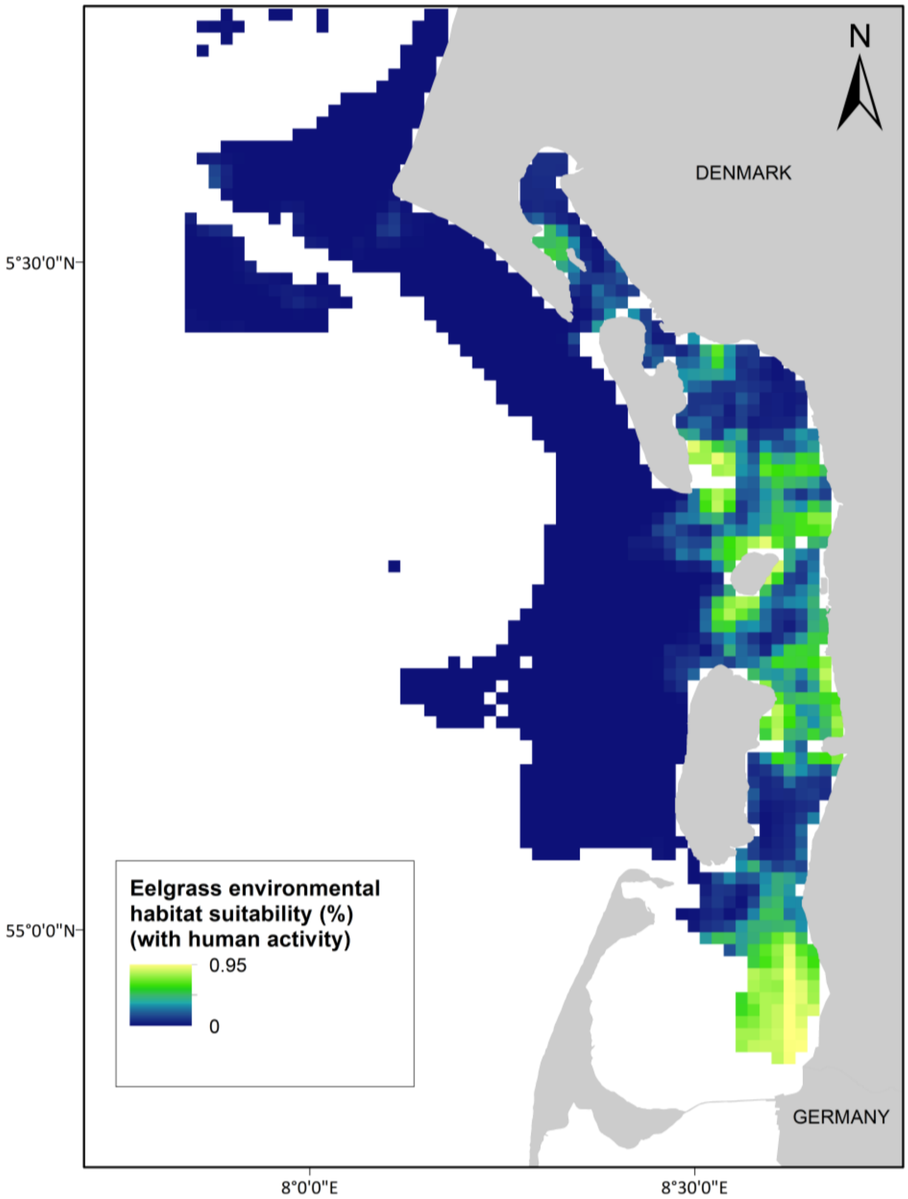

Figure 7. Eelgrass expected habitat suitability considering the cumulative effects of selected human activities and pressures in the Danish Wadden Sea.

During an online meeting in October 2025, the CIA outputs were presented to the SEG members for further comments and feedback. All comments from the meeting and other interactions with the SEG were used to guide the tool development described in paragraph 3.5.2.

Overall, SEG members considered the tool and its outputs to be highly valuable for supporting forthcoming decision-making processes, particularly in identifying and prioritising the most suitable areas for eelgrass restoration. In addition, the outputs generated by the tool are

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expected to make a meaningful contribution to ongoing and future trilateral UNESCO area evaluations.

Tool 2: Structured Ecosystem Service Sensitivity Assessment with Interactive Sankey Visualization

The tool was chosen in conversation with interested SEG members. In early discussions, the SEG members chose the area of application, i.e., study area and focus species. They also highly supported the idea of adding pressures to the diagram, which is one major element of tool development that was done to adapt the basic approach of Armoskaite et al., (2020) to the LL context. During an intermediate and a final meeting with the SEG, the SEG expressed engagement with the tool and seemed pleased with the process. The interactive interface was considered a highlight (Figure 8). While using the interface, one or more pressure intensities can be manipulated and the consequences thereof translate live into reduced service delivery, demonstrated through decreasing flows and nodes (Figure 9). There is also the possibility of hiding less sensitive links to reduce the visual complexity. When hovering over the links and nodes, users receive information on the background data concerning the link, including average scores, uncertainty measures and, where applicable, additional flagged information. There will also be the possibility of enabling manual expansion of the diagram on the pressure side. Users will be able to add their own pressures and impact scores directly in the app. This could help to address the concern that not all relevant pressures could be scored as part of the tool testing process. It would also add a new layer of flexibility for tool users. The SEG members did not request any additional major improvements or adjustments, so none were made in the tool development phase.

The tool aims to demonstrate the need for funding to decision-makers, including municipalities, and guide investment priorities by showing the real costs of losing nature. In that regard, the interactive interface can be used to simulate the effects of different scenarios of pressure intensity on ecosystem service delivery of eelgrass beds or Brent goose populations in the study area (Figure 9). It also serves as a strong communication tool, illustrating ecosystem interconnectedness and sensitivity to human pressures, and can support science outreach in the region. Its potential for adoption by local scientific working groups was highlighted.

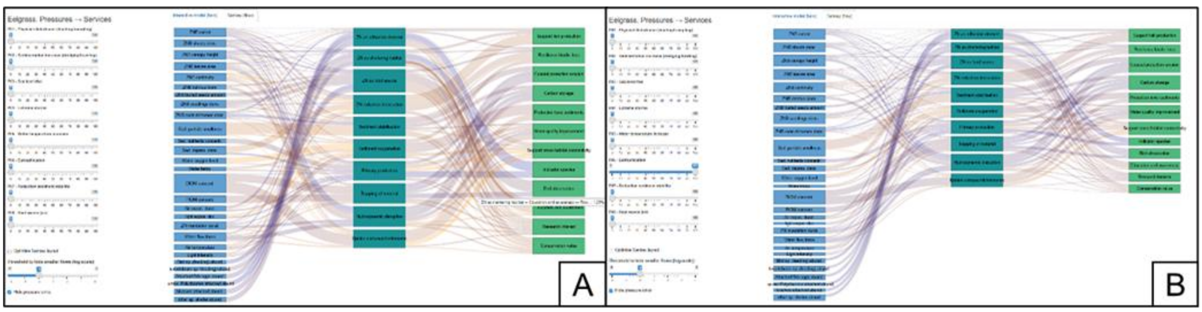

Figure 8. Sankey flow diagrams displayed in the R-generated interactive app illustrating ecosystem components, functions, and services related to a dwarf eelgrass bed (Zostera noltii) in the northern Danish Wadden Sea under two pressure scenarios.

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*(A) Baseline scenario with all pressures set to 0% and services at 100%, representing a balanced ecosystem in good ecological condition. (B) Scenario with eutrophication set to 100%, showing how support flow propagates through components, functions, and services. Node height reflects the modelled relative role in maintaining service delivery under the given pressure scenario, based on expert sensitivity scores (not absolute sensitivity). Link thickness represents how this support flow splits across connected nodes, with thicker links indicating a higher flow between nodes. Colours distinguish ecosystem components (blue), functions (teal), and services (green). *Results are preliminary and subject to further expert validation.*

The data validation and the development and upscaling of the tool are currently ongoing. An overview of developments and a user guide will be available in the following year.

3.4.3 Väinameri and Väike Väin

After compiling and integrating the required datasets into the web-based tool, cumulative impact assessments were carried out in PlanWise4Blue using the predefined test scenarios for Väinameri and Väike Väin. The resulting outputs were presented to the SEG during a dedicated workshop in October 2025, where participants provided feedback on both the assessment results and priorities for further tool refinement and development.

The Väinameri MPA test scenario examined the combined effects of tourism and leisure activities, shipping intensity, dredging and dumping, the invasive species *Rhithropanopeus harrisii (*Harris mud crab), and nutrient loading on sandbanks (Habitats Directive habitat type 1110) (Figure 9).

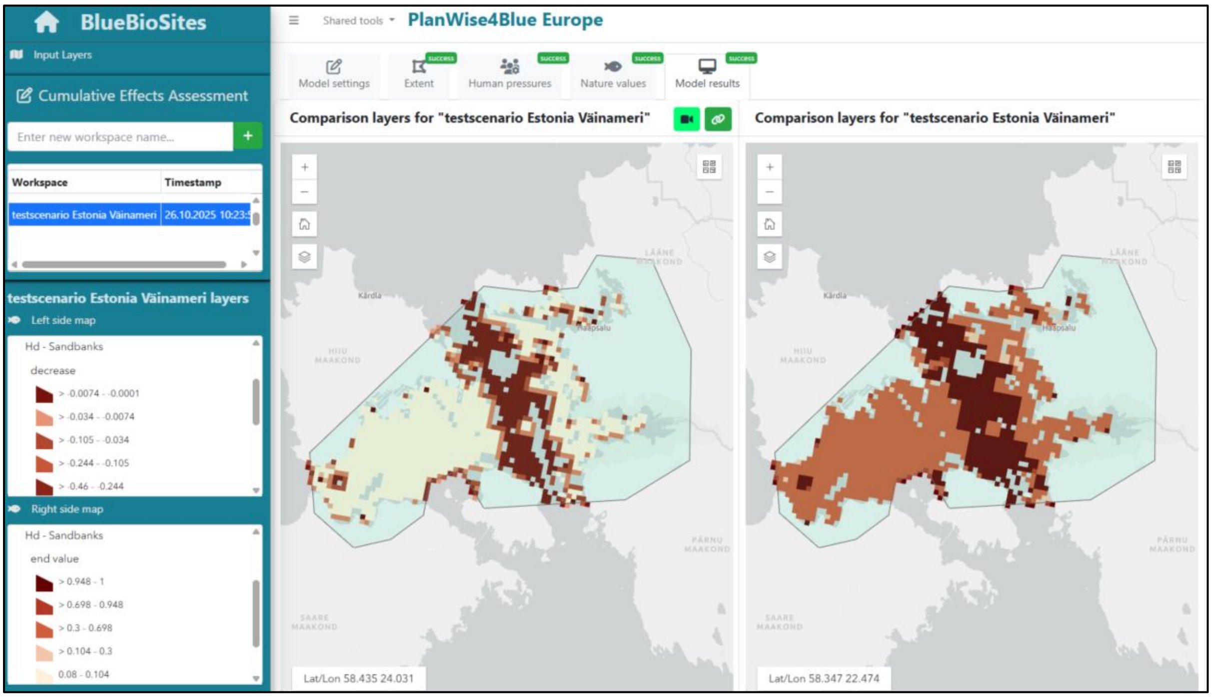

Figure 9. Decrease in probability of occurrence (left) and probability of occurrence after accounting for the cumulative impacts of human activities and pressures (right) for the sandbanks habitat in the Väinameri MPA.

The Väike Väin MPA test scenario assessed the cumulative effects of tourism and leisure activities, shipping intensity, dredging and dumping, the invasive species *Rhithropanopeus harrisii*, and nutrient loading on mudflats and sandflats (Habitats Directive habitat type 1140) (Figure 10).

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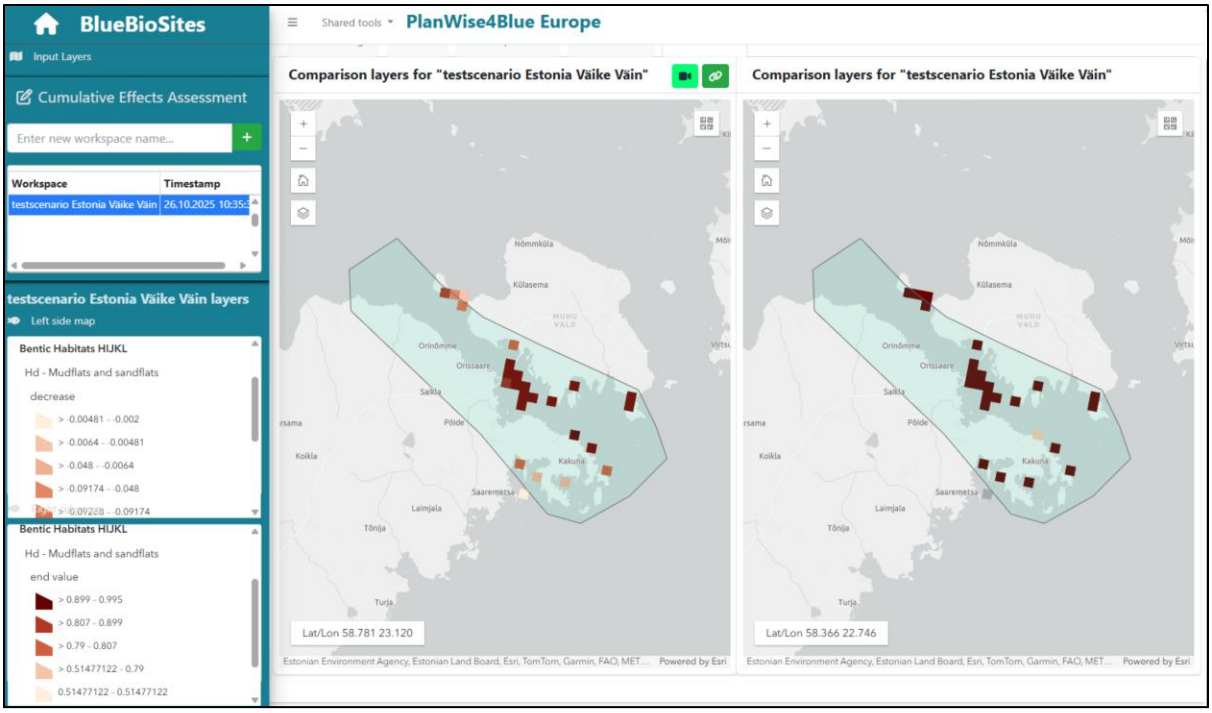

Figure 10. Decrease in probability of occurrence (left) and probability of occurrence after accounting for the cumulative impacts of human activities and pressures (right) for the mudflats and sandflats habitat in the Väike Väin MPA.

Feedback from the SEG on the tool outputs was very positive, while also pointing to several opportunities for further enhancement. In particular, MPA managers emphasized the added value of including a tabular summary of model results alongside the spatial outputs to support interpretation and comparison across areas. They also recommended adding information buttons for each analysis layer, enabling users to quickly access key metadata such as the data source, temporal coverage, spatial resolution, and any important assumptions or limitations. A detailed overview of the resulting tool developments is provided in Section 3.5 of this deliverable.

3.4.4 Irish MPA network

Following the compilation and harmonization of the relevant spatial layers CIAs were implemented for the Irish Sea LL using a desktop version of PlanWise4Blue and the locally combined sensitivity scores for three different reef habitats.

Overall, the assessed human activities and pressures do not appear to exert substantial pressure on the reef habitats in the Irish Sea. Both the estimated habitat loss and the total area affected by human activities are low to moderate depending on habitat type (Table 9).

Table 9. Habitat area size, potential loss, affected area and human activities contribution to the potential loss of habitat in the Irish MPA network area.

Nature value	Offshore circalittoral rock and biogenic reef	Circalittoral rock and biogenic reef	Infralittoral rock and biogenic reef
Initial area km^2	347	194	21
Loss of habitat %*	0	10.3	0

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Area affected %**	4.3	15.5	4.8
Wind parks contribution (%)	0	94.4	0
Shipping contribution (%)	0	1.4	75.4
Bottom trawling contribution (%)	100	4.2	24.6

Due to the overall small level of overlap between considered habitats and bottom trawling, and the overall low intensity of bottom trawling in the areas where "offshore circalittoral rock and biogenic reef" habitat and the activities overlap, bottom trawling exhibits only a small effect on the habitat, with 4.3% area affected and no habitat loss expected (Figure 11).

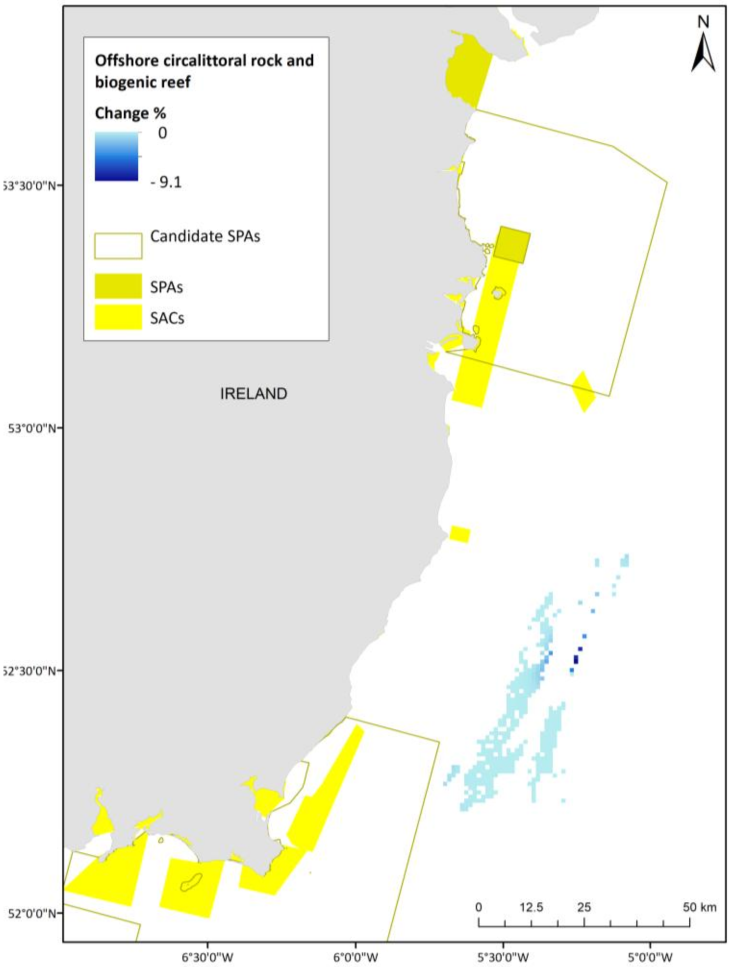

Figure 11. Expected change in offshore circalittoral rock and biogenic reef habitat probability of occurrence in the Irish Sea.

Wind farm development and use is the primary driver of predicted loss for the "circalittoral rock and biogenic reef" habitat, accounting for the vast majority of the estimated reduction (10.3%). In contrast, bottom trawling and shipping show only minor effects, consistent with their limited overlap with the habitat and the low activity intensity within those overlapping areas (Figure 12). Spatially, the strongest decreases are concentrated where wind farm footprints intersect with higher baseline habitat suitability.

Figure 12. Expected change in circalittoral rock and biogenic reef habitat probability of occurrence in the Irish Sea.

Finally, for the "infralittoral rock and biogenic reef" habitat, overlap with bottom trawling and shipping is minimal and activity intensity in overlap zones is low. As a result, only a small fraction of the habitat area is predicted to be affected (4.8%), with no overall habitat loss expected (Figure 13).

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Figure 13. Expected change in infralittoral rock and biogenic reef habitat probability of occurrence in the Irish Sea.

The results from the tool testing in the Western Irish Sea were found useful in showing the potential to expand the current MPA network in a way that both expands protection to ecologically valuable habitats without impacting Irish marine industries. The tools outputs were easy to convey to people involved in MPA design and matched their understanding of the area. However, due to a similar process which occurred for the Irish context in 2023 as part of a government led project (an ecological sensitivity analysis of the Western Irish Sea using prioritizr and Zonation) the results are a little bit redundant, as this information was previously identified during that separate process. The Irish stakeholders stated that it would be highly beneficial if a tool were able to show whether multiple pressures synergise antagonistically or not, as that information would be able to be taken to industry representatives (e.g., fishing interests), which the current outputs did not show. But overall, they saw a lot of value in the presented system.

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3.5 Tool developments and co-creation process

Task 3.3 delivered essential improvements across several DSTs, strengthening their capacity to translate both scientific evidence and local knowledge into practical input for decision-making in MPA and MPA network design and management. A key added value was the systematic integration of iterative user feedback, ensuring that tool outputs are not only scientifically robust, but also aligned with the realities of operational management processes.

The continuous co-creation cycle implemented with stakeholders from six LLs enabled an in-depth understanding of the day-to-day needs, constraints, and priorities of MPA managers and decision-makers. This sustained exchange helped steer developments towards greater usability and clarity, improving the relevance of outputs, strengthening interpretability, and ensuring that the tools support concrete questions faced in design and management workflows. As a result, the tools became more user-friendly and informative, while also reducing the time and effort required to run analyses, interpret results, and communicate findings, thereby lowering barriers to uptake scientific knowledge and supporting more efficient, transparent, and evidence-informed decision-making for MPAs and MPA networks design and management.

3.5.1 Non-indigenous species Effects Assessment Tool (NEAT)

The main development of NEAT within Blue4all was the extension of its geographic applicability beyond the Baltic Sea and Oslofjord to include the Greater North Sea and Celtic Seas. In addition, NEAT was further refined through the tool-testing and co-creation process, incorporating feedback from SEG members to improve its usability and better align the tool with the needs of MPA managers and decision-makers. Table 10 presents the development and improvement needs identified through SEG interactions, indicating which solutions were implemented in NEAT within the Blue4all project and which needs remain for potential future implementation.

Table 10. Development and improvement needs identified through SEG interactions for NEAT, solutions implemented within the Blue4all project, and additional needs identified for potential future implementation.

Tool development and improvement needs identified	Status of implementation	Solution
Spatially gridded and locally validated NIS occurrence maps for the French Natura 2000 network area	Implemented	Probability of occurrence maps were modelled for 21 NIS and integrated into NEAT as ready-to-use spatial data layers. The layers were refined and validated through consultations with local experts for the French Natura 2000 network area.
New scientific evidence on the ecological effects of NIS	Implemented	Scientific evidence-based effect sizes for the North Sea were incorporated into the NEAT online tool following a structured literature search conducted in Web of Science and Scopus. The current version of the tool includes science-based effect sizes for 13 taxa, six of which were added within Blue4all: *Gracilaria*

		vermiculophylla, *Magallana gigas*, *Sargassum muticum*, *Mnemiopsis leidyi*, *Hemigrapsus* spp., and *Crepidula fornicata*. The database will continue to expand as new evidence becomes available through ongoing and future projects.
Estimation of effect sizes for NIS with limited or no scientific evidence	Implemented	An expert assessment was carried out for all species in the French Natura 2000 network area to support effect evaluation where empirical evidence was limited or unavailable. Experts assessed the potential positive and negative impacts of each species at maximum densities across key ecological and environmental dimensions, including changes to abiotic conditions, habitat formation, predator–prey relationships, and competition. The overall effect size was calculated as the average across all relevant categories, with uncertainty represented by the standard error among experts. Expert-based effect sizes for species lacking sufficient scientific evidence were then incorporated into NEAT.
Expansion of the underlying NEAT effect-calculation algorithm to incorporate the use of probability of occurrence maps	Implemented	The underlying NEAT effect-calculation algorithm was further developed to allow the estimation of potential NIS effects using probability of occurrence maps. This development expanded the approach developed by Kotta et al. (2024b) by explicitly incorporating estimates of maximum potential abundance or biomass for each species into the effect calculations, based on available scientific information and local expert knowledge.
Improved capacity to identify hotspots of potential cumulative impacts from NIS	Implemented	The NEAT model algorithm was expanded to calculate the additive negative impacts of all NIS with negative effects within each grid cell. This allows users to identify areas where multiple NIS may jointly contribute to higher potential impacts.
Improved presentation and clarity of results to support decision-making	Implemented	In addition to calculating total additive negative impacts, NEAT now provides normalised maps of potential negative NIS impacts using a simplified and widely used 0-1 scale, making the results easier to present and interpret. The updated user manual (https://gis.sea.ee/bluebiosites/files/NEAT_manual.pdf) also includes short guidance on how the tool outputs can be interpreted and used in decision-making.
Possibility to further analyse and use the results beyond the tool interface	Implemented	All result layers can now be exported for further analysis as GeoTIFF and CSV files. This allows users to process, combine, and visualise the results in external GIS or statistical software.
Assessing potential NIS effects inside and outside MPAs	Implemented	Automatically updated conservation area boundaries from the World Database on Protected Areas (WDPA; https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA) were added to NEAT. These boundaries can be used to define the analysis extent for a specific protected area or MPA network. Users can also define custom extents covering selected MPAs and surrounding areas. To support rapid visual interpretation, conservation area boundaries can now be

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		overlaid with NEAT results, allowing users to compare potential NIS impact hotspots inside and outside protected-area borders.
Assessment of potential risk hotspots in relation to offshore wind development	Implemented	Offshore wind park locations were integrated into NEAT as an optional result-overlay layer. This supports screening of current and emerging NIS risk hotspots in relation to offshore wind development areas.
A common effect scale across species to support direct comparisons	Implemented	The tool visualisation was improved by using a consistent common colour scale for the representation of negative and positive effects. Users can also download spatial outputs and rescale or standardise them in external mapping software according to their specific comparison needs.
Exploring potential correlations between NIS impact hotspots and nuclear power stations	Future implementation	Conservation areas and offshore wind parks were prioritised within Blue4all as the most policy-relevant contextual layers. Nuclear power stations were not added directly because available data are limited to land-based point locations and do not include information on how potential effects propagate into the marine environment. Once such information becomes available, users can export NEAT outputs and overlay them with relevant power-station effect-propagation layers in external GIS software.
Incorporations of automated updates of NIS maps from national monitoring databases	Future implementation	Fully automated updates of species distribution maps were not feasible within the project timeframe. However, the user manual now clearly explains how new or updated maps can be added to the tool through user support. This enables the most recent available distribution maps to be used in future assessments of potential NIS effects.
Displaying current species occurrence records alongside modelled distribution maps	Future implementation	While occurrence information was not explicitly integrated into the online version of the tool, the occurrence records are openly available. Users can therefore download NEAT outputs and overlay these records in external GIS software to compare observed occurrences with modelled distributions. This provides a practical workflow for using occurrence data to support external validation, interpretation, and refinement of the modelled outputs.
Indication of the main introduction vector for each NIS directly on the maps	Future implementation	This functionality could not be incorporated directly into the web tool due to limited data availability and uncertainty around introduction pathways for several species. Once reliable pathway data become available this feature can be implemented.

3.5.2 PlanWise4Blue

During testing and implementation in Task 3.3 of the Blue4all project, PlanWise4Blue was iteratively improved based on SEG feedback gathered across five different MPAs and MPA networks, including inputs from a transnational MPA network (Table 11). This co-development process aligned the tool more closely with real-world management workflows and ensured that outputs are both scientifically robust and operationally useful. The resulting developments prioritized what practitioners most need for planning and targeting conservation measures, strengthening tools' ability to turn evidence into actionable guidance for restoration planning, management interventions, and spatial prioritization, while also reducing the effort required from end users to access, run, and interpret analyses and outputs.

Table 11. Development and improvement needs identified through SEG interactions for PlanWise4Blue, solutions implemented within the Blue4all project, and additional needs identified for potential future implementation.

Tool development and improvement needs identified	Status of implementation	Solution
Expanding the evidence-based effects size information to support the planning of conservation and restoration actions in the North Sea	Implemented	Based on a systematic review of the scientific literature, evidence on the effects of different human activities on *Zostera noltii*, an important habitat-forming seagrass species in the North Sea, was incorporated into PlanWise4Blue. This strengthens the evidence base for pressure reduction, spatial zoning, restoration targeting, and the justification of management measures for this important habitat.
Quantitative summaries of cumulative impacts on nature values beyond spatial maps to support reporting, communication, and decision-making	Implemented	The tool's output options were improved to include tabular summaries that provide quantitative information for a selected planning extent, including estimates of suitability reduction or probable habitat area loss. These outputs support comparison between areas and facilitate the communication of results in management plans and reporting. The tabular summaries can also be downloaded for further use.
Direct support for single MPAs and MPA networks planning	Implemented	The best-available MPA boundary layer from the World Database on Protected Areas (WDPA; https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA), including automatic updates, was incorporated into the tool. This enables direct overlay with model outputs, helping users identify priority action areas within individual MPAs and across MPA networks. It also reduces the need for post-processing and supports the visual prioritisation of targeted conservation actions.
More reliable, repeatable, and operational workflows	Implemented	Key spatial layers requested by Estonian MPA managers (Environmental Board of Estonia) are now included in PlanWise4Blue, linked to national Estonian databases, and updated automatically. This reduces manual data handling and helps ensure that analyses are based on current, authoritative data inputs.

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A clearer guidance to interpret outputs and apply results	Implemented	Improvements include an improved step-by-step guidance (Annex E), improved colour codes for the legends of the results maps, with blue colour scale indicating decrease and red indicating increase is nature values, and an updated user manual.
Simple testing of future scenarios involving changes in the distribution and intensity of human activities and pressures	Implemented	New scenario-testing features are now available in the web tool. Users can modify activity intensity or add and remove specific polygons, such as proposed wind park development areas, using the tool’s built-in spatial data layers. This enables the comparison of alternative scenarios to support management and planning decisions.
Outputs for individual conservation sites or multiple sites within an MPA network	Implemented	The extent-definition option was made more adaptable for use in MPAs and MPA networks. When defining the assessment extent, users can now overlay MPA boundaries and follow them while drawing one or several desired assessment extents.
Users’ ability to upload additional spatial layers directly into the web tool	Future implementation	The data upload functionality remains under development and is expected in 2027. Currently new spatial data layers can be uploaded through tool user support. Built-in human activity and pressure layers can already be adjusted by users within the web tool, to create modified data layers that fit user needs.
Reduce the barriers for practical implementation due to limited staffing and financial resources	Continuous development	PlanWise4Blue is an open-access web tool, which helps reduce costs associated with software licences or high-performance computing requirements. Additional improvements are expected to further lower implementation effort and staffing costs, including the updated step-by-step implementation guide in Annex E, the revised user manual, planned video tutorials to be made available in June 2026, and the reduced need for post-processing through the incorporation of conservation area maps directly into the tool.
Increase awareness of existing DSTs to increase uptake	Continuous development	Workshops within Blue4all were used to build familiarity with DSTs and showcase their practical application in real MPA contexts. Beyond the project period, the MPA Solutions Hub is expected to further strengthen the visibility, accessibility, and uptake of relevant tools by providing a dedicated entry point for practitioners, managers, and decision-makers.

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4. Guide for the effective implementation of decision-support tools

This guide synthesises the practical lessons learned from testing and co-creating ecological and environmental DSTs in Blue4all LLs. It provides a structured, step-by-step approach to support MPA managers, practitioners, and decision-makers in selecting, preparing, and applying DSTs in real-world MPA design and management processes. The guide is organised along the main stages of the DST implementation process, from defining management needs and decision questions, through data gathering and harmonisation, to tool selection and interpretation of outputs, and is intended to make the full data-to-decision chain more transparent, reproducible, and operational.

Through the testing process carried out across six LLs, different DSTs were iteratively improved and further developed in close exchange with end users. The lessons learned from this co-creation process, together with targeted technical upgrades and the integration of datasets into online, open-access web tools, will substantially reduced the time and effort required to apply these tools in practice.

As a result, the tested DSTs are now better positioned to support timely, transparent, and repeatable analyses that inform MPA and MPA network design and management processes. By making relevant data and outputs easier to access, interpret, and integrate into operational workflows, the tools strengthen the systematic uptake of ecological and environmental scientific evidence in decision-making, supporting more consistent prioritisation, clearer justification of measures, and more effective implementation of conservation and management actions.

4.1 Defining the needs in the area of interest

Effective use of ecological and environmental DSTs begins with a clear definition of the management need and the decision context in which results will be applied. In practice, these needs can be identified through a structured NA (see Deliverable 4.4) or through targeted discussions with local experts and practitioners. Additional drivers often stem from existing MPA management plans, national legislation, and overarching policy frameworks and directives, which may set specific conservation objectives, monitoring requirements, or reporting obligations.

Once broad goals and needs have been identified (e.g., improving MPA effectiveness, prioritising restoration, assessing cumulative pressures, or addressing invasive species), they should be translated into a concise, operational question that the tool is expected to answer. To ease this process a tool testing protocol (Annex A) was developed. This translation step is critical because it determines what data are required, what assumptions are acceptable, and how outputs should be interpreted. It should explicitly define the geographic extent and spatial resolution, the target conservation features (species and/or habitats), and if needed, the relevant human activities and pressures to be included. It should also specify the output

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formats required by end users, ensuring consistency with day-to-day management workflows, for example, spatial outputs (maps of hotspots, risk levels, or priority areas) to support planning and communication, complemented by tabular summaries to support reporting, comparison across sites, and documentation of model results (e.g., mean effects, uncertainty metrics, and occupancy indicators).

4.2 Data gathering and harmonization

Once needs are defined, the key enabling step is compiling and harmonizing the input datasets required by the selected DST. In practice, this involves (i) identifying suitable datasets for conservation features (e.g., habitat distribution or suitability layers; species occurrence/probability layers) and for human activities and pressures, (ii) assessing data fitness-for-purpose (spatial coverage, resolution, temporal relevance, uncertainty, licensing), and (iii) harmonizing layers into a common spatial and analytical format.

In example, across the project LL, datasets were typically sourced from a combination of European open-access services (e.g., EMODnet, Copernicus, OBIS/GBIF where relevant) and national portals, and then processed to align projection, spatial extent, and grid resolution (commonly 1 km^2), while standardizing values to comparable scales (e.g., 0–1 relative intensity for pressures). Depending on the tool selection, some of the needed spatial layers could already be incorporated in the tool and require only suitability check-up for the area of interest.

For some cases, the needed datasets are not available or unsuitable, thus modelling new data layers and the usage of suitable proxies could be necessary (e.g., species distribution modelling supported by expert validation; nutrient inputs as proxy for eutrophication).

4.3 Decision-support tool selection

During the tool-testing phase of Blue4all, the WP3 core team supported the LLs in selecting the most suitable decision-support tools for their specific objectives and local contexts. By the end of the project, this selection process for the wider public, will be further streamlined through the MPA Solutions Hub, which will guide users towards the most appropriate tools based on their management questions, available data, and decision-making needs.

Building on Task 3.3, several tools were co-developed together with MPA managers and other decision-makers to increase their usability and uptake in operational management. Development efforts focused on making the tools more user-friendly and informative, improving transparency (e.g., clearer assumptions, traceable inputs), and reducing the resources needed for implementation (e.g., simplified workflows and more readily reusable outputs). The simplified implementation process for new users of the tested tools, as examples, is outlined below.

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4.3.1 Non-indigenous species effect assessment tools

In general, spatial NIS impact assessment results (such as those produced by NEAT) are most useful as prioritization areas, helping managers decide where to look first and where action is most likely to be needed. The outputs can support several core management processes:

- Monitoring and early detection planning: identifying areas with higher predicted occurrence and/or higher potential effects to prioritize survey design, sampling locations, inspection frequency, and the allocation of monitoring resources.
- Prioritization of impact studies and field validation: guiding where to conduct targeted impact assessments, ecological surveys, and before–after studies, especially where modelled hotspots overlap with vulnerable habitats and conservation areas. This supports more efficient field campaigns and strengthens evidence for management decisions.
- Targeting prevention and biosecurity measures: informing where preventive actions are likely to yield the greatest benefit (e.g., awareness campaigns, cleaning protocols for vessels and equipment, controls around infrastructure or high-use areas), and where rapid response planning should be strengthened.
- Supporting restoration and conservation actions: helping to prioritize restoration feasibility assessments by flagging areas where NIS pressure may undermine recovery (or where restoration may need additional safeguards).
- Spatial planning and management zoning: complementing other pressure and biodiversity layers to support zoning decisions (e.g., stricter protection where high NIS pressure overlaps with sensitive habitats; targeted management zones for surveillance and mitigation), and to compare conditions inside versus outside protected areas.
- Reporting and communication: providing a transparent, map-based way to communicate risks and uncertainties to stakeholders and decision-makers and supporting documentation within management plans.

Overall, these results help translate scattered information into an actionable spatial picture, to support, not to replace a detailed local assessment.

To our knowledge, the only such DST, tailored to assess NIS potential effects in MPAs and MPA networks, was developed in this project. NEAT is an online, open-access decision-support tool applicable to inform design and management across the Celtic Seas, Greater North Sea, and Baltic Sea. It supports the assessment and visualization of potential NIS-related effects by combining species probability of occurrence layers with scientific and expert effect information to generate spatially explicit outputs, and it is readily applicable at both MPA and MPA-network scales.

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In the NEAT web tool, users can select an area of interest and NIS to include in the analysis. The results show each species separate effects and additive negative effects on maps and a summary table. NEAT can be used with 6 easy steps in the web tool (https://gis.sea.ee/neat/). A step-by-step guide can be found in Annex D.

4.3.2 Cumulative impact assessment tools

Cumulative impact assessment tools support marine planning and MPA management by helping users identify where multiple human activities and pressures overlap with sensitive habitats and species, and where their combined effects may concentrate. By integrating spatial layers on human uses (e.g., shipping, fisheries, energy infrastructure) with environmental components (e.g., habitats, species distributions) and applying impact pathways and weighting schemes, these tools provide a structured, transparent way to screen for potential risk hotspots, compare alternative scenarios, and prioritize management actions. They are therefore particularly useful for evidence-based planning, communication of complex pressure–impact relationships and reporting against management objectives.

Several CIA tools are currently in use across Europe (e.g., HELCOM SPIA, Tools4MSP, Symphony). Within Blue4all task 3.3, PlanWise4Blue was selected as the primary tool for co-development and testing because it (i) performed strongly in the comparative screening presented in Deliverable 3.2 (notably balancing technical robustness with user-friendliness), and (ii) is developed and maintained by a project partner. This ensured that stakeholder needs could be translated into concrete improvements quickly, enabling an iterative co-development cycle within the project timeframe and reducing barriers to implementation for end users.

Building on feedback gathered during the testing process in both individual MPAs and MPA networks, multiple enhancements were implemented in PlanWise4Blue to strengthen usability and decision relevance. Improvements focused on making workflows more intuitive for non-specialist users, increasing the transparency and interpretability of outputs (e.g., clearer presentation of assumptions, inputs, and result meaning), and reducing the resources required to run analyses (e.g., simplified steps, streamlined data handling, and outputs that can be readily exported for reporting and GIS use). Collectively, these refinements aimed to improve uptake in operational settings by ensuring the tool better matches manager workflows, supporting rapid screening of cumulative pressures, clearer identification and communication of hotspots, and easier comparison across areas or scenarios. A detailed overview of the assessed cumulative impact tools and their scoring against key characteristics is provided in Deliverable 3.2.

After establishing the need for a cumulative impact assessment in your area of interest, the PlanWise4Blue tool can be applied in the BlueBioSites platform (https://gis.sea.ee/pw4b-eu/). A step-by-step guide is available in Annex E. The users can choose an area of interest, human activities and pressures to include and nature values on which the cumulative impact assessment is conducted.

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5. Lessons learned and future steps towards a more science informed decision making in MPA and MPA network processes

Across the LLs, the tool testing and co-creation process demonstrated clear added value for MPA practice. In particular, when outputs are designed around concrete management questions and delivered in formats that practitioners can readily interpret, DSTs can shift from complex, opaque products to actionable decision support. Stakeholders in particular emphasised the usefulness of (i) cumulative impact outputs for prioritising, communicating, and justifying conservation and restoration measures (e.g., in the Danish Wadden Sea, the results were already used to inform the planning of restoration actions and indicated as valuable products), (ii) the long-term value of DST expansion and optimisation achieved under Task 3.3, most notably the delivery of an operational NIS impact assessment capability that previously did not exist in the DST landscape, and (iii) the value of visual flow diagrams.

At the same time, LL implementations confirmed that the primary bottleneck to operational, repeatable science-informed decision support is rarely the algorithm alone. It is more often the availability, fitness-for-purpose, transparency, and interoperability of data and prolonged time for expert and stakeholder interactions. Common challenges included datasets scattered across portals and jurisdictions, restricted access, confidentiality constraints, and the frequent absence of spatially explicit layers. In the frame of Blue4all, where critical layers were missing or unsuitable, progress depended on substantial additional work on data harmonisation, gridding, standardisation, and modelling. This underlines the importance of implementation guidance that makes the full data-to-decision chain explicit, including assumptions, limitations, and documentation needed so that results can be interpreted appropriately and reproduced over time.

In general, the use of ecological and environmental DSTs, particularly for ecosystem sensitivity assessments, is constrained by the considerable time required for expert identification, interviews, scoring exercises, and validation workshops, which are difficult to accommodate alongside routine management responsibilities. A recurring challenge is also selecting an appropriate level of detail, as overly complex approaches tend to exacerbate data gaps and uncertainty and can hinder the integration of ecological and social dimensions into outputs that are usable for management.

These barriers are amplified when ecological and environmental DSTs are used in a transnational MPA network. Harmonizing datasets across countries and setting shared conservation priorities require substantial time and repeated engagement among stakeholders from different countries, work that was not possible within the project timeframe. The implementation guidelines developed, together with DSTs improvements informed by feedback from MPA managers from multiple countries integrating the HELCOM Expert Group on Marine Protected Areas, provide an important step towards more consistent use of DSTs in both national and transnational MPA networks by clarifying workflows, data requirements, and practical pathways for cross-border comparability.

Beyond technical issues, several practice-related uptake barriers remain. Stakeholders repeatedly highlighted the need for capacity building (awareness, training, and practical guidance for non-specialists), long-term support and maintenance, and trust-building features (clear metadata and definitions, and, where feasible, confidence/uncertainty information). In transnational MPA network contexts, further constraints arise from governance and coordination realities, including differences in national priorities, planning processes, and data-sharing arrangements. Addressing these issues requires not only better tools, but also shared standards for data exchange, common indicators for network-level reporting, and agreed approaches to ensure comparability across borders.

While challenges remain with ecological and environmental DSTs, Task 3.3 took a significant step toward tackling some of the most pressing development needs across multiple DSTs. Within the tested tools, access to relevant and up-to-date data was strengthened, and practical guidance was provided on how to connect analyses more reliably to national, EU, and Global data services. In addition, the work demonstrated the capacity of existing tools, originally developed for different purposes, to support conservation and restoration actions in MPAs, showed their applicability beyond the geographic contexts for which they were originally developed, and contributed to improvements in underlying algorithms and resulting outputs, enabling outputs better aligned with the needs of managers, practitioners, and decision-makers.

A clear priority for the next phase is to continue improving management-ready functionality and outputs, for example: enabling users to define planning extents and zones more easily, simplifying scenario testing (e.g., human activities and pressures intensity adjustments), and providing reporting formats that complement maps, such as concise narratives, and exportable summaries that can be directly embedded in management plans, impact assessments, and stakeholder communication. Together, these steps lower barriers to uptake, reduce staff time needed to run and interpret assessments, and strengthen DSTs as routine inputs to iterative MPA processes.

Further progress will depend on better integrating DSTs and their outputs to address persistent gaps in MPA processes. Several needs raised by MPA managers and decision-makers, such as ecological and functional connectivity assessments and spatial prioritization, could directly build on, and benefit from, the developments delivered through the tested tools and should be targeted for integration or transfer. Both CIAs of human activities and pressures, and assessments of the potential effects of NIS, provide essential inputs for connectivity analyses and for prioritizing areas for conservation, restoration, and adaptive management actions when used alongside other DSTs. Strengthening interoperability between DSTs will therefore be key to more science-informed decision-making across MPA and MPA-network design and management processes.

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References

Aminian-Biquet, J., Gorjanc, S., Sletten, J., Vincent, T., Laznya, A., Vaidianu, N., ... & Horta e Costa, B. (2024). Over 80% of the European Union's marine protected area only marginally regulates human activities. One Earth, 7(9), 1614-1629.

Andersen, J.H., Hammer, K.J., Harvey, E.T., Knudsen, S.W., Murray, C.J., Carstensen, J., Petersen, I.K., Sveegaard, S., Tougaard, J., Edelvang, K. and Olsen, J., 2020. Supplementary material to ECOMAR: A data-driven framework for ecosystem based Maritime Spatial Planning in Danish marine waters.

Armoškaitė, A., Puriņa, I., Aigars, J., Strāķe, S., Pakalniete, K., Frederiksen, P., Schrøder, L., & Hansen, H.S. (2020). Establishing the links between marine ecosystem components, functions and services: An ecosystem service assessment tool. Ocean & Coastal Management, 193, 105229.

Barboza, F.R., Hoppit, G., Van Gerven, A., Trabulo, R., Stevens, M., Mancuso, P., … & Nurkse, K. (2025). Synthesis and detailed assessment of ecology-based tools to support MPA practitioners. Deliverable – D3.2 under the WP3 of the Blue4all project (GA n° 101094014).

Convention on Biological Diversity (CBD) (2022). Kunming-Montreal Global Biodiversity Framework (No. CBD/COP/DEC/15/4). https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Depellegrin, D., Hansen, H. S., Schrøder, L., Bergström, L., Romagnoni, G., Steenbeek, J., ... & Menegon, S. (2021). Current status, advancements and development needs of geospatial decision support tools for marine spatial planning in European seas. Ocean & Coastal Management, 209, 105644.

European Commission (EC) (2020). EU Biodiversity Strategy for 2030: Bringing nature back into our lives (No. COM/2020/380 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380

European Environmental Agency (EEA) (2025). Marine protected areas in Europe's seas. https://www.eea.europa.eu/en/analysis/indicators/marine-protected-areas-in-europes-seas

Grorud-Colvert, K., Sullivan-Stack, J., Roberts, C., Constant, V., Horta e Costa, B., Pike, E.P., Kingston, N., Laffoley, D., Sala, E., Claudet, J. and Friedlander, A.M., 2021. The MPA Guide: A framework to achieve global goals for the ocean. Science, 373(6560), p.eabf0861.

Hoppit, G., Nurkse, K., Beleem, I., Cadoni, N., Crowe, T., Bekaert, M., ... & Barboza, F. R. (2025). Enhancing marine protected areas with effective ecological and environmental data integration. Ecological Indicators, 178, 114119.

This publication was funded by the European Union. Its contents are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Union.

Hoppit, G., Nurkse, K., Szava-Kovat., R, Van Gerven, A., Kõivupuu, A., Stevens, M., … & Barboza, F.R. (2024). Revision and practical guidelines for the implementation of innovative ecological and environmental concepts in MPA processes. Deliverable – D3.1 under the WP3 of the Blue4all project (GA n° 101094014).

Kerwath, S. E., Winker, H., Götz, A., & Attwood, C. G. (2013). Marine protected area improves yield without disadvantaging fishers. Nature communications, 4(1), 2347.

Kotta, J., Douguet, J.M., Vollmer, E., Fetissov, M., Furlan, E., Grassi, G., Zennaro, F., Pagan, H.C. and Orav-Kotta, H., 2025. Assisting coastal and marine governance: Enhancing decision support through digital tools for cumulative impact assessment. Ocean and Society, 2.

Kotta, J., Fetissov, M., Szava-Kovats, R., Aps, R., & Martin, G. (2020). Online tool to integrate evidence-based knowledge into cumulative effects assessments: Linking human pressures to multiple nature assets. Environmental Advances, 2, 100026.

Kotta, J., Ojaveer, H., Kaasik, A., Szava-Kovats, R., Nurkse, K., Outinen, O., Einberg, H., Zaiko, A., Lehtiniemi, M., Orav-Kotta, H. and Barboza, F.R., 2025. Universal framework for assessing the environmental impact of marine non-indigenous species in different situations of data availability. Hydrobiologia, 852(8), pp.2507-2519.

Marine Protected Area Advisory Group (2020). Expanding Ireland's Marine Protected Area Network: A report by the Marine Protected Area Advisory Group. Report for the Department of Housing, Local Government and Heritage, Ireland. https://assets.gov.ie/static/documents/expanding-irelands-marine-protected-area-network.pdf

Mellin, C., Aaron MacNeil, M., Cheal, A. J., Emslie, M. J., & Julian Caley, M. (2016). Marine protected areas increase resilience among coral reef communities. Ecology Letters, 19(6), 629-637.

Menegon, S., Sarretta, A., Depellegrin, D., Farella, G., Venier, C., & Barbanti, A. (2018). Tools4MSP: an open source software package to support Maritime Spatial Planning. PeerJ Computer Science, 4, e165.

Pınarbaşı, K., Galparsoro, I., & Borja, Á. (2019). End users' perspective on decision support tools in marine spatial planning. Marine Policy, 108, 103658.

Reise, K. and Kohlus, J., 2008. Seagrass recovery in the northern Wadden Sea? Helgoland Marine Research, 62(1), pp.77-84.

Sala, E., Mayorga, J., Bradley, D., Cabral, R. B., Atwood, T. B., Auber, A., ... & Lubchenco, J. (2021). Protecting the global ocean for biodiversity, food and climate. Nature, 592(7854), 397-402.

This publication was funded by the European Union. Its contents are the sole responsibility of the author(s) and do not necessarily reflect the views of the European Union.

Schmidt, C., Karachaliou, E., Vandergast, A. G., Crandall, E. D., Falgout, J., Hunter, M. E., ... & Garroway, C. J. (2025). A survey of mammal and fish genetic diversity across the global protected area network. Conservation Letters, 18(2), e13092.

Staehr, P.A., Göke, C., Holbach, A.M., Krause-Jensen, D., Timmermann, K., Upadhyay, S. and Ørberg, S.B. (2019). Habitat model of eelgrass in Danish coastal waters: development, validation and management perspectives. Frontiers in Marine Science. 6(175). doi: 10.3389/fmars.2019.00175.

Timmermann, K., Stæhr, P.A.U., Göke, C. Upadhyay, S. & Erichsen. 2021. Klimaændringernes betydning for indsatsbehov til kystvande. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi, 30 s. - Videnskabelig rapport nr. 479 (http://dce2.au.dk/pub/SR479.pdf)

Topor, Z. M., Rasher, D. B., Duffy, J. E., & Brandl, S. J. (2019). Marine protected areas enhance coral reef functioning by promoting fish biodiversity. Conservation Letters, 12(4), e12638.

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Annex A. Protocol for the preparation and execution of the tool testing phase in WP3

This document frames the testing of ecological and environmental science-based tools to address key challenges highlighted by the Blue4all LLs in the Needs Assessment (NA). The testing process integrates and builds on the frameworks presented in Deliverable 3.1 of Blue4all and Deliverable 3.4 of MSP4BIO. Inspired by these two products, the present document provides a set of instrumental steps to guide the testing process. These steps should be regarded as a foundational framework, adaptable to the realities of LLs and evolving in response to the needs and insights presented during testing.

In the frame of WP3, we will address the tool identification and testing through the following guiding steps:

Step 1: Definition of a clear aim and the relevant context for achieving it

This step of the testing process is designed to identify and gather all necessary information to precisely define the specific need, building upon the initial description provided in the conducted NA. The objective is to address this need within the tool testing process while considering all relevant contextual dimensions. In this phase, we will:

1.A) Express the need(s) highlighted in the NA as a concrete and clear aim

Clearly specify the aim to be addressed in the tool testing process. Connect this aim to specific management objectives (e.g., optimizing the location of area-based protection measures by considering the distribution of relevant natural values and human pressures).

1.B) Identify the geographic scope

Define the area intended to be covered when addressing the aim defined in point A. Consider aspects such as the expansion of area-based protection measures, the assessment of the influence of human pressures acting on areas surrounding the Marine Protected Areas (MPAs) of interest, or the need to consider transboundary processes when defining the geographic scope.

1.C) Identify ecological and environmental targets and associated criteria and indicators

Identify and describe all biotic and abiotic elements that are a priority for conservation and are relevant to the aim defined in point 1.A. Include specific criteria and indicators used or suggested for the prioritization and assessment of the health of targets identified in the previous point.

1.D) Identify Human Activities and Pressures

Identify all human activities and pressures currently acting or expected to act in the area that affect or might affect the targets identified in point 1.C.

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Step 2: Data gathering and expected representation of outputs

This step is used for identifying and, when available, gathering the needed data to address the aims identified (1.A), considering the geographic scope (1.B), conservation targets (considering associated criteria and indicators, 1.C) and relevant human activities and pressures (1.D) identified and described in Step 1. In addition, in this phase, we will define the nature of the outputs to be obtained from the applications of selected tools.

2.A) Data for conservation targets

- Identify the spatially explicit data (layers) on conservation targets needed for addressing the aim(s) defined in 1.A, considering relevant criteria/indicators used or suggested for prioritization and health assessment (1.C) in the area (1.B).

- Screening and technical description of available layers, including information on their origin (raw data and statistical methods used to generate them), units, spatial resolution, geographic extent, and format.

- Information on their accessibility, needed permissions and potential restrictions for their implementation.

- Identification and description of potential proxies that could be as a replacement when the actual data on criteria/indicators for identified conservation targets are not available.

2.B) Data for human activities and pressures

- Identify the spatially explicit data (layers) on human activities and pressures needed for addressing the aim(s) defined in 1.A, considering the human activities and pressures listed in 1.D.

- Screening and technical description of available layers, including information on their origin (raw data and statistical methods used to generate them), units, spatial resolution, geographic extent, and format.

- Information on their accessibility, needed permissions and potential restrictions for their implementation.

- Identification and description of potential proxies that could be as a replacement when the actual data on human activities and pressures are not available.

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2.C) Nature of expected outputs

When selecting decision support tools (DSTs), understanding the expected outputs is critical to ensure that DSTs align with your decision-making needs. Here are two key points regarding the nature of expected outputs:

- Output format and flexibility: The DST should generate outputs that are actionable and aligned with user needs. This includes selecting appropriate output types (e.g., maps, graphs, and tables summarising key statistics) and allowing users to adapt both the content and the presentation to their specific objectives, with clear guidance on how to make these adjustments.

- Accuracy and data integration: Outputs must be robust and based on accurate, up-to-date information. The DST should be able to integrate data from internal and/or external sources where relevant, to support timely and well-informed decisions. This helps ensure that analyses and recommendations reflect current conditions and improves the overall reliability of the decision-making process.

Step 3: Tool selection, formal testing, and feedback analysis

3.A) Tools selection and testing

Based on the information provided in the NA, WP3 will offer a DST (or a set of DSTs, as defined by the needs), i.e., a tool for integrating and analysing ecological and environmental data to inform the design and management of area-based protection measures (see Box 1). The selection of the tool(s) will be further refined based on the information gathered in the first two steps. If most of the requested information is available, we will immediately proceed to testing the selected DST(s). If not, WP3 will provide tailored support and specific tools (Box 1) and protocols to gather the needed information.

Box 1. Typology for the classification of tools in the frame of WP3

In the frame of WP3 tools will be broadly classified into two main classes:

Monitoring and assessment: This class includes methods, approaches, and protocols for collecting baseline information to plan conservation, mitigation, and restoration measures and assess the achievement of expected goals. These tools include both purely scientific and participatory approaches to gathering relevant information, such as monitoring programs, expert-based assessments, systematic reviews with and without meta-analysis, participatory mapping or citizen science programs.

Design and management of area-based conservation measures: This class includes tools that support the integration and analysis of ecological and environmental data to inform the design and management of area-based conservation, mitigation and restoration measures. Examples are the tools designed for the identification and prioritization of

ecological and biological significant areas, (cumulative) assessment of the effects of human activities and pressures, spatial optimization of measures, and analysis of connectivity (among other).

3.B) Feedback gathering and analysis

After the initial testing of the selected decision-support tool(s) (DSTs), WP3 will use the feedback collected to (i) further refine and improve the tools, or (ii) identify and deploy alternative solutions where needed. Feedback will be gathered through dedicated in-person and/or online workshops and meetings that bring together tool developers, LL contact points, and members of the established Stakeholder Engagement Groups (SEGs).

Depending on the time available, each session will include presentations and demonstrations of tool implementations and updates. However, the core of these events will be structured around in-depth discussion with participants to ensure that user needs, usability constraints, and data or feature gaps are identified. Because the tool implementation and improvement will be treated as an iterative process, WP3 will organise multiple rounds of these events with the LLs.

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Annex B. Non-indigenous species: Probability of occurrence models and example maps

Table B1. Predictive variables for each species final models.

Species	Tidal amplitude	Nitrogen	NPP	Phosphorus	Depth	Salinity	Temperature	Substrate type	Vessel density	Wind speed
Acartia tonsa	X		X		X	X	X	X	X	X
Gracilaria vermiculophylla	X	X	X	X	X		X		X	X
Amphibalanus improvisus	X		X		X	X	X	X	X	X
Asparagopsis armata	X	X		X	X	X	X	X	X	X
Bonnemaisonia hamifera	X	X		X	X	X	X	X	X	X
Caprella mutica	X		X		X	X	X	X	X	X
Codium fragile	X	X		X	X	X	X	X	X	X
Cordylophora caspia			X		X	X			X	X
Crepidula fornicata	X		X		X		X			X
Dasysiphonia japonica		X		X	X	X	X	X	X	
Ensis leei					X	X	X			X
Ficopomatus enigmaticus			X			X	X		X	
Grateloupia turuturu	X	X		X	X	X	X	X	X	X
Hemigrapsus spp.	X		X		X	X	X	X	X	X
Magallana gigas	X		X		X	X	X	X	X	X
Mnemiopsis leidyi					X	X	X			X
Mya arenaria	X		X		X	X	X	X	X	X
Ruditapes philippinarum	X		X		X	X	X	X	X	X
Sargassum muticum	X	X				X	X	X	X	
Styela clava	X				X		X	X		X
Undaria pinnatifida					X		X		X	

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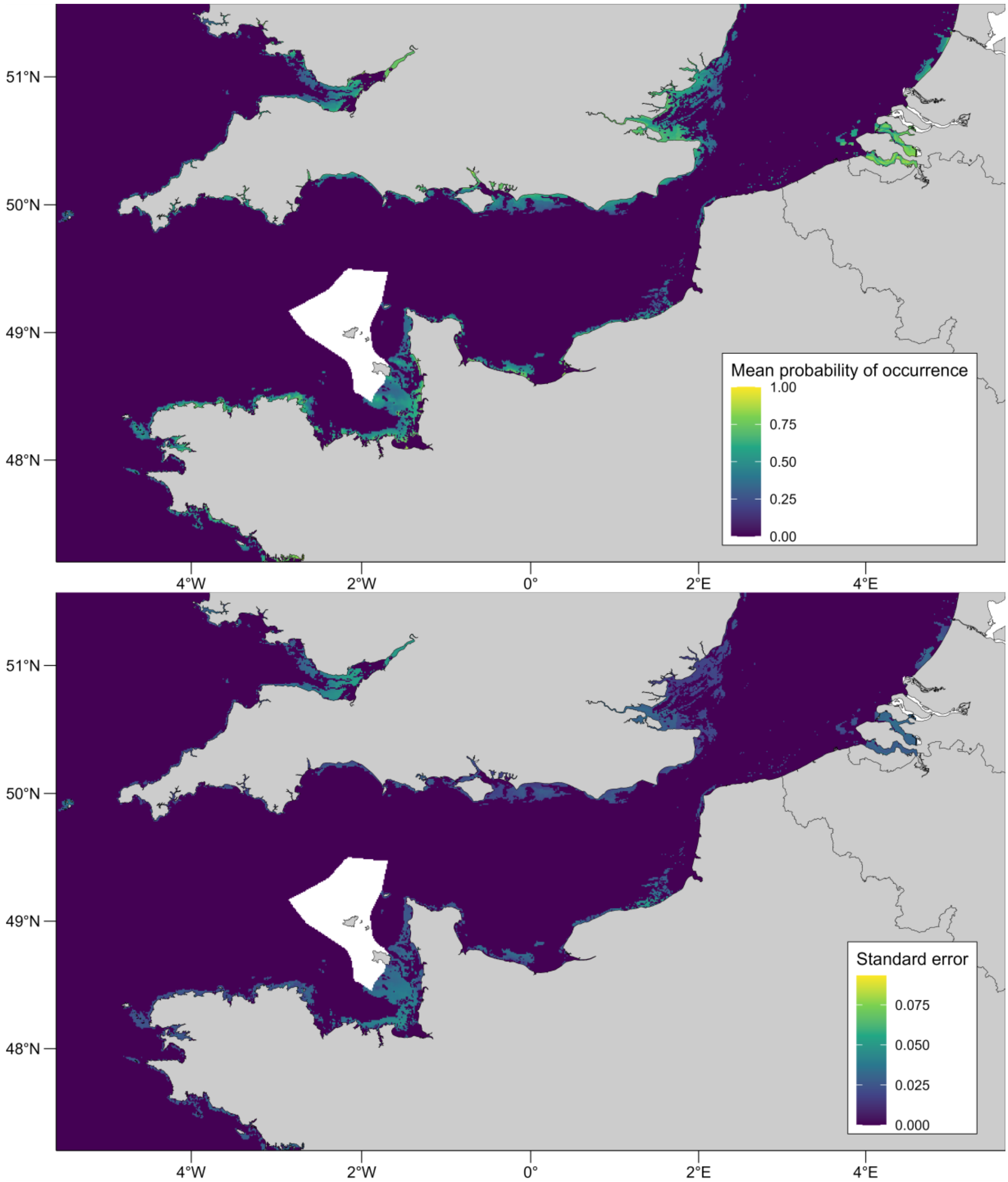

Figure B1. Mean (above) and standard error (below) of probability of occurrence of *Magallana gigas* in the French Natura 2000 network area.

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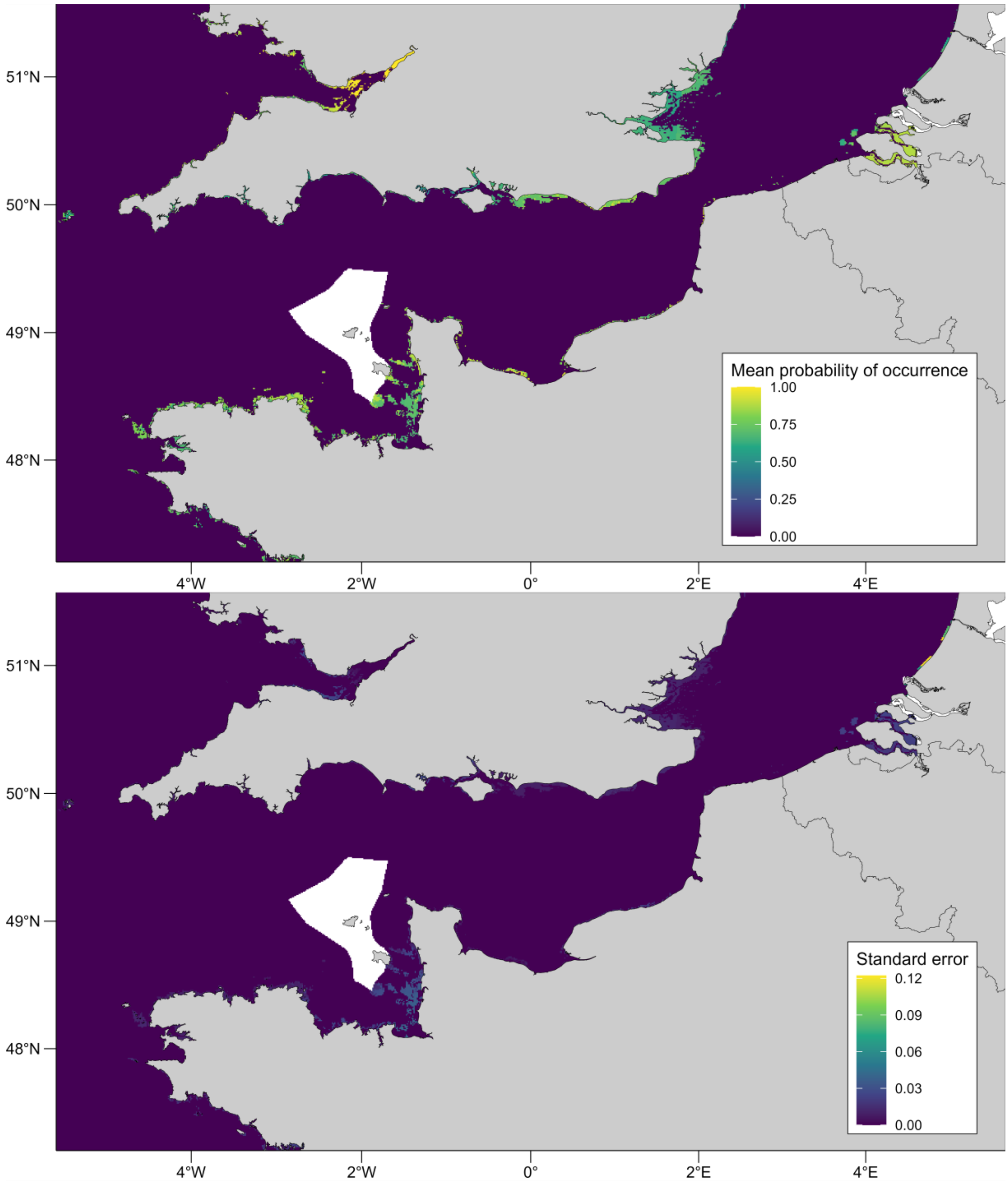

Figure B2. Mean (above) and standard error (below) of probability of occurrence of *Sargassum muticum* in the French Natura 2000 network area.

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Annex C. French Natura 2000 network results tabular output

Table C1. Species average effect, effect SE, occupancy, occupancy SE, calculated Hedges' g, Hedges' g SE, and type of evidence used for the calculations withing the model extent in the French Natura 200 network area.

Species	Type of evidence	Mean Effect	Effect SE	Occupancy	Occupancy SE	Hedges' g	Hedges' g SE
Acartia tonsa	opinion	0.0098	0.0001	0.101	0.0006	0.0972	0.5838
Amphibalanus improvisus	opinion	0.0193	0.0001	0.0994	0.0004	0.1944	0.2774
Cordylophora caspia	opinion	-0.0121	0.0001	0.0526	0.0003	-0.2292	0.1473
Mnemiopsis leidyi	data	-0.283	0.0009	0.1932	0.0006	-1.4645	0.402
Mya arenaria	opinion	0.1815	0.0005	0.2514	0.0007	0.7222	0.5422
Gracilaria vermiculophylla	data	-0.0006	0.00001	0.0238	0.0004	-0.0234	0.1694
Asparagopsis armata	opinion	-0.0687	0.0003	0.1736	0.0009	-0.3958	0.383
Bonnemaisonia hamifera	opinion	-0.0062	0.0001	0.0264	0.0005	-0.2361	0.3236
Caprella mutica	opinion	-0.1887	0.0006	0.2157	0.0007	-0.875	0.5303
Codium fragile	opinion	-0.0101	0.0002	0.0302	0.0005	-0.3361	0.5375
Crepidula fornicata	opinion	-0.0836	0.0001	0.5013	0.0008	-0.1667	0.0722
Dasysiphonia japonica	opinion	-0.0059	0.0001	0.0327	0.0006	-0.1806	0.4256
Ensis leei	opinion	0.1597	0.0005	0.259	0.0008	0.6167	0.6252
Ficopomatus enigmaticus	opinion	0.0034	0.0001	0.0134	0.0004	0.25	0.15
Grateloupia turuturu	opinion	-0.0081	0.0001	0.0275	0.0005	-0.2944	0.5261
Hemigrapsus spp.	data	-0.2844	0.0014	0.1372	0.0007	-2.0727	0.277
Magallana gigas	data	0.0261	0.0003	0.0544	0.0007	0.4801	0.5041
Ruditapes philippinarum	opinion	0.0154	0.0001	0.1541	0.0009	0.1	0.5657
Sargassum muticum	data	-0.0636	0.0011	0.0405	0.0007	-1.569	0.1099
Styela clava	opinion	0.0686	0.0002	0.4118	0.001	0.1667	0.878
Undaria pinnatifida	opinion	-0.0868	0.0004	0.2232	0.0009	-0.3889	0.6003

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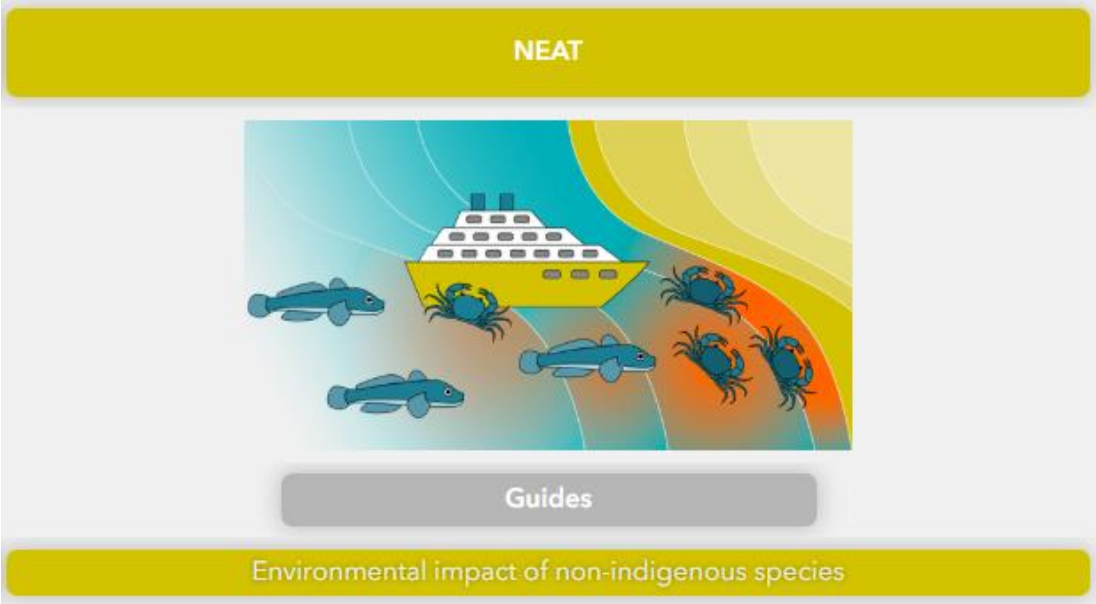
Annex D. Non-indigenous species Effects Assessment Tool step-by-step guide

NEAT can be applied in **6 easy steps**:

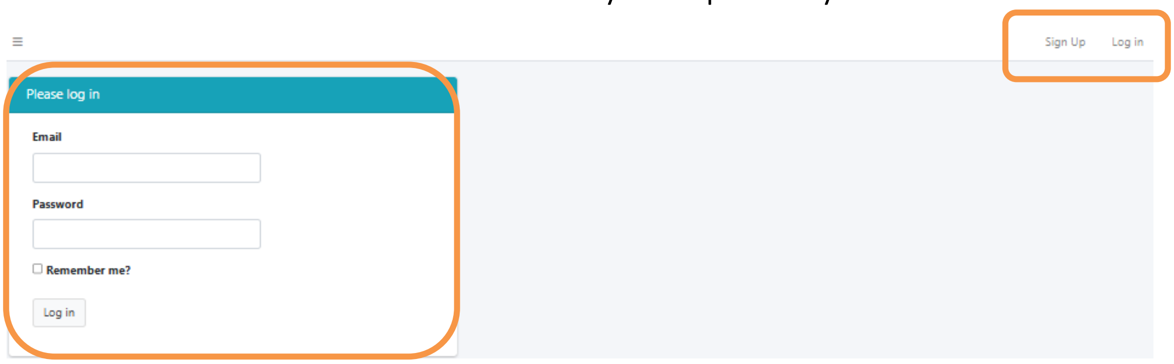
STEP 1: Create a user account and log in

1. Go to https://gis.sea.ee/bluebiosites/ and select NEAT.



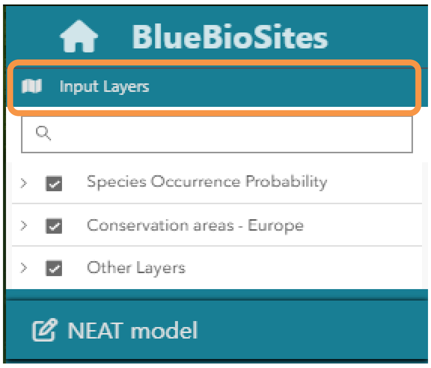
Click “Register” (new users) or “Log in” (existing users).

NOTE: For new users the confirmation email may take up to 2 days.



STEP 2: Verify the suitability of species probability of occurrence maps

Before running an analysis, users should review the species’ probability-of-occurrence maps in the “**Input Layers**” section to ensure that the underlying distribution patterns are reasonable for the area of interest. Depending on the region, three pathways are available:



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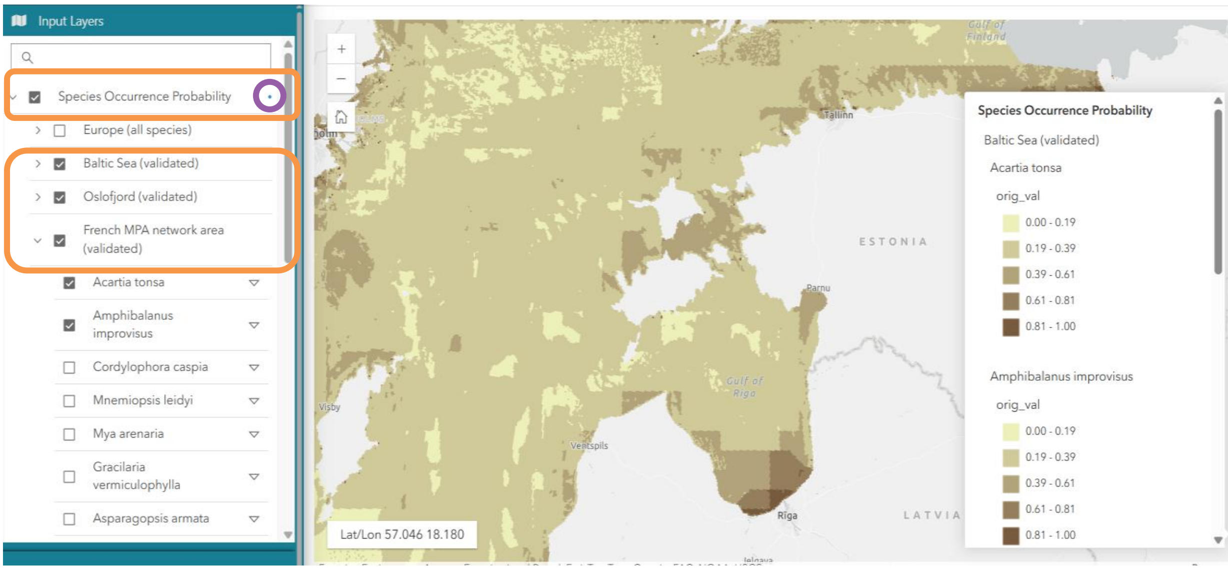
Option A: Expert-validated areas:

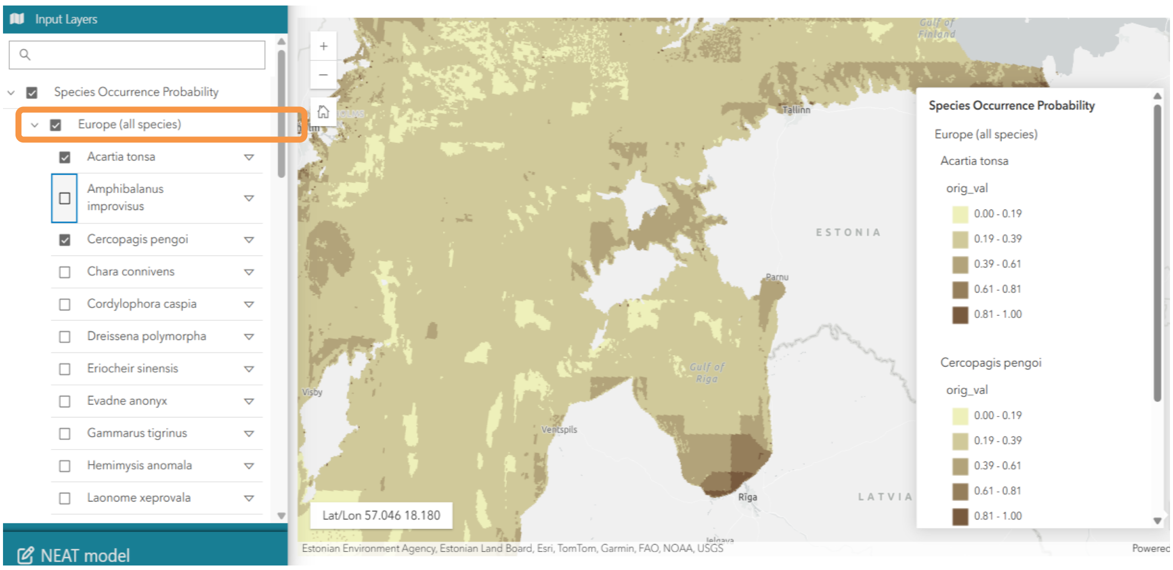
If the area of interest falls within regions where input layers have been validated using local expert knowledge (currently the French Natura 2000 MPA network area, the Oslofjord, and the Baltic Sea), users can proceed with the existing layers. The probability of occurrence maps for each species can be viewed in the "Species occurrence probability" layer within the Input Layers section. **"(Validated)"** indicates that the species occurrence probability maps have been validated for the specific area by local expert knowledge. The maps can also be checked when selecting species for the NEAT model (STEP 5).



NOTE: A small blue dot (purple circle) indicates that the selected layer is still loading.

Option B: Areas covered by existing maps but not yet locally validated

If the area is included in existing distribution layers (dropdown list "Europe (all species)) but lacks local validation, users should verify the maps for the selected species in consultation with relevant experts (e.g., scientists with local expertise, national monitoring specialists, taxonomic experts).



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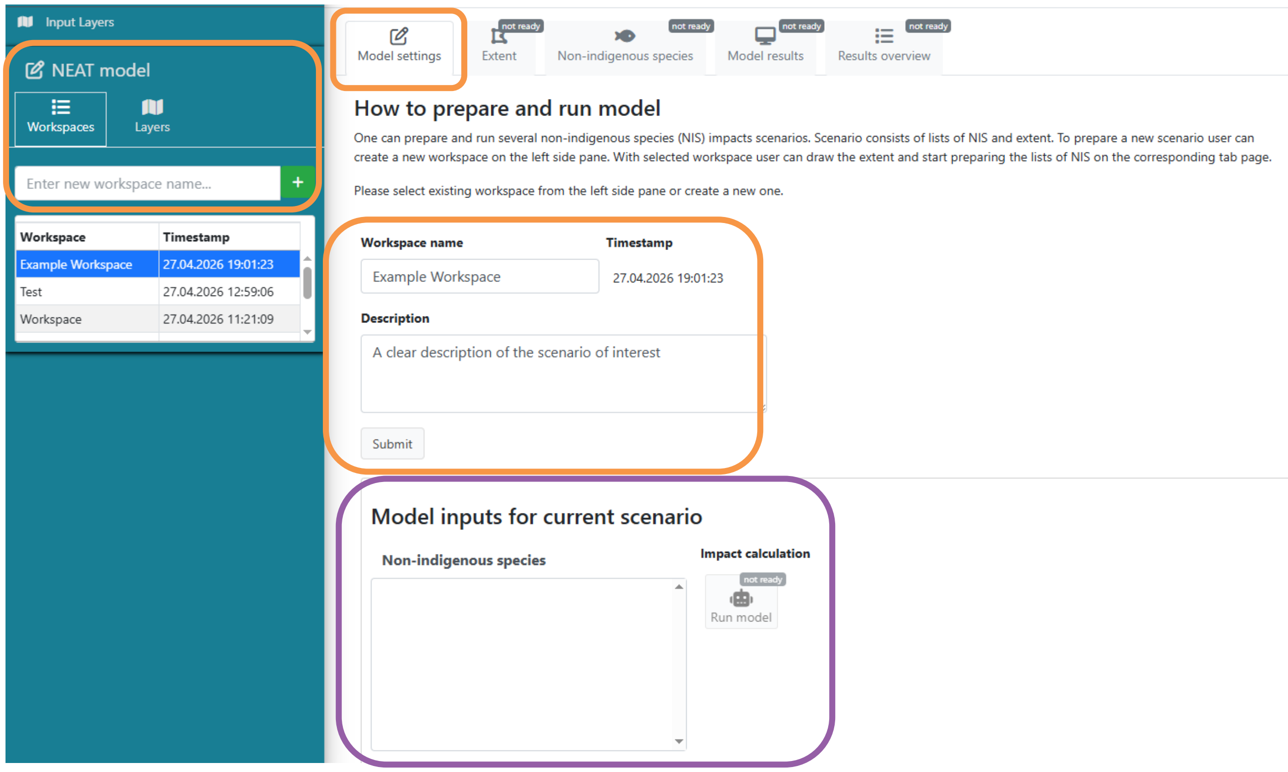
Option C: Areas not covered by existing maps
If the area is not covered by current distribution layers, users should contact NEAT user support (bluebiosites@ut.ee) and provide new spatially gridded input data for integration. Where suitable maps are unavailable, new modelling will be required.

STEP 3: Create a new workspace in the "NEAT model" section

To prepare a new scenario, users can create a workspace using the left-side panel by clicking the **"+"** icon. Users can either:

1) Name the workspace in advance by entering a name before clicking "+", or
2) Click the green "+", then provide a name and description, and select "Submit" to save

NOTE: After running the model and getting the results, an overview of the non-indigenous species used in that workspace will be available in the "Model inputs for current scenario" tab.



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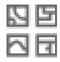
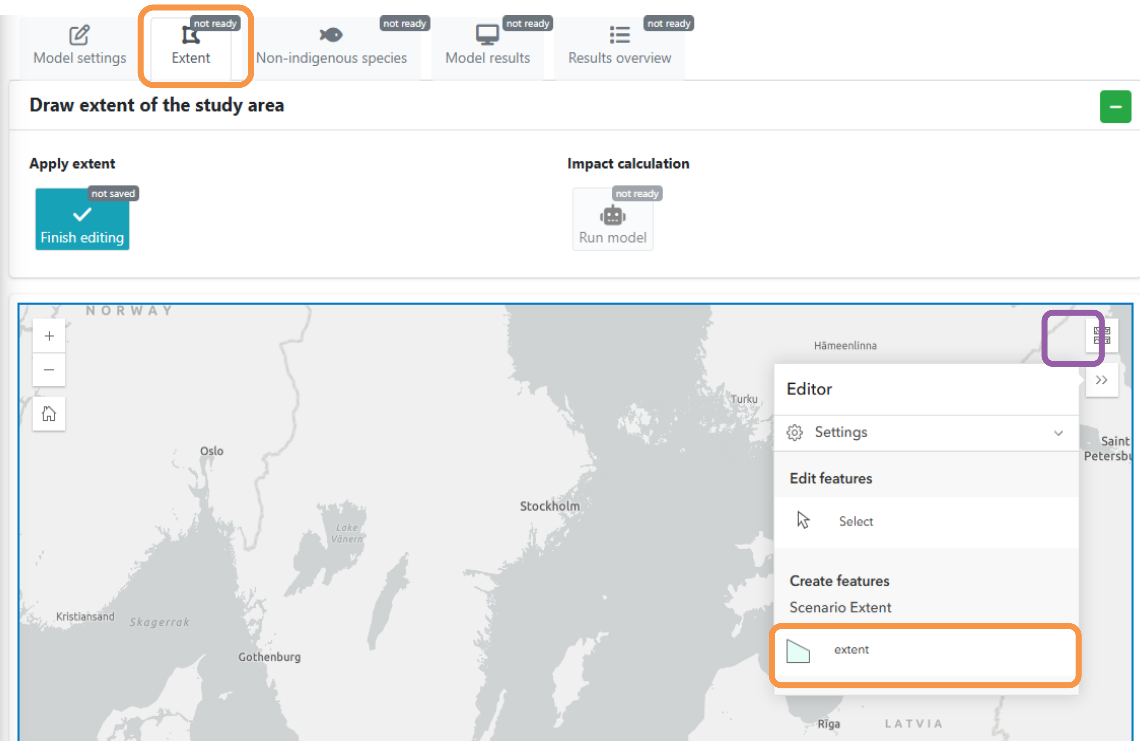
STEP 4: Define the extent of analysis

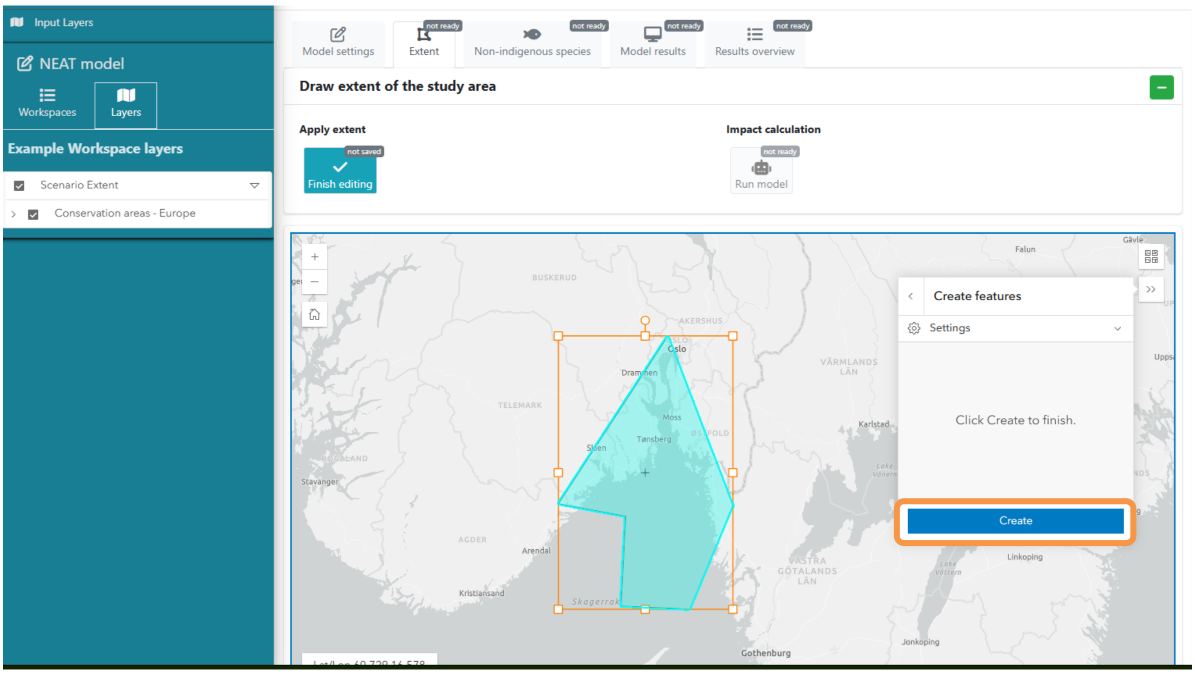
To run the model for a specific study area, define the extent in the "**Extent**" tab.

NOTE: The map style can be changed using the button in the top-right corner. 

1) Select "extent" under the "Create features" in the editor box.



2) Click on the map to begin drawing; double-click to complete the extent. The defined area can then be resized or repositioned as needed. Once done, click "Create".



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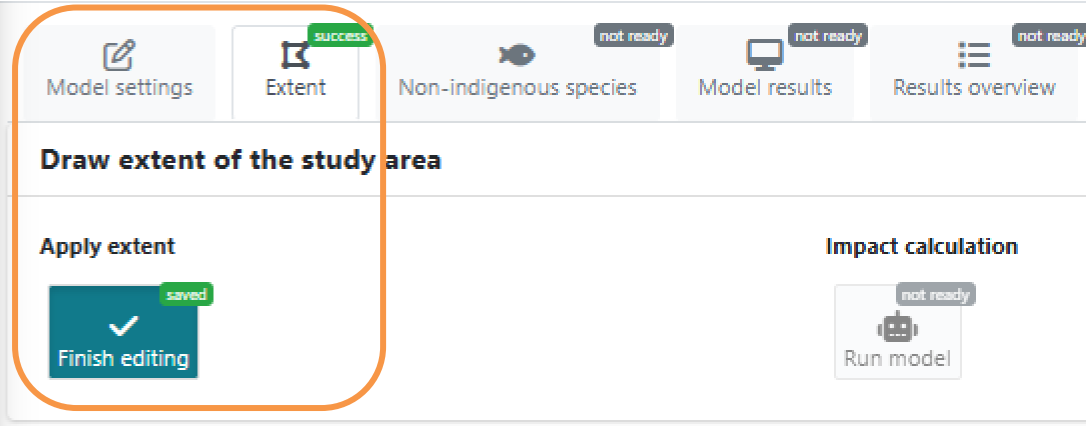
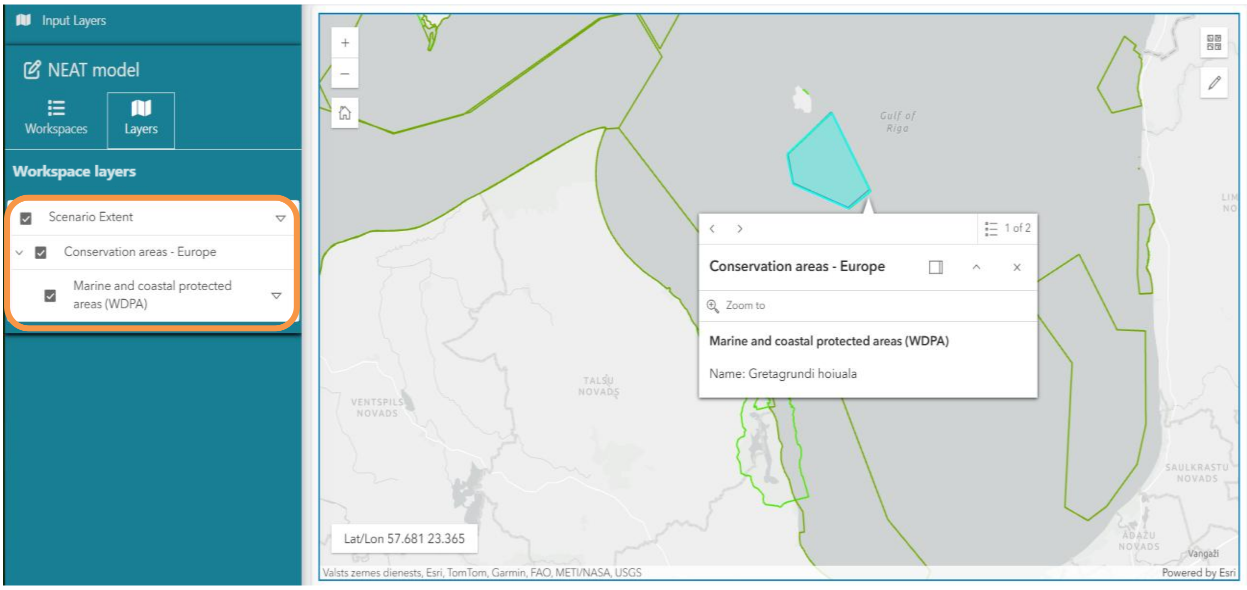
3) Click "Finish editing". A green "success" indicator will confirm completion in "**Extent**" tab.



Optional: To align the extent with conservation areas (e.g., MPAs), enable "Marine and coastal protected areas (WDPA)" (areas will be displayed in green) and follow their boundaries when drawing. This allows analysis within a specific conservation area and supports viewing corresponding values in the results table.

NB! You can also draw multiple extents, to assess potential effects within a MPA network.



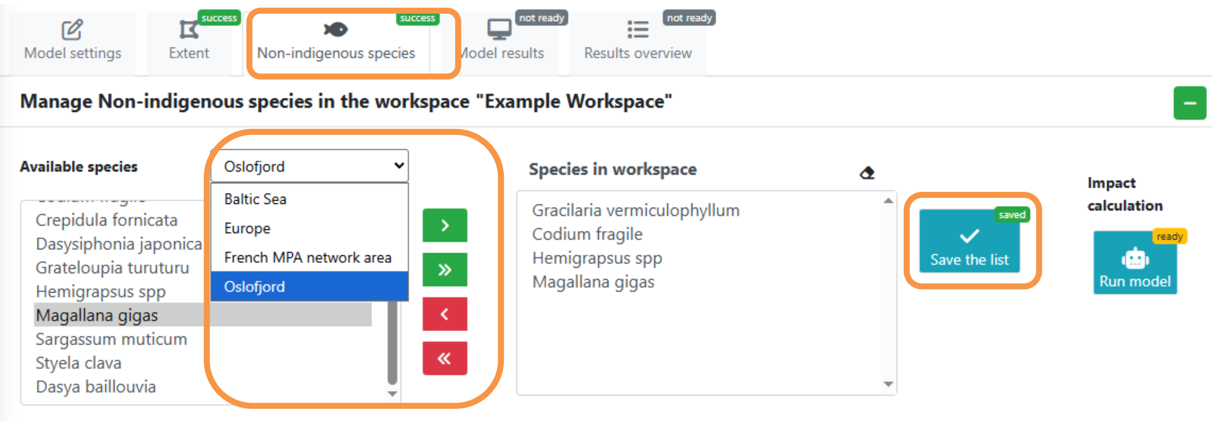
STEP 5: Species selection

In the “**Non-indigenous species**” tab, users define the scenario by selecting species relevant to the area of interest. Selection should be guided by local knowledge or monitoring data where available to ensure the scenario reflects current conditions and likely risks. If such information is unavailable, users may:

1. Select all species for a precautionary screening overview
2. Consult local experts (e.g., scientists with local expertise, national monitoring specialists, taxonomic experts) to define an appropriate subset

Managing the list of species:

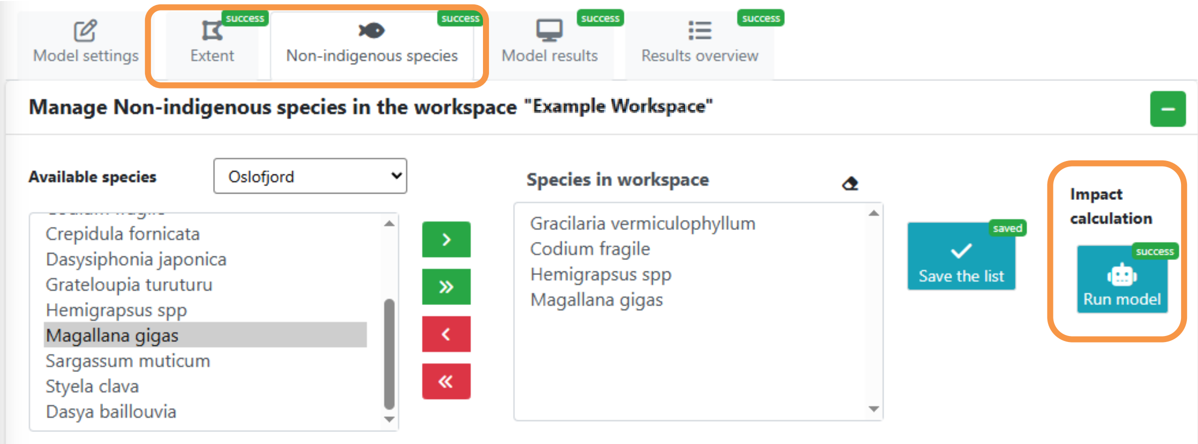
- “Europe” species list contains all species, while Baltic Sea, French MPA network area, and Oslofjord lists contain only the species whose maps have been validated using local expert knowledge.
- Use single arrows to add (green) or remove (red) individual species. Use double arrows to add or remove all species.
- After selection, click “Save the List”. A green “success” indicator confirms completion.



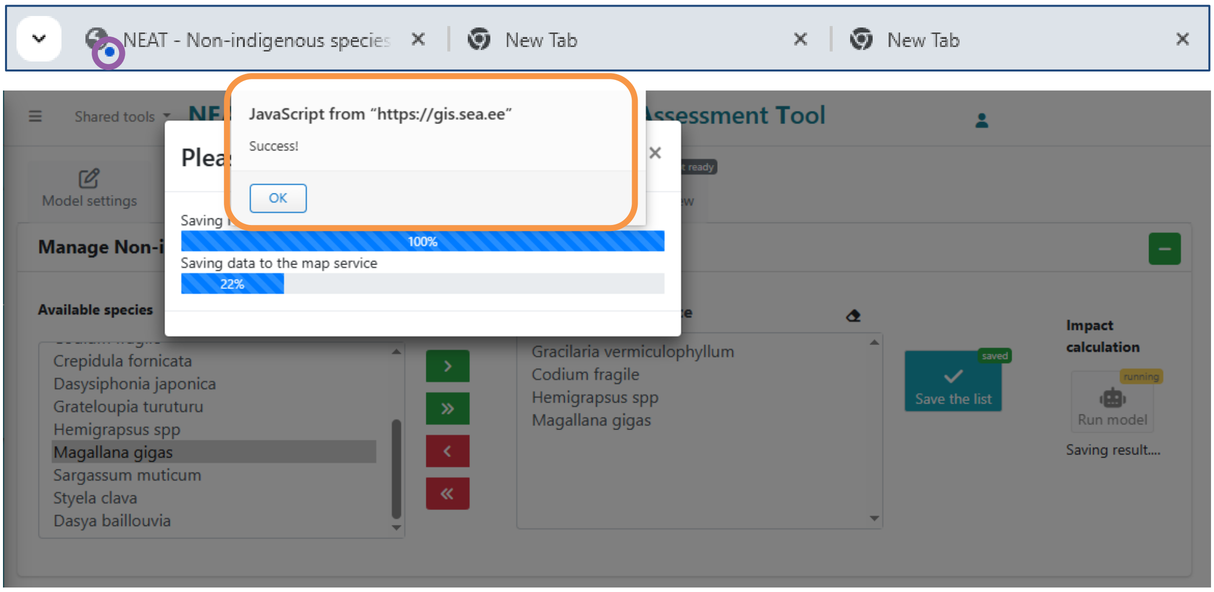
NOTE: High-resolution maps (50m x 50m) are only available for Oslofjord area, other areas maps are at 1 km^2 resolution.

STEP 6: Run the model

Once both the "**Extent**" and "**Non-indigenous species**" tabs display a green "success" indicator, click "Run model" to start the effects calculation.



NOTE: Processing time depends on the number of selected species and the size of the analysis extent, ranging from a few minutes to an hour or more. Once the model has finished running, a blue dot will appear in the browser tab along with "Success!" on the website



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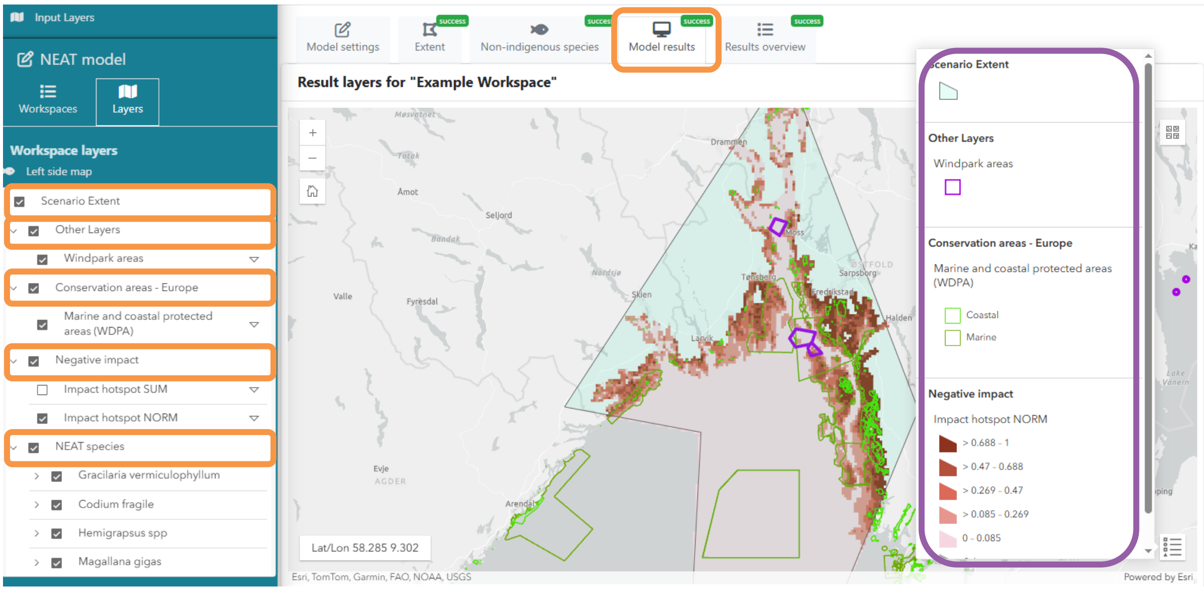
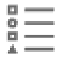
RESULTS

The tool generates potential effect maps and a summary table for the selected extent. The results can also be overlaid with conservation areas and wind park development areas to support interpretation.

Spatially explicit outputs

Under the "**Model results**" tab, results are presented as interactive spatial maps for interpreting both species-specific effects and cumulative impacts. All layers and controls are accessible via the left-side panel, where users can explore the results maps and additional layers, by adjusting visibility and each layer's opacity (i.e., visual transparency).



NOTE: Open the **legend** by expanding the bottom right corner button. 

Scenario Extent: Displays the extent chosen for the scenario and where the calculations are made.

Conservation areas – Europe: Displays marine and coastal protected areas in Europe from the World Database on Protected Areas (WDPA). The WDPA is updated monthly, and updates are automatically reflected in the NEAT tool: https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA

NEAT species: Potential effect maps for each NIS, including both mean potential effect and associated uncertainty, indicating where individual NIS are most likely to exert stronger ecological effects within the study area.

Negative impact: Additive negative impact for all species included in the scenario, indicating potential negative impact hotspots of NIS. Both total sum and normalized (0–1) values are available. While each species effect size is evaluated from -3 (strong negative) to +3 (strong

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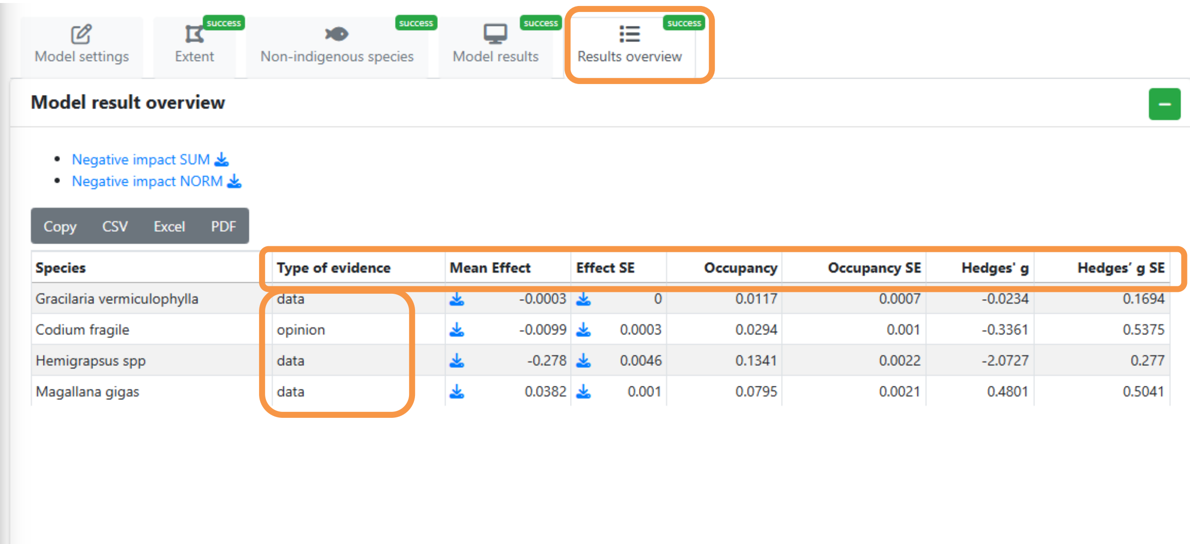
positive effect), the total sum value should be considered with caution, as the potential negative effects of different NIS could be related to not spatially overlapping nature values.

Other Layers: Areas of interest (e.g., wind park areas), that could be overlapped with model results to evaluate potential effects withing a specific area.

Tabular outputs

NEAT provides a results overview table for the selected NIS and analysis extent, available in the "**Results overview**" tab. For each species in the chosen extent, the table reports:

- Average potential effect and associated effect uncertainty
- Average probability of occurrence and associated occurrence uncertainty
- Effect-size values used in model calculations
- Source of effect estimates ("data" for scientific literature-based, "opinion" for expert-based assessment)



Species	Type of evidence	Mean Effect	Effect SE	Occupancy	Occupancy SE	Hedges' g	Hedges' g SE
Gracilaria vermiculophylla	data	-0.0003	0	0.0117	0.0007	-0.0234	0.1694
Codium fragile	opinion	-0.0099	0.0003	0.0294	0.001	-0.3361	0.5375
Hemigrapsus spp	data	-0.278	0.0046	0.1341	0.0022	-2.0727	0.277
Magallana gigas	data	0.0382	0.001	0.0795	0.0021	0.4801	0.5041

Download: Results can be downloaded as tables (.csv, .xlsx, .pdf) and maps, by clicking on the blue icons (GeoTIFFs compatible with GIS software such as ArcGIS or QGIS)

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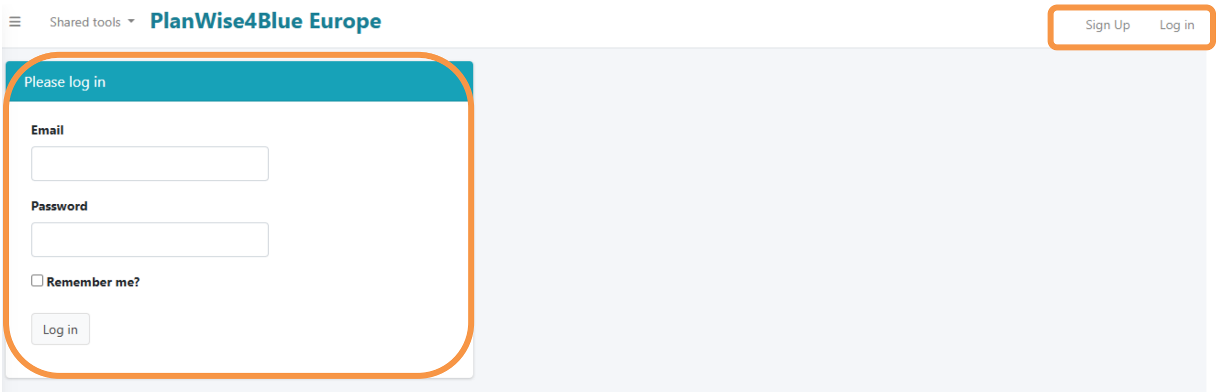
Annex E. PlanWise4Blue step-by-step guide

STEP 1: Create a user account and log in

Go to https://gis.sea.ee/bluebiosites/ and select PlanWise4Blue Europe.

Click “Register” (new users) or “Log in” (existing users).

NOTE: For new users the confirmation email may take up to 2 days.

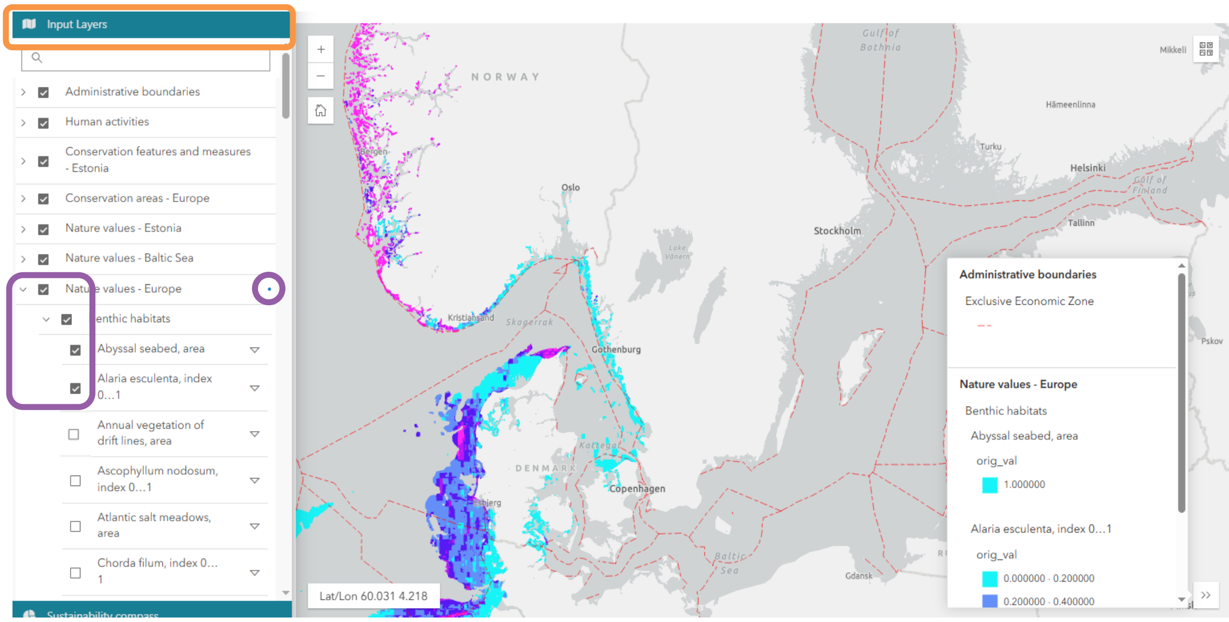


STEP 2: Verify the suitability of nature values and human activities maps

Check the availability of suitable data for nature values and human activities and pressures. To ease the process of identifying the data layers needed for the Cumulative impact assessment (CIA).

Option A: The suitable data layers for nature values and human activities and pressures are already incorporated into the tool. Assess their availability and suitability for your area from the "**Input Layers**".

Option B: Locate the missing suitable layers for your area and contact user support (bluebiosites@ut.ee) to integrate the layers into the tool.



NOTE: A small blue dot (purple circle) indicates that the selected layer is still loading. The blue dot can also appear on your browser tab, after the model calculations are complete.

NOTE: Selecting a category (e.g. *Nature values - Europe*) does not automatically display its contents on the map.

To view specific data:

1) Click the arrow next to the category to expand it. >
2) Review the list of available layers.
3) Select the individual layers to display them on the map.

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NOTE: The map style can be changed using the button in the top-right corner.

NOTE: The legend can be opened using the button in the bottom-right corner.

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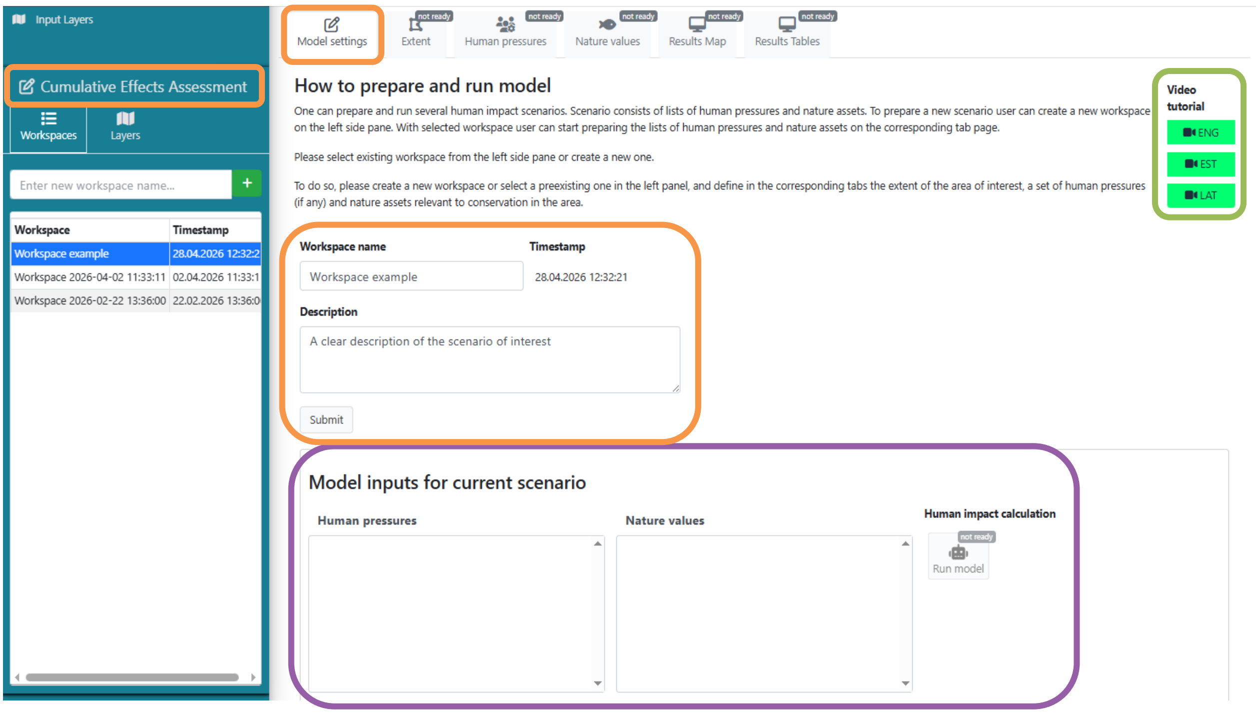
STEP 3: Create a new workspace in the “Cumulative Effects Assessment” section

To prepare a new scenario, users can create a workspace using the left-side panel by clicking the **“+”** icon. Users can either:

3) Name the workspace in advance by entering a name before clicking “+”, or
4) Click the green “+”, then provide a name and description, and select “Submit” to save.

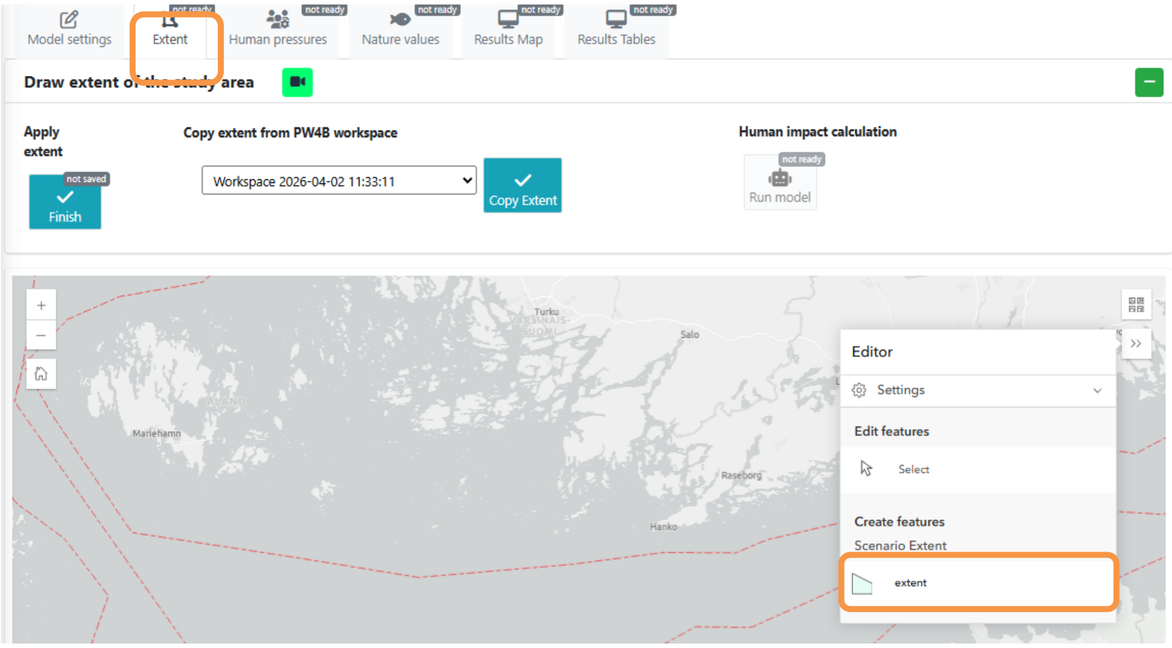
NOTE: Tutorial videos are available for each step to assist the process.



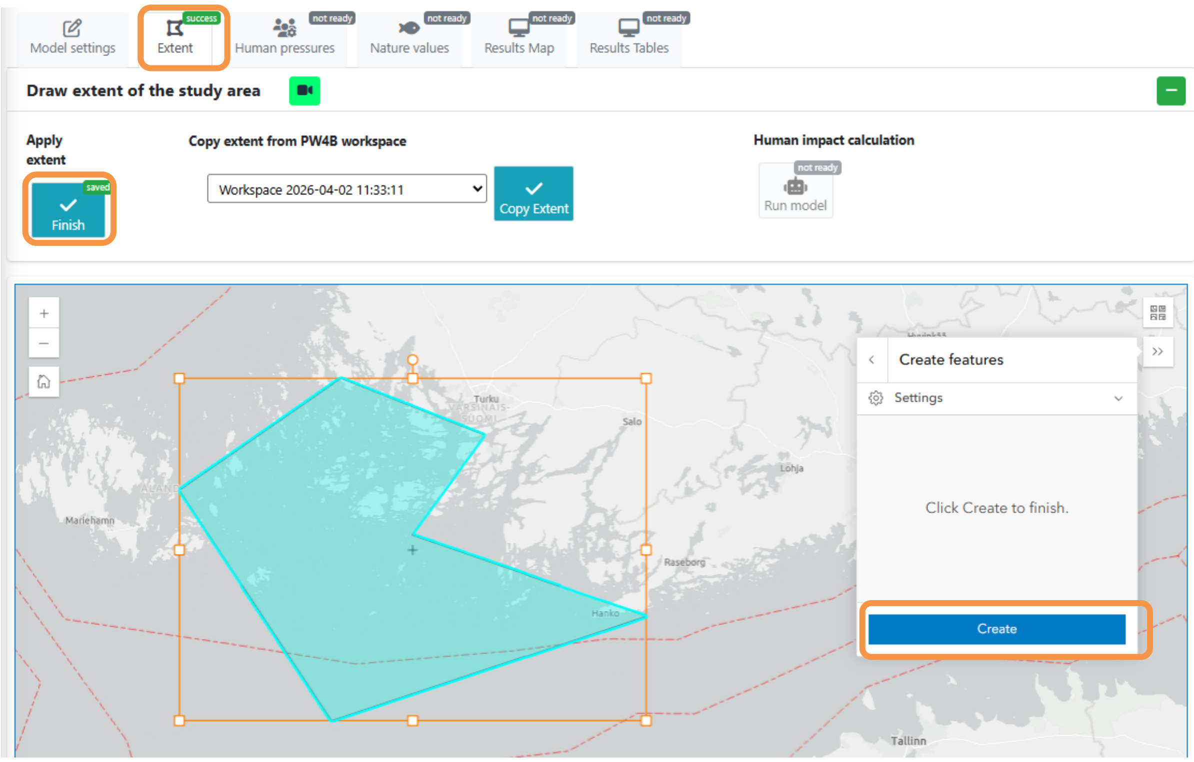
NOTE: After running the model, an overview of the “Human pressures” and “Nature values” used in the workspace is available in the “Model inputs for current scenario” tab.

STEP 4: Define the extent of the scenario

4) To run the model, you must define a specific area of interest. The model calculations will be performed within the selected study area. Define this area in the **"Extent"** tab. Select "extent" under the "Create features" in the editor box.



5) Click on the map to begin drawing; double-click to complete the extent. The defined area can then be resized or repositioned as needed. Once done, click "Create" and "Finish". A green "success" indicator will confirm completion in "**Extent**" tab.



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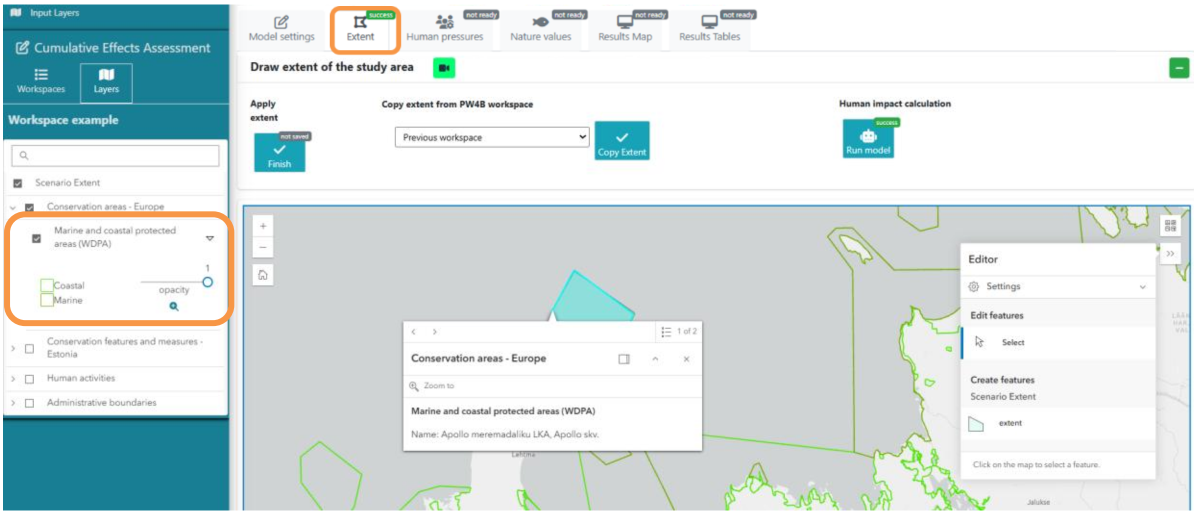
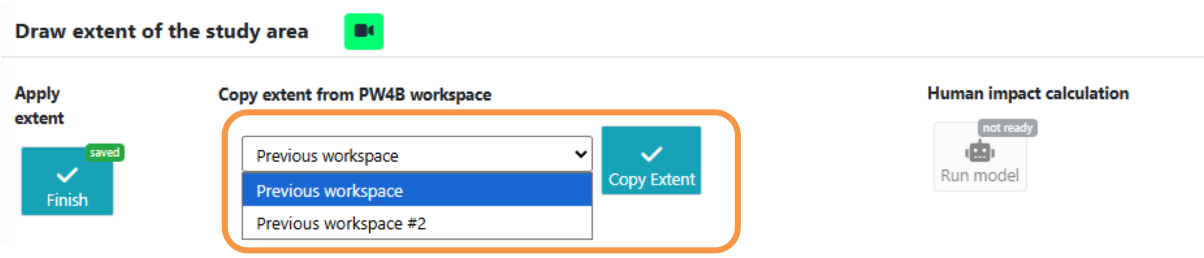
MPA boundary option: When drawing the extent, display the MPAs in the background. This allows the user to run the model for specific MPAs and view the calculated values in the table if needed. To do that, enable the “Marine and coastal protected areas (WDPA)” and follow their boundaries. Then “Create” and “Finish editing” as before.



“Copy Extent” option: The Copy Extent function allows the users to reuse of a previously defined study area from another workspace, avoiding the need to redraw it. This is useful for comparing multiple scenarios covering the same geographic extent.



Steps

1) Select a workspace from the dropdown list.
2) Click “Copy Extent” and wait for the process to complete.
3) The study area will automatically appear on the map.
4) Click “Finish” to apply and save the extent.

Important notes

- The selected workspace must already contain a defined extent.
- The copied extent replaces any existing drawn area.
- The function will not work if no workspace is selected.
- The extent is only saved after clicking “Finish”.

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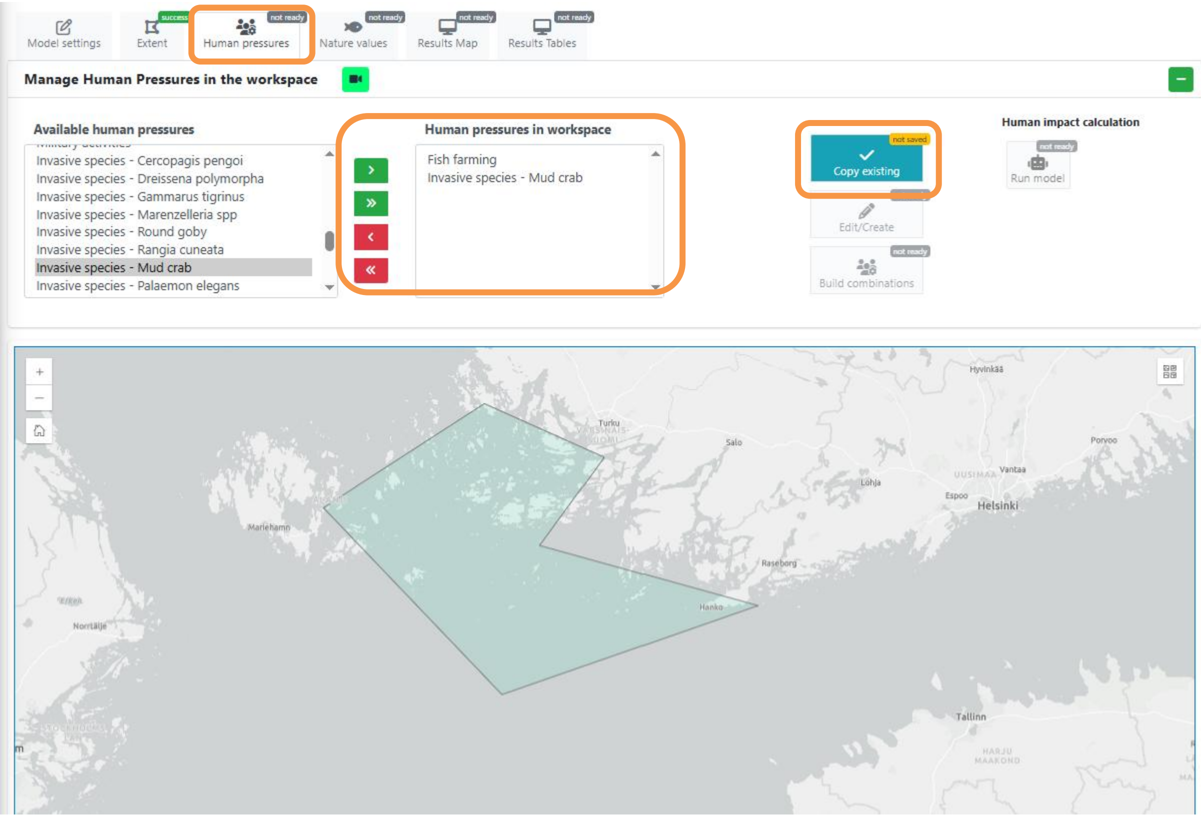
STEP 5: Select and edit Human Pressures

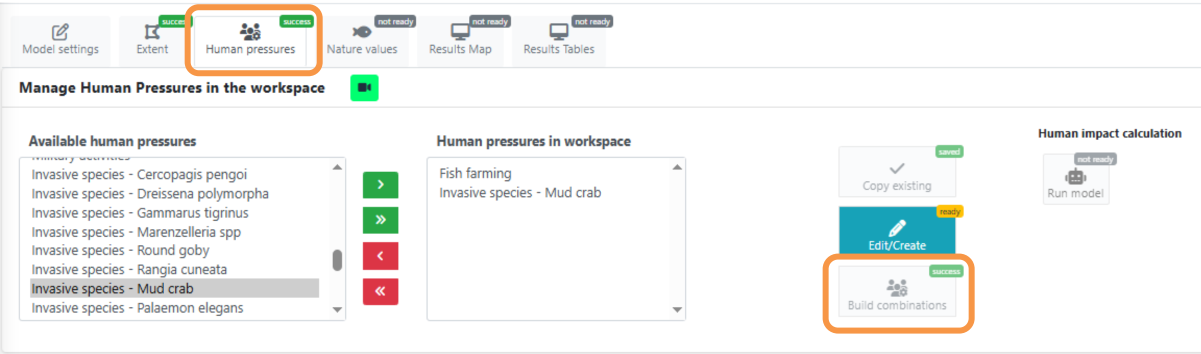
This step defines which human activities and pressures will be included in the assessment.

1) Select human activities and pressures:
    - Use single arrows to add (green) or remove (red) individual items.
    - Use double arrows to add or remove all items.



2) Prepare the selection:
    - Click "Copy existing" once done with selections.
    - Click "Build combinations" to finish.

A notification "Combinations successfully built!" confirms completion and the "Human pressures" tab and "Build combinations" button will display a green "Success" label.



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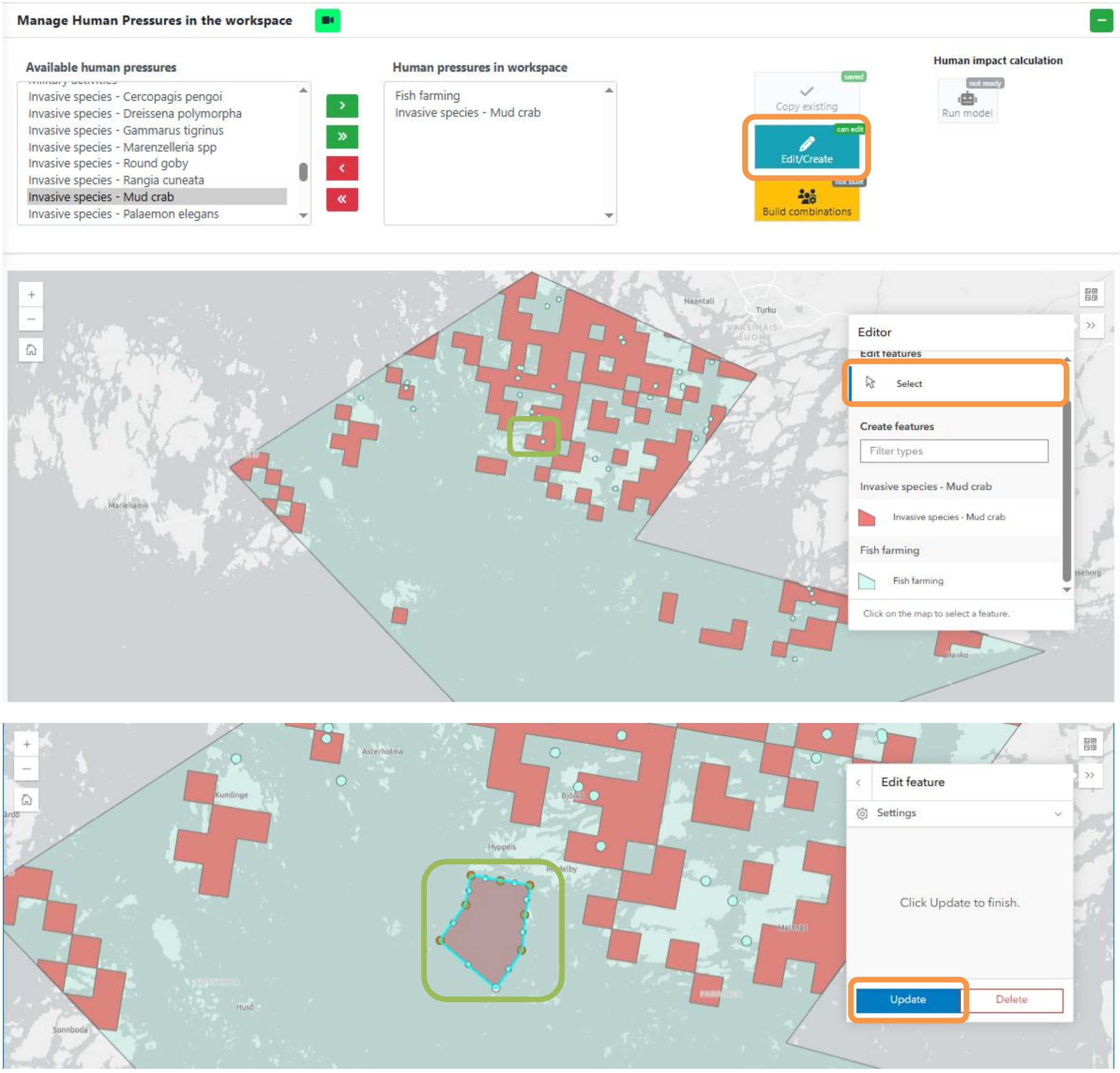
Optional scenario building*:* The tool allows modification of activity extent to reflect changes in the activity extent and new developments.

1) Click “Edit/Create”.
2) Click “Select” to choose the area to modify.
3) Adjust the extent and click “Update”.
4) Click “Build Combinations” to apply the changes.



NOTE: If the extent is modified after the model has already been run, click “Copy existing” again, even if a green “Success” label is displayed.

Adjusting human activity intensity: By clicking on the human pressure layer, the users can adjust the overall intensity of the pressure via the “Intensity” tab. This enables scenario testing without modifying the underlying spatial distribution.

- A value of **1** represents the current (baseline) intensity.
- Values **< 1** indicate a decrease (e.g., **0.5** = 50% of current intensity).

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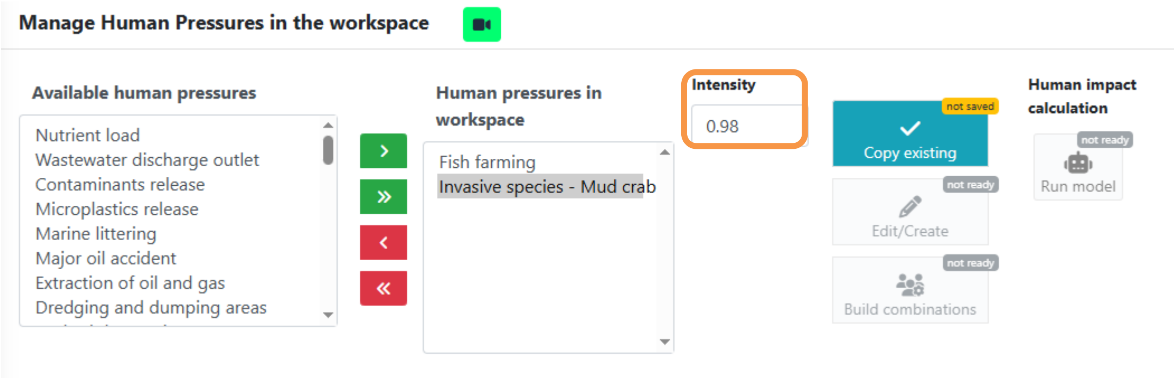
- Values **> 1** indicate an increase (e.g., **1.2** = 20% higher intensity).

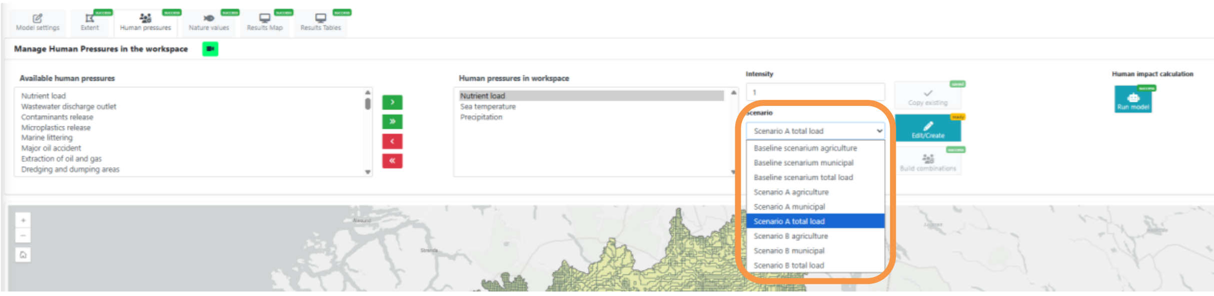
This feature supports rapid assessment of scenarios such as increased shipping traffic or reduced fishing pressure.



Selecting predefined activity scenarios

In some regions, multiple pre-calculated human activity scenarios may be available. These can be selected directly in the **"Human Pressures"** tab under "Scenario" for use in the analysis. These datasets are predefined and cannot be uploaded arbitrarily by users. In the future, users may also be able to upload such maps themselves.

NOTE: Where multiple maps exist for a single human pressure, users can select the appropriate scenarios and contact BlueBioSites to have the required datasets prepared and made available for them to look over.



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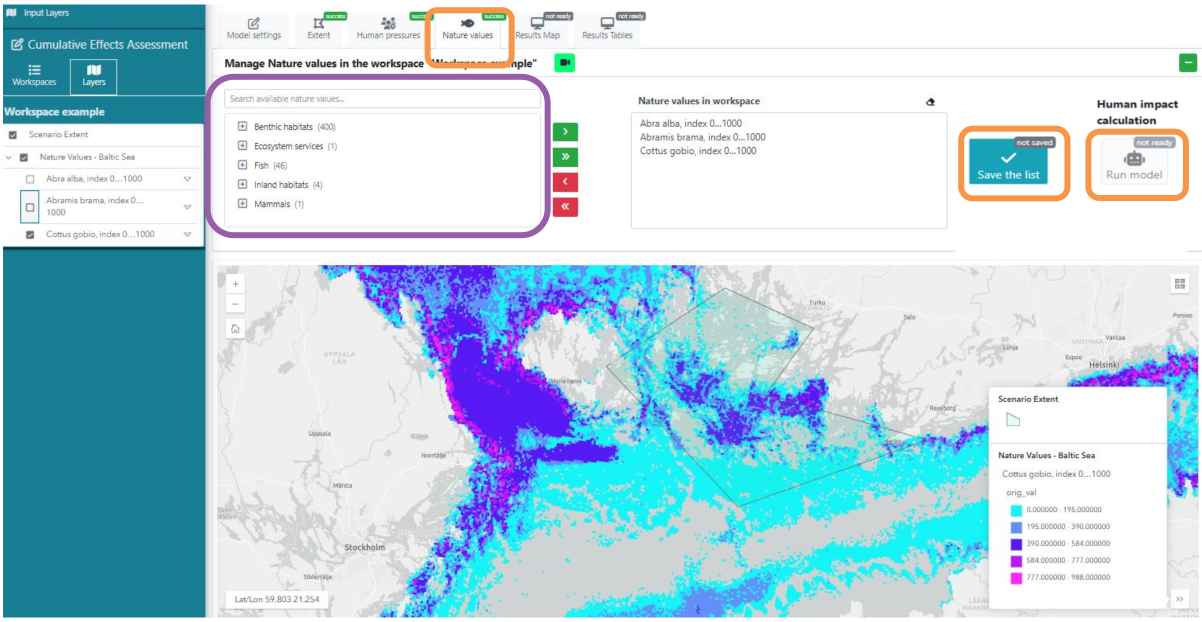
STEP 6: Select nature values & calculate model

In the “Nature values” tab, users select the environmental features to be assessed.

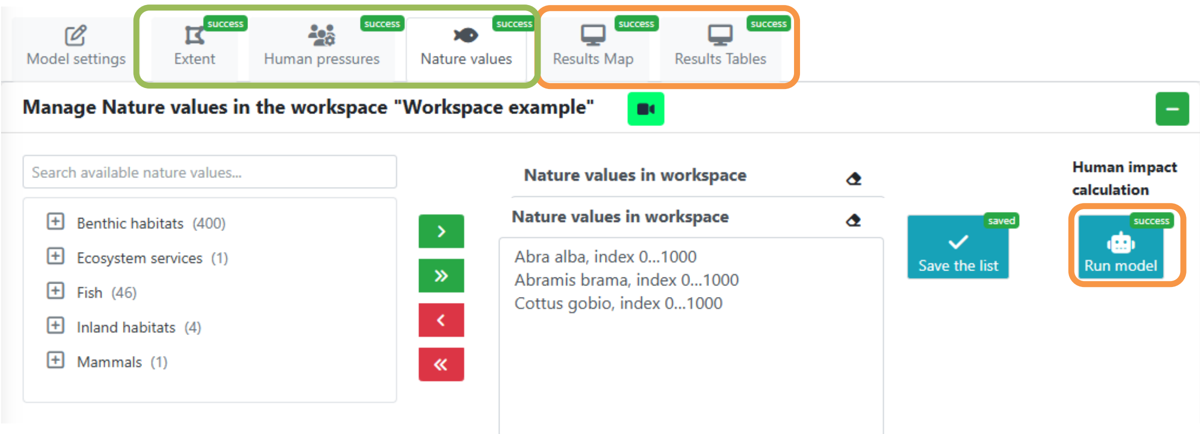
NOTE: Displayed nature values are specific to the selected extent. Users can select values different categories. Multiple values can be selected, and the assessment will be conducted separately for each. A search bar is also available to quickly locate specific items.



Steps

1) Review and select available nature values:
    - Single arrows to add (green) or remove (red) individual values.
    - Double arrows to add or remove all values.
2) Click “Save the List”.
3) Click “Run model” to start the analysis.

NOTE: Before running the model, ensure that all tabs have a green label “success”. The model calculation time is dependent on the size of the extent and number of nature assets and human pressures chosen, approximately 1 to 15min. Once the model has finished running, a blue dot will appear in the browser tab along with “Success!” on the website.



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RESULTS:

Under the “Results Map” tab, the tool provides spatial maps for interpreting:

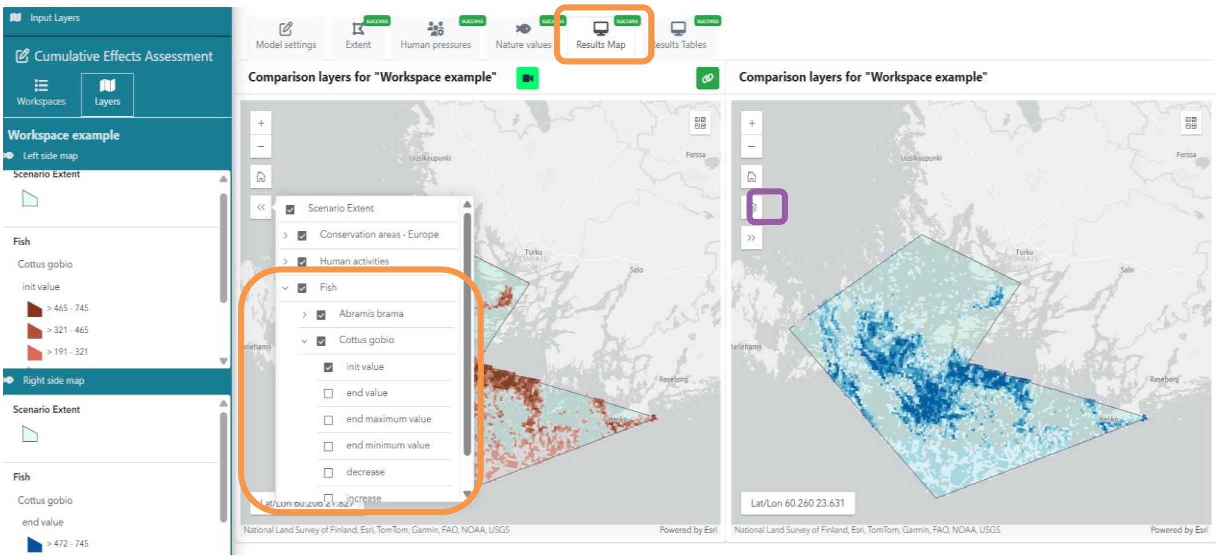
init value	Original nature value (species, habitat, or ecosystem service occurrence or biomass) size
end value	Expected nature value size under the cumulative effects of selected human activities and pressures
end maximum value	Expected maximum (upper CI) nature value size under the cumulative effects of selected human activities and pressures
end minimum value	Expected minimum (lower CI) nature value size under the cumulative effects of selected human activities and pressures
decrease	Expected decrease in nature value due to human activities
increase	Expected increase in nature value due to human activities

These maps can be overlaid with **MPA boundaries** to support interpretation in a management context.

NOTE: The model is applied **only within the selected extent**; areas outside display initial values. Results should therefore be interpreted within the defined study area boundaries. In some areas, data on natural values or human activities may be missing. In such cases, impacts cannot be calculated for those pixels. The proportion of the extent lacking data is reported in the summary table (see “Results tables”).

Map display and comparison

- Two maps are shown side by side for comparison
- Select any options to see how the area is affected
- Each map has its own **legend**, accessible via the panel controls
- Layer colours can be adjusted using the available controls



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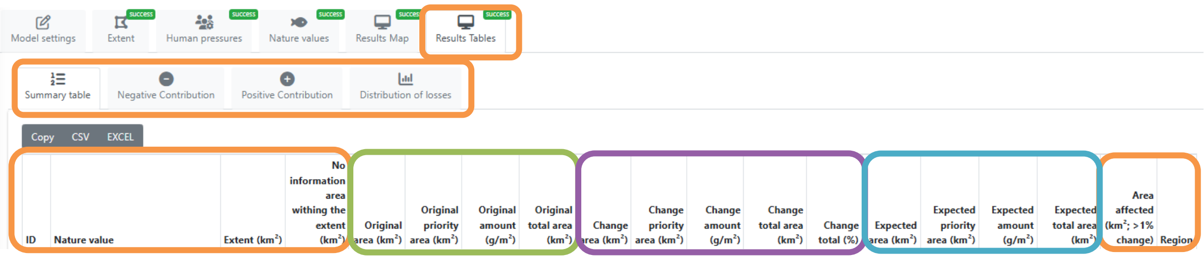
Under the **“Results Tables”** tab, outputs are also available in tabular format, with download options (.csv, .xlsx). The tabs include:

Summary Table



- ID – nature value ID within the tool
- Nature value – species, habitat, or ecosystem service
- Extent – total extent investigated (based on user input).
- No information area – Area within the selected extent lacking data for the given nature value.
- Original area – Area covered by the nature value. In case of probability of occurrence of the nature value, the standardized input layers are rounded to two decimals and values below 0.005 are considered as no nature value.
- Original priority area – Area where values exceed a defined threshold, representing the high-value or high-quality portion of each nature asset. For probability of occurrence, the threshold is set at 0.5.
- Original amount – Total biomass or abundance within the selected extent (only for quantitative layers; otherwise not applicable).
- Change area – Change in the area covered by the nature value due to human activities and pressures.
- Change priority area – Change in the priority area size, where nature values exceed a defined threshold, considering the cumulative effects of human activities and pressures.
- Change amount – Change in the total biomass or abundance within the selected extent (only for quantitative layers; otherwise not applicable) due to human activities and pressures
- Expected area – Expected area size of the are covered by the nature value, considering the cumulative effects of human activities and pressures.
- Expected priority area – Expected area size of the nature value, that exceed a defined threshold, representing the high-value or high-quality portion of the nature value, considering the cumulative effects of human activities and pressures.
- Expected amount – Expected total biomass or abundance of the nature value within the selected extent (only for quantitative layers; otherwise not applicable), considering the cumulative effects of human activities and pressures.

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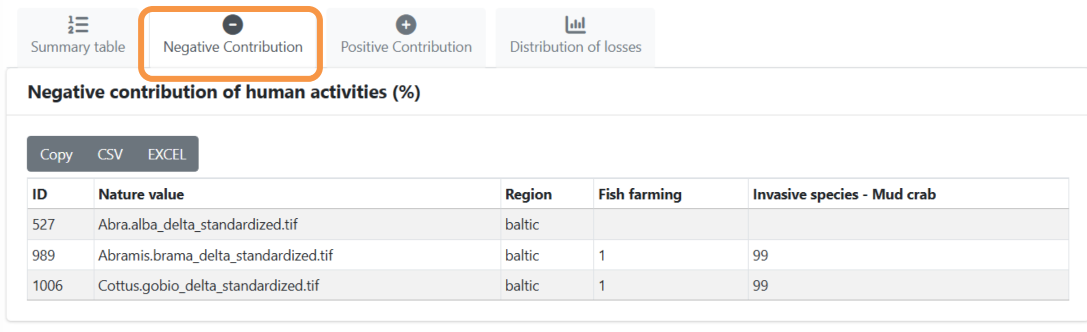
- **Area affected** – Area showing more than 1% change due to the cumulative effects of human activities and pressures. This metric indicates how much of the total nature value area is influenced by human activities, supporting assessment of overall spatial impact.
- **Region** – Geographic area or spatial unit used for aggregation or reporting of results.

Negative contribution

The Negative contribution tab shows the table of expected decrease in the nature value due to human activities. It quantifies how much each human activity contributes (%) to the observed negative change and helps identify which pressures are driving declines in species, habitats, or ecosystem services. Overall, this table supports interpretation of how different human uses contribute to decreased changes and helps prioritise management actions.

NOTE: If only ID, Nature value, and Region are displayed (with no additional metrics), this indicates that no effect has been found for that entry.

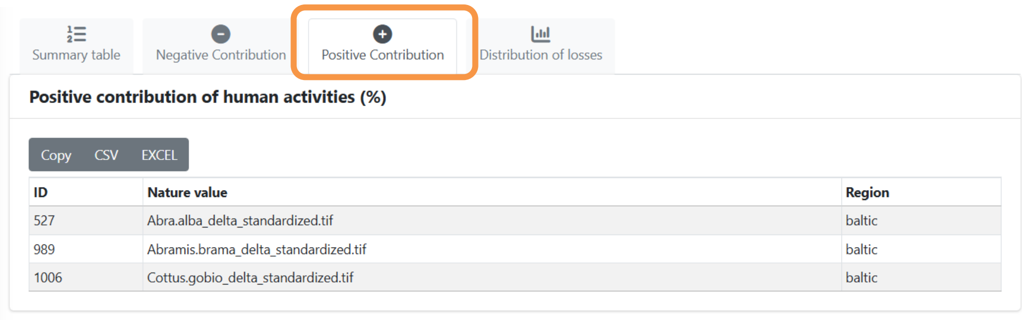


ID	Nature value	Region	Fish farming	Invasive species - Mud crab
527	Abra.alba_delta_standardized.tif	baltic		
989	Abramis.brama_delta_standardized.tif	baltic	1	99
1006	Cottus.gobio_delta_standardized.tif	baltic	1	99

Positive contribution

The Positive contribution tab shows the table of expected increases in nature value due to human activities. It quantifies how much each human activity contributes (%) to the observed positive change and helps identify which pressures are associated with improvements in species, habitats, or ecosystem services. Overall, this table supports interpretation of how different human uses contribute to increased changes and helps inform management and planning decisions.

NOTE: If only ID, Nature value, and Region are displayed (with no additional metrics), this indicates that no effect has been found for that entry.



ID	Nature value	Region
527	Abra.alba_delta_standardized.tif	baltic
989	Abramis.brama_delta_standardized.tif	baltic
1006	Cottus.gobio_delta_standardized.tif	baltic

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Distribution of losses

The “Distribution of losses” table presents a histogram for each nature value, showing the number of pixels across different magnitudes of change. This provides an overview of both the **extent** and **intensity** of losses or increases under the selected scenario.