Interreg
Baltic Sea Region

Co-funded by
the European Union

PROJECT PLATFORMS
SEABAS

Methodological framework for the effective implementation of CIA in Baltic Sea MSP processes

1.3

June 2026

This document is developed within the SEABAS project platform to provide practical step-by-step guidance for integrating cumulative impact assessment (CIA) into strategic environmental assessment (SEA) and maritime spatial planning (MSP) processes in the Baltic Sea region.

SEABAS, Strategic ecosystem-based planning for a sustainable future of the Baltic Sea, is a project platform co-funded by the Interreg Baltic Sea Region Programme.

Deliverable Title	Methodological framework for the effective implementation of CIA in Baltic Sea MSP processes
Deliverable Number	WP 1, 1.3
Activity Lead	UTARTU
Author(s)	Francisco R. Barboza (UTARTU), Janica Borg (HELCOM), Kristīna Veidemane (BEF-Latvia), Jacek Zaucha (GMU), Laura Pietilä (FI RCSW), Toms Skadiņš (MSARDL), Philipp Arndt (BSH), Aino Ahvo (HELCOM), Joanna Pardus (GMU), Mariliis Nurkse (UTARTU), Mihkel Kotta (UTARTU), Kristiina Nurkse (UTARTU)
Deliverable Due Date	30/06/2026
Actual Delivery Date	30/06/2026
Document Format	Guidance document
Dissemination Level	Public

Please cite this deliverable as:
Barboza F.R., Borg, J., Veidemane, K., Zaucha, J., Pietilä, L., Skadiņš, T., Arndt, P., Ahvo, A., Pardus, J., Nurkse, M., Kotta, M., Nurkse K. (2026) Methodological framework for the effective implementation of CIA in Baltic Sea MSP processes. Deliverable – D1.3 under the WP1 of the SEABAS project (GA n° #P006).

Update of the document

Date	Ver.	Contributors	Comment
20.04.2026	1	Francisco R. Barboza, Kristiina Nurkse	Initial draft
02.06.2026	2	SEABAS partnership	Revised version incorporating comments received during the 2026 SEABAS General Assembly in Tallinn.
30.06.2026	3	SEABAS partnership	Final deliverable for submission

Table of Contents

List of figures and tables 2

1. Executive summary 3

2. Introduction 4

3. Framework 7

3.1 General set-up of the framework for incorporation of CIA to SEA 7

3.2 SEA process 9

3.2.1 Screening phase for SEA 9

3.2.2 Scoping phase for SEA 9

3.2.3 Environmental report 12

3.2.4 Consultation phase 13

3.2.5 Revision and finalisation of the draft MSP and environmental report 14

3.2.6 Decision-making on plan alternatives 14

3.2.7 Information on the adopted plan 15

3.2.8 Monitoring and evaluation of the plan's impact 15

3.3 CIA workflow in the frame of SEA 15

STEP 1: Scoping for CIA 17

STEP 2: Data screening, tool selection, and sensitivity matrix development 28

STEP 3: Preparation of layers for CIA 50

STEP 4: CIA implementation 58

STEP 5: Interpretation of CIA outputs 61

STEP 6: CIA report to inform the environmental report 65

3.4 Data sources overview 67

HELCOM Map and Data Service (MADS) 67

European Marine Observation and Data Network (EMODnet) 69

Copernicus Marine Service 71

Global Fishing Watch 74

ICES data portals 74

Global Biodiversity Information Facility (GBIF) 75

Ocean Biodiversity Information System (OBIS) 75

European Environment Agency (EEA) 76

Marine Regions 76

Copernicus Land Monitoring Service (CLMS) 76

References 78

Annex A. Potential cumulative impact tools for the Baltic Sea, their characteristics and implementation specifics 84

List of figures and tables

Figures

Figure 1. General framework for integrating cumulative impact assessment (CIA) into strategic environmental assessment (SEA) and maritime spatial planning (MSP) processes, developed based on the MSP and SEA Directives and on CIA implementation workflows developed within relevant European and regional projects (see Section 3.1). The MSP process (orange band) provides the overarching planning pathway, from goal setting and plan development to the evaluation and impact assessment of alternatives, plan refinement, adoption, and monitoring. Within this pathway, the SEA process (yellow band) defines the procedural structure, timing, scope, and information needs for the overall environmental assessment of the plan and its alternatives, including the implementation of the CIA. The CIA workflow (light green box) provides the analytical basis for assessing the potential environmental effects of the MSP plan and, where relevant, additional scenarios, also supporting the identification of mitigation measures and the preparation of reporting outputs. The figure further indicates where stakeholder engagement and transboundary consultation may take place. The dashed line represents the pathway for refining the environmental report (ER) and CIA in response to feedback received during the MSP and SEA consultation phase. 8

Figure 2. Six-step workflow for cumulative impact assessment (CIA) implementation within the strategic environmental assessment (SEA) of maritime spatial planning (MSP) planning processes. The figure summarises the main steps and key sub-steps, from scoping and data preparation to CIA implementation, outputs interpretation, and reporting to inform the SEA environmental report (ER). 16

Figure 3. Linkages between human activities and environmental pressures used in HELCOM spatial pressure and impact assessment [27]. Small updates to this figure are foreseen in August 2026..........23

Tables

Table 1. Ecosystem components identified in Table A4.2 of the “HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016-2021”[27]. 17

Table 2. Candidate indicators / characteristics for assessing potential effects on prioritised nature values, based on Annex III of the MSFD as amended by Commission Directive (EU) 2017/845[22]. 26

Table 3. An example of sensitivity score levels, based on Blue Connect Deliverable 3.1 [26]. 48

Table 4. Potential cumulative impact tools for the Baltic Sea, their characteristics and implementation specifics. 84

1. Executive summary

Maritime spatial planning (MSP) is a public, participatory and forward-looking process for analysing and allocating the distribution of human activities across marine space and time, in order to achieve ecological, economic and social objectives. In guiding where sectors such as shipping, fisheries, offshore energy, aquaculture and conservation are allowed, restricted, expanded or prioritised, MSP also influences where environmental pressures concentrate and interact across marine ecosystems. Strategic environmental assessment (SEA) provides the formal process through which the likely environmental effects of MSP plans and their alternatives are evaluated before decisions are adopted. Within this context, cumulative impact assessment (CIA) plays a critical analytical role. It supports understanding of how multiple activities and pressures interact, where they overlap with sensitive nature values and the ecosystem services they provide, and whether competing planning alternatives reduce, redistribute or intensify cumulative impacts. CIA can therefore support more informed decisions on zoning, siting, coexistence, mitigation, trade-offs and monitoring, by clarifying where cumulative pressures are likely to arise and how different planning choices may reduce or redistribute them. By making cumulative effects more visible and comparable, it also strengthens dialogue among authorities, sectors, stakeholders and neighbouring countries. This is especially important in the Baltic Sea, where ecosystems, human activities and environmental pressures are tightly interconnected across national borders. Yet although the analytical value of CIA is widely recognised, Baltic Sea countries still diverge, not only in the methods, datasets, tools, assumptions and levels of detail they apply, but also in how far CIA is implemented and integrated into MSP and SEA at all. This undermines comparability, weakens transboundary consultation, and obscures how planning decisions in one country may affect shared marine ecosystems. This deliverable responds to that need with practical, step-by-step guidance for integrating CIA into MSP-related SEA. Its framework links three connected processes: the MSP process, the SEA process and a six-step CIA workflow. It clarifies how CIA can support plan preparation, the assessment of alternatives, data and tool selection, interpretation of results, mitigation, consultation, reporting and monitoring. The result is a structured yet flexible basis for more transparent, consistent and transboundary-coherent assessment across the Baltic Sea region.

2. Introduction

Cumulative impact assessment (CIA) has become an increasingly important analytical approach in maritime spatial planning (MSP) and management in Europe and the Baltic Sea, particularly as the expansion and intensification of human uses at sea have increased the need to understand their combined environmental effects across space and time [1–6]. Marine ecosystems and their components are exposed to multiple, co-occurring activities and pressures whose effects converge on the same ecological receptors. Long-established maritime sectors and uses such as shipping, fisheries, tourism, coastal development, already shape environmental conditions across European seas, while newer and rapidly expanding uses, such as offshore energy production, are introducing additional pressures and spatial demands [2,7,8]. The combined effects of these activities and their pressures may be additive, synergistic, or antagonistic, and may accumulate over time through pressures such as repeated physical disturbance, habitat alteration and fragmentation, changes in water quality, underwater noise, and other impacts on species and ecosystem functioning. In this context, CIA seeks to address this reality by moving beyond single-activity or pressure perspectives and providing an integrated way to examine how multiple human uses and their pressures interact and affect marine ecosystems across marine space and time.

The importance of CIA is evident in MSP, where proposed solutions and/or decisions on the allocation, coordination, and regulation of human uses shape how pressures are distributed, combined, and potentially intensified across marine ecosystems. As a strategic and forward-looking process, MSP seeks to organise the spatial and temporal distribution of activities at sea in ways that support ecological sustainability, reduce conflicts among uses, and promote more coherent and efficient patterns of marine development [9–11]. Because MSP outcomes may define where activities are allowed, restricted, expanded, or prioritised, they influence how sea-based pressures are distributed across ecosystems and how impacts may accumulate under different planning arrangements. This makes CIA highly relevant to MSP during plan preparation, the assessment of planning alternatives, and the monitoring of MSP plans following their implementation. In practical terms, CIA can help reveal whether a proposed plan reduces the overlap of harmful pressures on sensitive ecosystem components, shifts impacts from one area to another, intensifies cumulative burdens in already stressed locations, or creates opportunities for improving compatibility between uses and ecological objectives (conservation and restoration). It can therefore support better-informed decisions on zoning, siting, coexistence, mitigation, and trade-offs among competing uses and environmental priorities [5,12]. CIA can also function as a boundary object that facilitates stakeholder engagement, by making cumulative effects more visible and comparable across sectors and interests, supporting structure discussions around spatial options and their implications [13–15]. This dual role strengthens the CIA's contribution to MSP by combining analytical rigor with more inclusive, dialogue-based planning processes. At the same time, CIA should be an integral part of strategic environmental assessment (SEA). SEA provides the formal procedural and legal framework for assessing the likely environmental effects of proposed plans and their alternatives, including their probable consequences, mitigation measures, and consultation requirements [6,16,17]. Within this framework, CIA supports a more systematic examination of how the activities and spatial choices envisaged in an MSP plan(s) may interact to generate cumulative effects on the marine ecosystem in which it will be implemented.

Across the Baltic Sea region, the integration of CIA into MSP and SEA still varies considerably. Although its importance is widely recognised, countries differ in how explicitly they address the cumulative effects of human activities and pressures, the extent to which they apply dedicated methods and tools, and the degree to which the results inform planning and assessment. These differences persist despite a shared HELCOM-VASAB regional policy framework [18], which explicitly calls for strengthening CIA, including the objective to "promote the use of methods and tools in MSP for assessing cumulative environmental and other impacts of sea-based activities" (Goal 3.5). In some cases (e.g., Estonia, Sweden), CIA is supported by well-developed and clearly described assessment methods and spatially explicit digital tools specifically designed for this purpose. In others (e.g., Latvia, Finland), cumulative effects are considered more indirectly or only partially, for example, through expert judgement, qualitative matrices, broader SEA appraisal, or scenario and mapping exercises that are not fully translated into a formalised, quantitative CIA [10,17]. These differences reflect broader variations in legal frameworks, planning traditions, institutional mandates, data availability, access to analytical tools, and technical capabilities. In some settings, planners and SEA practitioners have access to relatively mature datasets, mapping platforms, and tools that enable more explicit and spatially resolved analyses. In others, assessment relies more heavily on expert judgement because data coverage is uneven, the nature of effects between human activities and pressures and nature values remain uncertain, or institutional resources are limited. They also reflect differing interpretations of the relationship between MSP and SEA, particularly with respect to the role assigned to CIA, whether as a formal requirement within the mandatory environmental assessment or as an integral component of planning.

Variation in the nature and extent of CIA implementation among countries creates challenges when addressing transboundary issues in MSP. This is particularly important in light of the requirements of the Espoo Convention [19], which demands states to assess and consult on the transboundary environmental impacts of proposed plans and activities. Inconsistent methodological approaches and data availability (among others) can hinder comparability and coordination across jurisdictions, thereby complicating the effective application of CIA in shared marine areas. The Baltic Sea functions as a highly interconnected socio-ecological system in which ecological dynamics, human uses, and the pressures they generate extend across jurisdictions. Human uses, the pressures they generate, and the ecological and environmental processes through which their effects unfold are embedded within a connected marine system, meaning that their consequences often extend beyond the areas and jurisdictions in which they originate and link decisions taken in one area to ecological and environmental change in another [20]. Under these conditions, coherent regional assessments become challenging when neighbouring countries apply

CIA using different assumptions, methods, data standards, or levels of detail. Differences in approach can make it difficult to compare planning alternatives, interpret cross-border interactions, identify shared hotspots of cumulative pressure, or evaluate how one country's planning decisions may influence environmental conditions in another. For this reason, the key challenge is not whether CIA is integrated into MSP and the associated SEA, but how systematically, transparently, and consistently it is applied to support national planning processes and broader regional coherence [21].

What is needed, therefore, is a clearer and more operational approach to the technical integration of CIA into MSP and the associated SEA, in a way that is practical, transparent, and transferable. Such an approach needs to acknowledge the diversity of existing national practices while still providing enough methodological structure to support greater consistency in how cumulative impacts are assessed, interpreted, and incorporated into planning decisions. It should clarify when and how CIA can be used during plan preparation to inform the design of alternatives and spatial options, and how it can then be integrated into SEA to assess the likely environmental effects of proposed plans and alternatives. It should also help identify what analytical steps, types of data, and tools are needed, what can be done under different levels of information availability, and how cumulative effects can be examined in ways that remain useful even where methodological sophistication varies. Importantly, it should support not only national MSP processes, but also a more coherent regional understanding of cumulative effects and transboundary interactions in the Baltic Sea.

This deliverable responds directly to this need, as it focuses on the operationalisation of CIA within SEA and MSP processes through the development of a practical methodological step-by-step guidance. The purpose is not to position CIA as a separate assessment track, but to clarify how it can be integrated into SEA in a consistent, usable, and decision-relevant way, while recognising its additional value during the earlier planning stages in which alternative spatial options are developed. Building on existing regional practice, the outputs of Horizon and Interreg projects, as well as initiatives supported under DG MARE and the European Maritime, Fisheries and Aquaculture Fund (EMFAF), available data, and established tools, identify, structure, and explain the steps through which CIA can support both the preparation of MSP plans and the formal SEA-based assessment of their environmental effects. This also includes clarifying how decision support tools and best available evidence can be incorporated into the process, and how the assessment of cross-sectoral and transboundary interactions can be made more coherent and transparent. In this way, the deliverable serves to bridge methodological clarification and practical application. By developing a framework that is sufficiently structured to improve comparability, yet flexible enough to remain applicable under different national conditions, the task represents a first comprehensive effort to support a more coherent and operational approach to CIA in MSP-related SEA across the Baltic Sea region. It is not intended as a final or exhaustive solution, but as a practical and methodologically grounded basis on which further refinement, adaptation, and testing can build. In this way, it is expected to strengthen the environmental assessment of national MSP plans, support more informed comparison of planning alternatives, provide a basis for framing the scope of subsequent monitoring of MSP implementation outcomes, and contribute to the wider regional SEA framework being developed in SEABAS.

3. Framework

3.1 General set-up of the framework for incorporation of CIA to SEA

The aim of the framework and step-by-step guidance presented in the following sections is to improve the integration and transboundary coherence of the implementation of CIA in the frame of SEA processes for MSP in the Baltic Sea region. In line with Directive 2001/42/EC[16], SEA is understood as a structured process for assessing the environmental effects of plans and programmes. The assessment results must be considered during MSP plan preparation and adoption (Directive 2014/89/EU) [22], and monitoring of significant environmental effects after adoption. Within this broader SEA process, CIA represents one analytical component rather than the full assessment process. It provides a technical and analytical basis for identifying, describing, and evaluating likely significant effects, comparing MSP plan alternatives or additional scenarios, and informing the definition of mitigation measures and the design of monitoring actions. However, SEA also includes other forms of environmental assessment and considerations that extend beyond cumulative impacts, such as ecosystem-specific analyses and policy-level evaluations, which are further described in Deliverable 1.2 of SEABAS.

The framework and guidance are structured around three closely connected parallel processes (Figure 1): (1) the MSP process, (2) the SEA process, and (3) the CIA workflow. Together, they provide an overview and indicative timeline of how the steps in each process inform one another, focusing on the part of the MSP process where CIA becomes relevant (A full description of the SEA and MSP process will be provided in Deliverable 1.2). Within this framework, the MSP process provides the MSP plan and, where available, plan alternatives to be assessed through the SEA. These plans and alternatives form the basis for CIA, which is used to assess and compare their potential effects on nature values. The SEA process provides the procedural structure, following the requirements of the SEA Directive, while the CIA workflow describes how the cumulative impact assessment is technically implemented through a series of clearly defined practical steps.

The framework follows a “synthesis-and-integration” approach and therefore does not develop SEA- and CIA-support methods from scratch, but builds on the knowledge, validated outputs, datasets, tools, and good practices generated during the development of national MSP processes across the Baltic Sea region, introduced by pan-European and Baltic Sea-focused projects, and recommended by strategic and guiding documents issued by relevant European and regional governance bodies and conventions. Regarding projects, the framework draws on the compilation of SEA methods and practices performed in Deliverable

1.1, with special focus on the technical and implementation outputs and recommendations produced in MSP4BIO, MAREA, Blue4all, Blue Connect, PROTECT BALTIC, eMSP NBSR, ReMAP, NESBp, and PanBaltic Scope. Based on these projects, the framework provides transferable solutions for supporting scoping, data use, stakeholder involvement, plan-alternative comparison, and impact evaluation. The framework also builds on regional tools and data services, including HELCOM SPIA, BASEMAPS, the Sea2Land Navigator, and PlanWise4Blue, as well as on project-specific outputs such as MSP4BIO, Blue4all, PROTECT BALTIC, and MAREA methodologies for ecosystem service assessment and mapping, and ReMAP's work on interoperability and assessment support. In this way, the framework combines existing regional practice, the best available data, decision support tools, and stakeholder-oriented processes into a coherent, operational methodology intended to practically support CIA in MSP processes while remaining consistent and transferable in a transboundary Baltic Sea context.

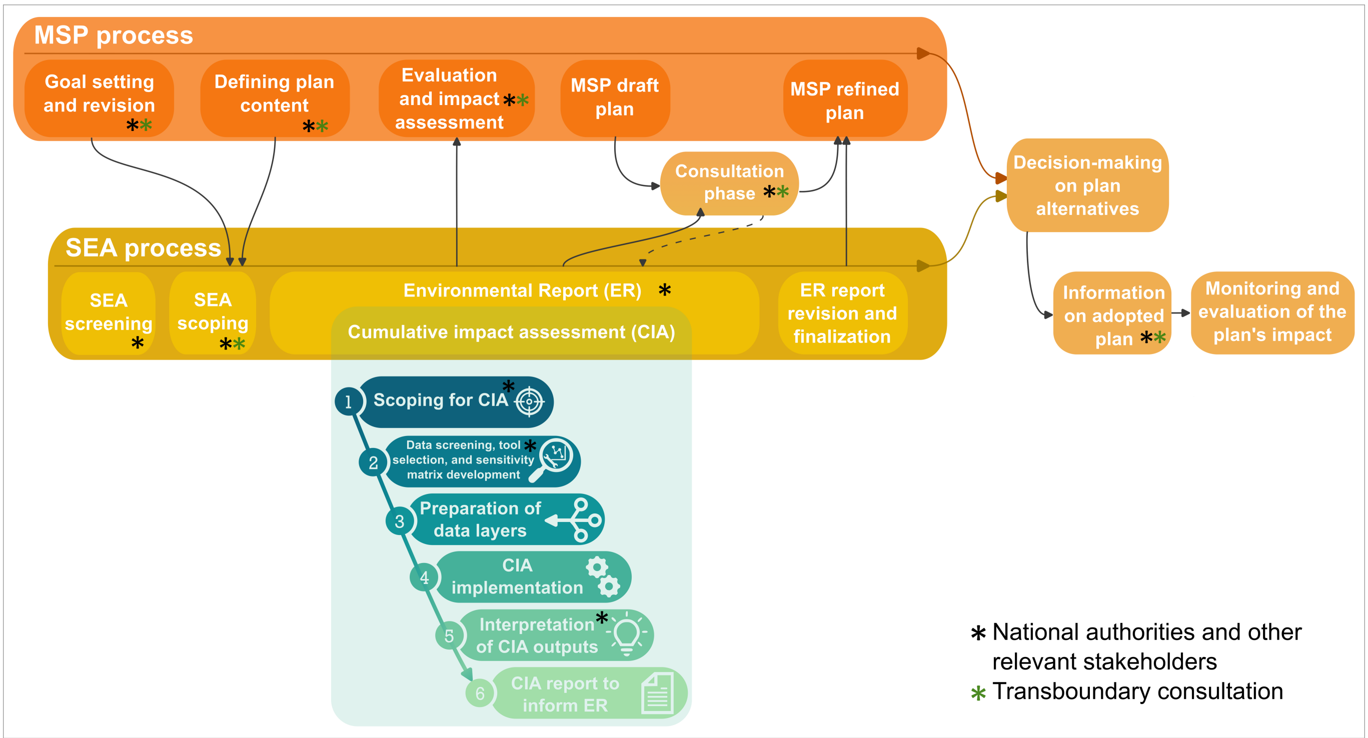

Figure 1. General framework for integrating cumulative impact assessment (CIA) into strategic environmental assessment (SEA) and maritime spatial planning (MSP) processes, developed based on the MSP and SEA Directives and on CIA implementation workflows developed within relevant European and regional projects (see Section 3.1). The MSP process (orange band) provides the overarching planning pathway, from goal setting and plan development to the evaluation and impact assessment of alternatives, plan refinement, adoption, and monitoring. Within this pathway, the SEA process (yellow band) defines the procedural structure, timing, scope, and information needs for the overall environmental assessment of the plan and its alternatives, including the implementation of the CIA. The CIA workflow (light green box) provides the analytical basis for assessing the potential environmental effects of the MSP plan and, where relevant, additional scenarios, also supporting the identification of mitigation measures and the preparation of reporting outputs. The figure further indicates where stakeholder engagement and transboundary consultation may take place. The dashed line represents the pathway for refining the environmental report (ER) and CIA in response to feedback received during the MSP and SEA consultation phase.

3.2 SEA process

3.2.1 Screening phase for SEA

The screening and scoping phase establishes the legal and methodological basis for the SEA. First, the competent authority should document whether the particular MSP process developed falls within the scope of Directive 2001/42/EC and whether SEA is mandatory under Article 3, which defines the types of plans and programmes that require environmental assessment based on their likely effects. Whether the MSP process involves establishing a new plan, revising an existing one, or implementing a locally limited intervention, the **responsible authority should clearly document the screening conclusions** and justify whether SEA is required or not. This information should also be made publicly available.

3.2.2 Scoping phase for SEA

Once SEA applicability is confirmed, in the scoping phase the competent authority for SEA should define the scope and level of detail of the environmental report in consultation with all relevant environmental authorities and related governance bodies. SEA scoping should clearly identify and define, based on the ongoing MSP process:

1. **The main objectives of the MSP plan:** The strategic objectives of the MSP plan should be clearly identified at the outset to provide the foundation for the SEA process. This includes defining the overall purpose of the plan, the policy priorities it is intended to advance, and the environmental, social, and economic outcomes it seeks to achieve. A clear articulation of the plan's objectives is essential for framing the assessment and linking it to the existing environmental objectives, areas of a particular environmental importance, such as areas designated pursuant to Directives 79/409/EEC and 92/43/EEC, selecting relevant evaluation criteria, and comparing plan alternatives in a consistent and transparent manner.
2. **Additional scenarios to be assessed**: The MSP plan and its plan alternatives should be developed within the MSP process. Depending on the stage at which SEA and CIA are initiated, these plan alternatives may already be defined in relation to a draft MSP plan, or they may still be under development during the planning process. Where plan alternatives are already available, they should provide the basis for defining the additional scenarios to be assessed through the CIA within the SEA. Where plan alternatives are not yet available, the CIA scoping should identify the relevant marine sectors, activities, pressures and foreseeable developments that can inform both the later development of MSP plan alternatives and the definition of additional scenarios for assessment. The identification of sectors, activities, and their associated pressures provides the basis for defining additional scenarios that may influence the likely environmental effects of the plan and alternatives. These may include the following:

a) Climate change: Projected future climatic conditions that may affect the status, distribution, or resilience of nature values within the assessment area should be considered where relevant [23]. This may include, for example, increases in water temperature, changes in salinity, altered ice conditions, sea level rise, shifts in storm frequency or intensity (and other extreme events), or other climate-related changes that could influence the exposure and sensitivity of species and habitats to other human pressures.

b) Socio-economic and cultural landscape change: Expected changes in the intensity, distribution, or character of human activities should also be taken into account where these are likely to influence assessment outcomes. Examples may include increased shipping intensity, growth in recreational boating, expansion or decline of aquaculture and fisheries activities, changes in tourism pressure, or reductions in pollution loads resulting from improved wastewater treatment and other infrastructure developments.

c) Changes in management measures: Known or reasonably foreseeable management actions that may affect the assessed scenarios should be incorporated where relevant. These may include mitigation measures, ecological restoration actions, new protection measures, revised zoning arrangements, seasonal restrictions, or other regulatory and management interventions that may alter pressures, reduce impacts, or improve ecosystem condition over time.

In addition, a current-state or without-plan alternative(s) should be prepared, depending on whether the MSP process involves revising an existing plan or establishing a new one. This should provide the baseline against which all MSP plan alternatives and additional scenarios are interpreted and evaluated, reflecting conditions at the start of the assessment process and serving as a consistent reference point for comparison.

3. **Links with other relevant plans and programmes, and the wider policy and legal context:** The scoping process should also identify relevant plans, programmes, strategies, and legal instruments that provide the broader framework within which the MSP plan is being developed. These may include environmental, sectoral (e.g., defence), spatial, climate, biodiversity, water management, and marine protection instruments at local, national, regional, and EU levels. Identifying these links helps define the external assumptions, constraints, and policy commitments that should inform both the baseline and the MSP plan alternatives assessed through the CIA. It is also important to identify whether these plans and programmes may be influenced by, interact with, or be affected by the MSP plan alternatives, in order to ensure consistency and support the assessment of cumulative and cross-sectoral effects. For example, Marine Protected Areas (MPA) plan could be influenced by MSP plan alternatives wind park development areas.

4. **The spatial and temporal scope of the assessment**: The geographic and temporal boundaries of the SEA, and therefore of the and CIA, should be clearly defined during scoping. This should include the planning area covered by the MSP, the relevant ecological and administrative subareas, and any broader analytical extent needed to address spatially extensive or dynamic pressures, ecosystem linkages, or transboundary effects. The temporal scope should identify the planning horizon, reference years, and any relevant short-, medium-, and long-term assessment periods. At this stage, the likely need for transboundary consultation should also be identified, particularly where significant environmental effects may extend beyond national jurisdiction or affect neighbouring marine areas, as well as where external activities or designations may influence environmental conditions within the planning area.
5. **Key nature values and areas likely to be significantly affected** – The scoping phase should identify the nature values, considering also the ecosystem services they provide, and geographic areas that may be significantly affected by the human activities and pressures addressed in the MSP plan. The initial identification of nature values and areas likely to be affected, will provide a starting point for identifying and prioritizing nature values to be included in CIA scoping phase.

In addition, in the SEA scoping phase, the competent authority for SEA should clearly establish:

1. **Institutions, experts, and stakeholders involved in each step of the process**: The scoping phase should identify the authorities, institutions, scientific experts, sector representatives, and stakeholders that should be involved in the different stages of the SEA and CIA process. Their respective roles in the consultation process should be considered in relation to:
   i. identifying and prioritizing nature values,
   ii. identifying and prioritizing human activities, pressures, and pressure pathways,
   iii. data provision,
   iv. expert knowledge on species sensitivities toward human pressures,
   v. review and assessment of CIA outputs and proposing measures, and
   vi. revision of the resulting environmental report.

   Early clarification of participation arrangements helps ensure that the assessment is informed by relevant expertise and that key interests are appropriately considered from the outset.
2. **Allocate responsibilities** for report preparation and consultation: Clear responsibilities should be assigned for the development of the steps involved in the technical implementation of the CIA, the preparation of the environmental report, the organisation of consultations, and the coordination of communication between competent authorities and stakeholders. This should include identifying which institutions and specific teams are responsible for drafting, quality

control, stakeholder engagement, and integration of the assessment results into plan preparation and revision.

3. **Establish a timetable and resource plan** for the assessment process: The scoping phase should establish a timetable and resource plan for the SEA and CIA process, explicitly considering the timeframe of the MSP process, including key milestones for data collection, analysis, consultation, reporting, and integration with the MSP planning schedule. Although budget allocation and scheduling are not explicit requirements under the SEA Directive, they are important practical implementation arrangements that help ensure that the assessment is proportionate, timely, and feasible. Establishing these parameters early in the process also supports realistic planning of staff capacity, technical inputs, and consultation activities.

3.2.3 Environmental report

The environmental report is the central SEA document and should contain, in accordance with Article 5 and Annex I of Directive 2001/42/EC:

- An outline of the plan's content, objectives, and relationship with other relevant plans and programmes
- Describe existing environmental problems relevant to the plan, including pressures on protected or otherwise sensitive areas. The report should also identify the environmental protection objectives applicable at international, EU, regional and national levels and explain how these objectives were taken into account in preparing the plan and the assessment.
- An outline of the reasons for selecting the alternatives dealt with, and a description of how the assessment was undertaken including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information
- Description of the methods used, and any data or knowledge limitations encountered.
- Production of clear non-technical summaries accessible to non-specialist readers.

From the outputs of the CIA to be performed, the following information and outputs are expected:

- Description of the current state of the environment and its likely evolution under the relevant baseline, which may refer either to the absence of an MSP plan or an already established plan that is being revised.
- Description and evaluation of the likely significant effects of implementing the plan, including cumulative, synergistic, short-, medium- and long-term, permanent and temporary, positive and negative effects on both biotic and abiotic components and compartments, material assets, cultural heritage, and the interrelationships among these factors in the area covered by the MSP plan.

- Consideration of transboundary aspects throughout the assessment, including potential cross-border environmental effects, shared ecosystem components, pressures originating outside the MSP plan area, and the plan's consistency with relevant neighbouring plans, regional objectives, and transboundary consultation outcomes.

  Identification of measures envisaged to prevent, reduce and, as far as possible, offset significant adverse effects. While the CIA can indicate where measures are needed and which pressures, activities, or areas should be targeted, the specific measures may be defined through the broader SEA, MSP and consultation process. These may include spatial planning measures, mitigation or restoration actions, legal or regulatory provisions, licensing conditions, governance arrangements, monitoring requirements, or other management interventions. The report should explain the reasonable alternatives considered, the reasons for selecting the proposed measures, and the purpose of the monitoring measures.

3.2.4 Consultation phase

Once the draft MSP plan and environmental report have been prepared, they should be issued together for consultation in accordance with Article 6 of the SEA Directive (2001/42/EC). The consultation "information package" should include:

1. The draft MSP plan.
2. The environmental report.
3. The non-technical summary.
4. Practical information on how and within what timeframe comments may be submitted.

The designated environmental authorities and relevant stakeholders should be given an early and effective opportunity to comment before the adoption of the plan. Building on the initial transboundary screening carried out during SEA scoping, the consultation phase should confirm whether implementation of the draft MSP plan is likely to have significant effects on the environment of neighbouring countries and whether formal transboundary consultation is required. This is particularly important in the Baltic Sea, a semi-enclosed sea bordered by eight EU countries, where national waters are closely connected, and environmental pressures can easily extend beyond administrative boundaries. Depending on national practice, consultation may target neighbouring countries likely to be affected or be extended more broadly to all Baltic Sea countries. If the plan is likely to have significant transboundary environmental effects, or where another Member State requests it, the draft plan and environmental report should be shared for transboundary consultation under Article 7 of the SEA Directive (2001/42/EC) and in accordance with the Espoo Convention.

The consultation phase should therefore collect and document input on:

1. The technical adequacy and scientific robustness of the assessment methodology applied.
2. The relevance and appropriateness of the alternative plans or additional scenarios assessed.
3. The significance and reliability of the predicted environmental effects.
4. The consideration and treatment of transboundary impacts.
5. The feasibility and effectiveness of the proposed mitigation measures.

These inputs should be systematically recorded and linked to subsequent revisions of the plan and the assessment.

3.2.5 Revision and finalisation of the draft MSP and environmental report

Following consultation, the competent authority for MSP should revise both the draft plan and the environmental report. This revision phase should demonstrate how comments from environmental authorities, relevant stakeholders, and neighbouring countries have influenced the final assessment and the proposed planning solution. In this context, the CIA and obtained results may need to be updated if consultation has led to changes in spatial allocations, sectoral assumptions, mitigation measures, sensitivity parameters or scenario design.

The revised environmental report should therefore present:

1. The final comparison of reasonable alternatives.
2. The refined evaluation of significant effects.
3. The final package of mitigation and avoidance measures.
4. The monitoring framework associated with the preferred planning solution.

The purpose of this step is not only to improve the technical quality of the assessment, but also to ensure transparency and traceability between evidence, consultation, and the final planning proposal.

3.2.6 Decision-making on plan alternatives

The final decision on the preferred planning alternative should be taken only after the environmental report, the opinions received from the designated authorities and the public, and the outcomes of any transboundary consultations have been considered in full, as required by Article 8 of SEA Directive. The decision-making phase should include a documented justification of the selected alternative, showing how environmental considerations influenced the final planning solution and how CIA findings informed choices on zoning, coexistence measures, safeguards, mitigation conditions and restrictions. This phase should also make clear how trade-offs between development objectives and environmental protection were handled, and how the final option contributes to ecosystem-based MSP, biodiversity conservation, and climate resilience in the Baltic Sea context.

3.2.7 Information on the adopted plan

After adoption of the plan, the competent authority should inform all relevant environmental authorities, the relevant stakeholders and the general public, and neighbouring states consulted under the transboundary procedure. The adopted plan should be made available together with a statement explaining how:

1. Environmental report considerations were integrated into the plan.
2. How the consultation results were considered.
3. Why was the final option chosen in light of the alternatives considered.
4. What mitigation and monitoring measures have been established.

This post-adoption information step is essential for transparency, accountability, and knowledge transfer, because it closes the SEA cycle and provides a formal link between the assessment evidence, the decision taken, and the mitigation and monitoring commitments that follow.

3.2.8 Monitoring and evaluation of the plan's impact

Monitoring should be designed to track the significant environmental effects of implementing the adopted MSP plan, with particular attention to identifying unforeseen adverse effects at an early stage and enabling appropriate mitigation actions. The established monitoring program should specify which criteria and indicators, and threshold values will be tracked, what data sources will be used, how often monitoring will occur, what thresholds or trigger values will be used to identify concern, and how monitoring results will feed back into plan review or adaptive management.

Existing national or regional monitoring systems should be used where possible to avoid duplication. However, the monitoring should be sufficiently targeted to test the key assumptions of the SEA and CIA, including the persistence of impact hotspots, cumulative pressure levels, condition of sensitive ecosystems, effectiveness of mitigation measures, and emergence of transboundary effects.

3.3 CIA workflow in the frame of SEA

The CIA in the SEA process follows a 6-step process (Figure 2), based on CIA implementations in demo sites in EU Horizon projectsMSP4BIO, Blue4all, and Blue Connect [24–26], to provide the needed input for the SEA Environmental Report, and refining plan alternatives in the MSP process (Figure 1).

Figure 2. Six-step workflow for cumulative impact assessment (CIA) implementation within the strategic environmental assessment (SEA) of maritime spatial planning (MSP) planning processes. The figure summarises the main steps and key sub-steps, from scoping and data preparation to CIA implementation, outputs interpretation, and reporting to inform the SEA environmental report (ER).

STEP 1: Scoping for CIA

In Step 1 (Figure 2), all MSP plan alternatives, the current-state assessment, and any additional scenarios or assumptions identified during SEA scoping, such as climate change, management measures, or socio-economic development cases, should be translated into a technical CIA scoping workplan. This workplan should define what will be assessed, for which scenarios, at what spatial and temporal scale, which outputs are needed for the environmental report, and which evidence is required to support the identification and reporting of likely significant environmental effects.

To improve comparability across Baltic Sea MSP processes and to facilitate transboundary consultation, for example, the scoping of nature values (and the ecosystem services they provide) and human activities and pressures to be considered should be based on the most recent HELCOM Holistic Assessment (e.g., HOLAS 3 in the present). The HOLAS 3 [8] provides a suitable regional basis for identifying both candidate nature values and relevant pressure for CIA. National or local additions may then be included where they are necessary to reflect finer-scale ecological importance, statutory obligations, specific plan features, or known local sensitivities not sufficiently captured at the regional scale.

Identifying and prioritizing nature values

Nature value identification should begin with the development of a comprehensive candidate list. This list should be based first on HOLAS 3 [8,27] ecosystem components to improve comparability across Baltic Sea MSP processes (Table 1) and the nature values identified in the SEA scoping phase. This candidate list should then be reviewed and complemented through national expertise and locally grounded ecological, social, and cultural knowledge to ensure that it reflects threatened or protected species and habitats, national conservation designations, restoration priorities, the potential supply of ecosystem services, and culturally important marine areas. Relevant contributors should be selected to cover the main types of knowledge needed for the scoping process. These may include scientific and technical expertise from marine scientists, institutional expertise from competent planning authorities, sectoral expertise from representatives of relevant maritime activities, and place-based knowledge from coastal municipalities, local communities, and traditional users. This helps ensure that the scoping list is both regionally comparable and locally meaningful [28].

Table 1. Ecosystem components identified in Table A4.2 of the "HELCOM Thematic assessment of spatial distribution of pressures and impacts 2016-2021"[27].

No	Ecosystem component	Type
1	Infralittoral coarse sediment	Broad-scale habitat
2	Infralittoral mixed sediment	Broad-scale habitat
3	Infralittoral mud	Broad-scale habitat

4	Infralittoral mud or sand	Broad-scale habitat
5	Infralittoral rock and biogenic reef	Broad-scale habitat
6	Infralittoral sand	Broad-scale habitat
7	Circalittoral coarse sediment	Broad-scale habitat
8	Circalittoral mixed sediment	Broad-scale habitat
9	Circalittoral mud	Broad-scale habitat
10	Circalittoral mud or sand	Broad-scale habitat
11	Circalittoral rock and biogenic reef	Broad-scale habitat
12	Circalittoral sand	Broad-scale habitat
13	Offshore circalittoral coarse sediment	Broad-scale habitat
14	Offshore circalittoral mixed sediment	Broad-scale habitat
15	Offshore circalittoral mud	Broad-scale habitat
16	Offshore circalittoral mud or sand	Broad-scale habitat
17	Offshore circalittoral rock and biogenic reef	Broad-scale habitat
18	Offshore circalittoral sand	Broad-scale habitat
19	Sandbanks (1110)	EU Habitats Directive / Natura
20	Estuaries (1130)	EU Habitats Directive / Natura
21	Mudflats and sandflats (1140)	EU Habitats Directive / Natura
22	Coastal lagoons (1150)	EU Habitats Directive / Natura
23	Large shallow inlets and bays (1160)	EU Habitats Directive / Natura
24	Reefs (1170)	EU Habitats Directive / Natura
25	Submarine structures made by leaking gases (1180)	EU Habitats Directive / Natura
26	Baltic esker islands (1610)	EU Habitats Directive / Natura
27	Boreal Baltic islets and small islands (1620)	EU Habitats Directive / Natura
28	Charophyte distribution	Benthic species / macrophytes
29	Fucus distribution	Benthic species / macrophytes
30	Furcellaria lumbricalis distribution	Benthic species / macrophytes
31	Mytilus distribution	Benthic species
32	Zostera marina distribution	Benthic species / macrophytes
33	Potamogeton distribution	Benthic species / macrophytes
34	Myriophyllum distribution	Benthic species / macrophytes
35	Najas marina distribution	Benthic species / macrophytes
36	Fontinalis distribution	Benthic species / macrophytes
37	Callitriche distribution	Benthic species / macrophytes

38	Zanichellia distribution	Benthic species / macrophytes
39	Productive surface waters, Chl-a	Pelagic / food web
40	Availability of deep-water habitat, based on occurrence of H_2S	Deep-water habitat
41	Breeding areas for birds	Birds
42	Wintering areas for birds	Birds
43	Grey seal distribution	Marine mammals
44	Harbour seal distribution	Marine mammals
45	Ringed seal distribution	Marine mammals
46	Harbour porpoise importance map	Marine mammals
47	Cod abundance	Fish
48	Herring abundance	Fish
49	Sprat abundance	Fish
50	Potential spawning areas for cod	Essential fish habitat
51	Potential spawning areas for sprat	Essential fish habitat
52	Potential spawning areas for herring	Essential fish habitat
53	Potential spawning areas for European flounder	Essential fish habitat
54	Potential spawning areas for Baltic flounder	Essential fish habitat
55	Potential nursery areas for flounders	Essential fish habitat
56	Potential recruitment areas for perch	Essential fish habitat
57	Potential recruitment areas for pikeperch	Essential fish habitat

Once this candidate list has been established, the final set of nature values to be included in the CIA should be selected through a transparent prioritisation process, to determine which nature values are most relevant for assessment considering the MSP plan alternatives and scenarios. The criteria used for prioritisation should be clearly documented in a scoping report and applied consistently across the assessment area. Based on systematic biodiversity conservation planning, EBSA-type ecological significance criteria, marine spatial prioritisation approaches, and cumulative impact assessment frameworks, the following criteria may be used to prioritise nature values for inclusion in the CIA. These criteria support a transparent selection of nature values and associated ecosystem, socio-economic, and cultural values that are rare or threatened, functionally significant, sensitive or vulnerable to human pressures, spatially exposed to the activities considered in the MSP plan alternatives and additional scenarios, and relevant to conservation, restoration, management, cultural heritage, or social objectives [24,29–32]:

1. **Ecological functional role**

Nature values that make an important contribution to ecosystem structure, functioning, or resilience. These may include habitat-forming species, key benthic habitats, spawning or nursery grounds, trophic hotspots, and areas that support nutrient cycling, productivity, or ecological connectivity. Such values are often central to the integrity and stability of the wider ecosystem and may therefore have disproportionate importance in the assessment.

2. **Rarity, uniqueness and irreplaceability**

Nature values should be prioritised where they are spatially rare, regionally uncommon, unique in character, or difficult to replace if damaged or lost. In the context of MSP plan assessment, this criterion is especially important because impacts on such values may not be easily offset. Their inclusion can therefore help identify nature values for which avoidance or strong mitigation is particularly necessary.

3. **Vulnerability or sensitivity to pressures relevant to the plan**

Nature values that are known, or can reasonably be expected, to respond strongly to pressures generated by the human uses considered in the MSP plan alternatives. A nature value should be selected not only because it is important in itself, but also because it is materially exposed and sensitive to the types of pressures that may arise under the plan alternatives. This helps ensure that the CIA focuses on nature values for which cumulative effects are most likely to be significant.

4. **Policy and legal relevance**

Priority should be given to nature values that are directly relevant to legal obligations, environmental objectives, or established assessment frameworks. This may include already protected habitats and species, Natura 2000 features, MSFD and Habitat directives listed habitats, HELCOM ecosystem components, nationally designated features, and nature values linked to biodiversity objectives, restoration commitments. Including such values helps ensure that the CIA is aligned with statutory requirements and policy commitments.

5. **Climate and future-oriented relevance**

Where the MSP horizon is long-term, nature values may also be selected with regard to climate-related change. Relevant considerations may include sensitivity to warming, deoxygenation, salinity change, erosion, and shifts in species distributions, as well as the potential role of areas as climate refugia. This criterion helps ensure that the assessment remains relevant under future environmental conditions rather than reflecting only present-day distributions and sensitivities.

6. **Socio-economic value**

Nature values may also be prioritised where they underpin important commercial or livelihood-related activities, provided this is considered alongside ecological significance. This may include fish spawning and nursery areas that support commercial fisheries, habitats important for shellfish harvesting, or ecosystems that contribute to tourism, recreation, or other marine-based economic uses. Including commercial value as a criterion can help ensure that the CIA reflects not only ecological importance but also the dependence of coastal and marine economies on healthy ecosystems. However, this criterion should not override ecological importance; rather, it should be used to highlight nature values whose degradation could have both environmental and socio-economic consequences.

7. **Cultural value**

Nature values may also be prioritized where they support culturally important marine areas, seascape values, underwater cultural heritage, traditional practices, local identity, recreation, education, spiritual values, or other place-based relationships between people and the sea. This may include areas valued by coastal communities, culturally significant species or habitats, traditional fishing grounds, historically important maritime landscapes, or areas where ecological features contribute to cultural ecosystem services. Including cultural values helps ensure that the CIA and SEA consider ecological and economic aspects, but also the cultural and social meanings associated with healthy marine ecosystems. As with socio-economic value, this criterion should not override ecological importance but help identify nature values whose degradation could have cultural, social, or heritage-related consequences.

To support transparent prioritisation, it is recommended to generate a scoring matrix in which each nature value is scored against the selected criteria. Such approaches have been applied in previous conservation planning and marine spatial prioritisation processes to support the systematic selection of nature values for assessment or protection [29,33–35]. The scoring approach can vary depending on data availability, the purpose of the assessment, and the level of expert judgement required. For example, a simple binary screening approach may be used to indicate whether a nature value meets or does not meet a given criterion, such as whether it is legally protected, rare, functionally important, or relevant to the MSP plan alternatives. Qualitative categories, such as low, medium, and high relevance, may be used where available information is limited but expert judgement can support a reasoned assessment. Ordinal scoring systems may also be applied, where nature values are ranked along a scale according to their relative importance for each criterion.

As one practical option, a weighted multi-criteria scoring approach may be used. Multi-criteria decision analysis is widely used in environmental and conservation decision-making to compare alternatives against multiple criteria, make trade-offs explicit, and test how weighting choices influence outcomes [36]. In this case, each nature value can be scored against each prioritisation criterion using, for example, a Likert-type scale from 1 to 5, where the lowest value represents the lowest relevance of the nature value for that criterion and the highest value represents the highest relevance (Table 3). The criteria may also be weighted, using values between 0 and 1, to reflect their relative importance in the MSP process. The sum of all criterion weights should equal 1. Where criteria are considered equally important, they can be assigned equal weights. A final prioritisation score for each nature value can then be calculated by summing the products of the score for each criterion and its corresponding weight. This provides a systematic and transparent way to compare candidate nature values and select those most relevant for inclusion in the CIA, while still allowing expert judgement, stakeholder input, and qualitative justification to remain central to the process.

Identifying human activities, pressures, and pressure pathways

Building on the SEA scoping phase identified marine sectors and activities initial list, the CIA scoping step should create a structured list of all human activities that are relevant for each MSP plan alternative and any additional scenario considered in the assessment. This list should include existing activities, planned activities, and reasonably foreseeable future activities that may contribute to cumulative effects within the assessment area. As in the identification and prioritisation of nature values, the identification of human activities, pressures, and pressure pathways should combine available spatial data, scientific evidence, expert judgement, and stakeholder knowledge. The role of experts and stakeholders is not only to provide data, but also to verify whether the activity list is complete, identify locally important or emerging pressures, comment on realistic activity patterns and management practices, highlight missing or uncertain pressure pathways, and review whether the assumptions used in the CIA are plausible. To ensure a transboundary approach, the pressure list should also consider the human activities and pressures included in the HELCOM activity-pressure matrix (Figure 3). The matrix has recently undergone major developments in the PROTECT BALTIC project together with regional HELCOM stakeholders. The updates include semiquantitative categorisations of how strongly human activities contribute to different pressures and whether the pressure is direct or indirect. This new version of the matrix will be published in August 2026.

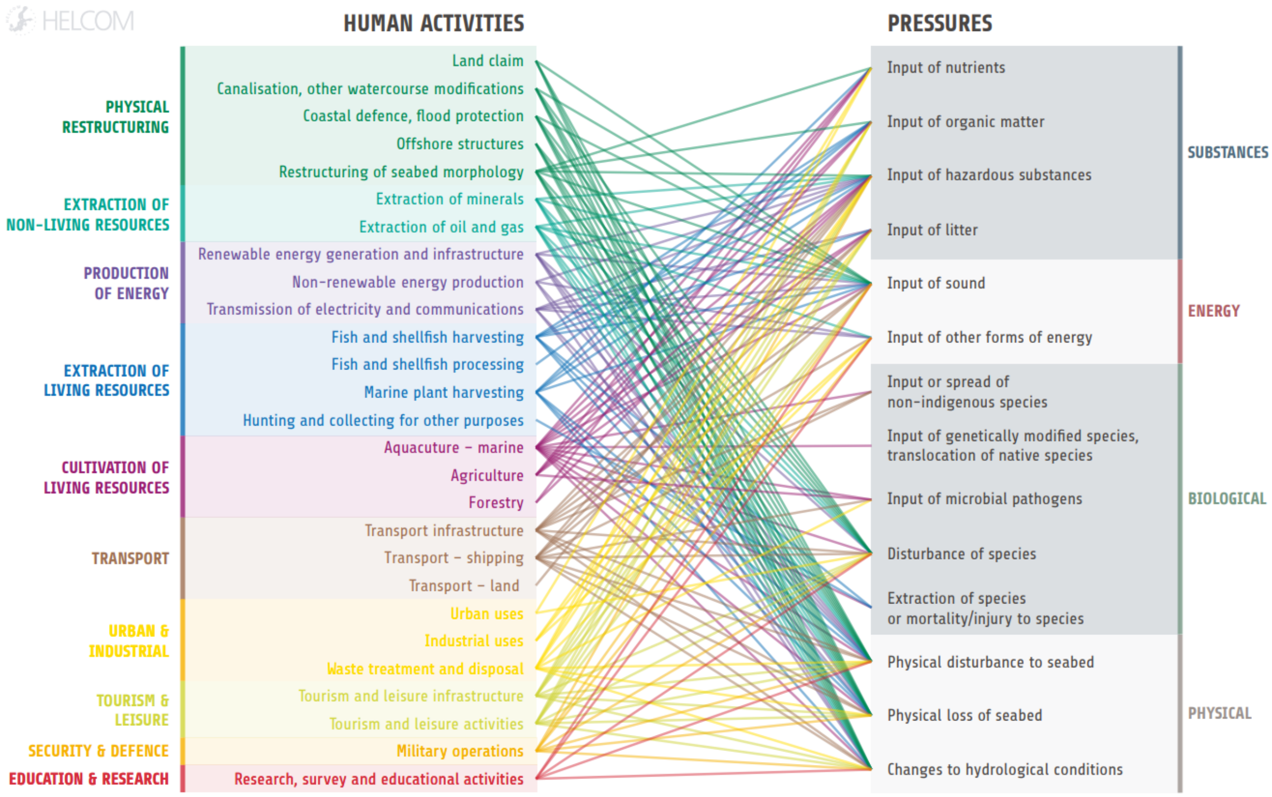

Figure 3. Linkages between human activities and environmental pressures used in HELCOM spatial pressure and impact assessment [27]. Small updates to this figure are foreseen in August 2026.

Once the candidate list of activities and pressures has been compiled, it should be prioritised so that the CIA focuses on the most relevant pressures for the assessment spatial and temporal scope. Prioritization of human activities and pressures should be based on the potential pressure pathways that exist. All activities and pressures with a significant pressure pathway for any of the prioritized nature values should be included in the CIA.

The identification of activities, pressures, and pressure pathways should be structured using the DAPSIR framework (Drivers - Activities - Pressures - State (Change) - Impact - Response (Measure)) [37–40]. These frameworks provides a clear conceptual basis for understanding how societal drivers give rise to human activities, how those activities generate pressures, and how these pressures lead to changes in ecosystem state, which may ultimately result in impacts on ecosystem services or environmental objectives, and trigger management responses. It is particularly useful in CIA because it allows multiple drivers, activities, and pressures to be considered together within a single, coherent cause-effect chain.

In the context of CIA for MSP, the most relevant part of this framework is the explicit linkage between activities, pressures, and resulting ecological changes. This logic is consistent with marine activity-pressure and linkage-framework approaches developed for ecosystem-based management and CIA, including

ODEMM, OSPAR, and HELCOM applications [37,41–43]. This pressure pathway can therefore be understood as the causal chain: **activity → pressure → exposure pathways → nature value**. Within this logic, activities should not be treated as impacts in themselves, but as sources of one or more pressures. These pressures may affect nature values through pathways that can be direct or indirect, operate at different spatial scales, and vary over time, for example, in response to seasonal changes or the movement of pressures across the marine environment. The same pressure may affect different nature values in different ways and at different magnitudes. Making these relationships explicit is essential to ensure that cumulative effects are systematically identified, the inclusion of each pressure pathway is transparent and justified, and the results of the CIA can be consistently interpreted and linked to the evaluation of likely significant effects.

It should be recognised that pressure pathways cannot always be defined with the same level of certainty. Determining links between human pressures and ecosystem state changes remains a known challenge in marine and coastal assessment, and many CIA rely partly on expert judgement and qualitative confidence evaluation where empirical evidence is incomplete [37,40,43,44]. For some activities and pressures, the link between the activity, the generated pressure, pressure pathway, and the resulting change in the state of the marine environment may be well documented and spatially explicit. For others, the pathway may be uncertain, indirect, context-dependent, or difficult to predict with the available data and models. Such knowledge gaps should be documented explicitly during CIA scoping, including whether the uncertainty relates to the existence of the pathway, the sensitivity of the nature value, or the magnitude or direction of the effect. Where uncertainty is high, the pathway may still be retained for assessment using qualitative judgement, precautionary assumptions, sensitivity testing, or expert and stakeholder review, rather than being excluded only because quantitative evidence is incomplete.

Identifying pressure pathways form each activity, pressure, and nature value means asking six linked questions for each identified current or future activity:

1. **What pressures does the activity generate?** - For example, shipping may generate underwater noise, collision risk, seabed disturbance in port approaches, emissions, and the spread of non-indigenous species; bottom-trawling may generate abrasion, sediment resuspension, habitat disturbance, and mortality of benthic organisms.
2. **Which prioritised nature values may be affected?** - The pathway should identify the specific receptors (i.e., nature values sensitive to the specific pressures), i.e., the species, habitats ecosystem processes or services.
3. **How does the pressure reach the nature value? -** This should describe the exposure mechanism through which pressures are transmitted to nature values, including processes such as direct spatial overlap, physical or hydrodynamic propagation, sediment or contaminant transport,

behavioural responses (e.g. avoidance), collision risk, or indirect ecological interactions such as food-web mediation.

4. **When and where is exposure likely to occur?** - The pathway should consider spatial footprint, seasonal timing, frequency, duration, and whether the pressure extends beyond the activity footprint. The footprint of the pressure is often different from the footprint of the activity itself. Georeferenced human activity layers may act as the origins of pressure propagation, and that modelling can be used to represent how pressures spread from those source locations. This is particularly relevant for pressures such as underwater noise, sediment plumes, contamination, hydrodynamic change, where the area of ecological effect may extend well beyond the immediate location of the activity.
5. **What type of state change or ecological effect may result?** - Examples include mortality, injury, displacement, disturbance, reduced abundance, habitat loss, habitat degradation and fragmentation, reduced reproductive success, or reduced ecological function.
6. **What response or mitigation option may be relevant?** - Examples include spatial measures (e.g. exclusion zones, buffers, routing measures), temporal measures (e.g. seasonal restrictions), operational or intensity-related controls (e.g. activity limits or technology requirements), ecological restoration or enhancement actions, and monitoring and adaptive management measures implemented to evaluate effectiveness and support iterative adjustment.
7. **How certain is the pathway and what knowledge gaps remain?** The assessment should record whether the pressure pathway is well established, partly known, uncertain, or mainly based on expert judgement. It should also identify the main reason for uncertainty, such as a lack of spatial data, limited evidence on pressure intensity, unclear exposure mechanisms, unknown sensitivity of the nature value, or difficulty predicting the resulting change in environmental state.

Answers to the questions should be informed by both scientific and local knowledge, scientific evidence and local expert knowledge, drawing on comprehensive reviews of scientific literature and technical reports, as well as structured expert consultation and discussion. The identification of pressure pathways should not rely solely on the spatial datasets available. Where evidence is incomplete, the relationship between activity and pressure should still be made explicit and the uncertainty described. For CIA, this is essential because many effects are overlooked not because the activity is unknown, but because the pathway connecting the activity to the nature value has not been made explicit.

The identification of pressure pathways should therefore be documented in the scoping report through an activity-pressure-pathway-receptor table. For each included activity, this table should specify the relevant pressures, the nature values likely to be affected, the pathway by which exposure occurs, and any key assumptions, potential proxies, or uncertainties. It also helps avoid two common problems: (1)

including activities without showing why they matter ecologically, and (2) excluding important effects simply because the pathway has not been made explicit at the start.

Assessment indicators

Based on the identified pressure pathway, for each prioritised nature value, the scoping phase should specify not only the nature value itself but also the assessment indicator or indicators through which cumulative effects will be calculated. These indicators should be selected so that they are compatible, as far as feasible, with the MSFD assessment logic: they should relate to clearly defined ecosystem elements, pressures, and impacts under Annex III of Directive 2008/56/EC (Table 2), and where possible should be traceable to relevant MSFD descriptors, criteria and methodological standards under Commission Decision (EU) 2017/848.

For each prioritised nature value, one or more indicators from Table 2 should be selected during scoping. The selected indicator should match the expected pressure pathway and the type of potential effect that must be assessed in CIA and SEA. For example, disturbance pathways may require indicators of distribution, behaviour, movement, or habitat use; extraction or collision pathways may require mortality, injury, abundance, or population-structure indicators; and seabed disturbance pathways may require habitat extent, condition, substrate, morphology, or benthic-community indicators. Indicator selection should therefore be explicitly linked to the receptor, pressure pathway, expected effect type, available evidence, and relevant MSFD descriptor, criterion, or methodological standard. Potential indicators suggested in Annex III of MSFD (2008/56/EC) are available in Table 2.

Table 2. Candidate indicators / characteristics for assessing potential effects on prioritised nature values, based on Annex III of the MSFD as amended by Commission Directive (EU) 2017/845[22].

Nature value type	MSFD Annex III ecosystem element	Candidate indicators / characteristics for CIA scoping	Main relevance for CIA interpretation	Relevant MSFD descriptors
Marine birds, mammals, reptiles, fish and cephalopods	Species groups of marine birds, mammals, reptiles, fish and cephalopods	Distribution; abundance; density; biomass; size structure; age structure; sex structure; fecundity; survival rate; mortality rate; injury rate; movement; migration; behaviour; extent and suitability of habitat used by the species; species composition of the group	Used to assess changes in population status, displacement, disturbance, mortality/injury, habitat loss, migration barriers, or reduced ecological function	D1 Biodiversity; D3 Commercial fish and shellfish, where relevant

Pelagic habitats	Broad habitat types of the water column and associated biological communities	Habitat distribution; habitat extent or volume; species composition; abundance and/or biomass of associated biological communities; size and age structure of species where appropriate; physical characteristics; hydrological characteristics; chemical characteristics; chlorophyll-a concentration; plankton bloom frequency; plankton bloom spatial extent	Used to assess water-column habitat change, altered productivity, eutrophication-related effects, food-web change, pressure exposure, and changes in habitat condition	D1 Biodiversity; D6 Seafloor integrity where relevant; D4 Food webs may also be relevant
Benthic habitats	Broad seabed habitat types and associated biological communities	Habitat distribution; habitat extent; species composition; abundance and/or biomass of associated benthic communities; size and age structure of species where appropriate; physical characteristics; hydrological characteristics; chemical characteristics; seabed substrate; seabed morphology	Used to assess physical loss, disturbance, abrasion, smothering, habitat degradation, fragmentation, and changes in benthic community condition	D1 Biodiversity; D6 Seafloor integrity
Other specific habitat types, including protected, threatened, functionally important, or locally important habitats	Other habitat types, including associated biological communities	Distribution; extent; area; condition; associated species composition; abundance and/or biomass; structural integrity; physical, hydrological and chemical characteristics; ecological function; connectivity with other habitats	Used where the prioritised nature value is more specific than a broad MSFD habitat type, for example reefs, seagrass, mussel beds, spawning habitats, nursery areas, or Natura 2000 habitat features	D1 Biodiversity; D6 Seafloor integrity; D4 Food webs where functional links are assessed

STEP 2: Data screening, tool selection, and sensitivity matrix development

CIA Step 2’s (Figure 2) purpose is to turn the agreed list of priority nature values, human activities, pressures, and pressure pathways into a workable plan for data collection, tool selection, and sensitivity scoring.

Data screening and gathering

Data screening should begin by converting the Step 1 scoping report into a data-needs table. The table should capture the full set of information needed to support modelling actions and spatial and temporal assessments. This includes the core assessment layers, i.e. prioritised nature values, human activities and pressures, together with relevant administrative, management, environmental, and spatial context layers. These may include administrative boundaries, designated areas and management zones, cultural heritage layers, seabed characteristics, hydrological and oceanographic conditions, together with relevant potential data sources. Such information is essential for interpreting pressures and effects and supporting additional modelling.

In data-rich contexts, ready-to-use spatial layers may already be available. In data-poor contexts, however, the required spatial layers may need to be generated from underlying datasets. Therefore, data screening should consider both existing spatial layers and the datasets needed to create them. These may include point records of nature-value or human-activity locations, environmental datasets for species distribution modelling, and data sources needed to map human activities and pressures. Potential data inputs should be systematically identified, screened, and evaluated across multiple relevant sources:

1. **National databases:** National marine data should be identified through the institutions and authorities responsible for managing, monitoring or regulating maritime areas. Priority should be given to officially recognized, up-to-date and well-documented sources, including national environmental monitoring databases, marine biodiversity inventories, hydrographic and geological data services, fisheries and shipping datasets, protected-area registers, cultural heritage data, and maritime spatial planning datasets. Some open data may be available through publicly accessible national portals or data services managed by relevant institutions. In other cases, access to restricted or more detailed datasets may require additional permissions granted by the responsible authorities, in accordance with national procedures. Such databases may include time-series data, survey-based datasets, point observations, interpreted products, modelled spatial layers or management boundaries. Where national datasets are reported onward to wider regional or international systems, including HELCOM databases, EMODnet, OBIS or GBIF, the national source should still be checked where possible, as it may contain more complete metadata, methodological documentation, quality information, recent updates, and nationally validated interpretations.

2. **Open-access regional, pan-European, and global databases:** Regional and international data portals should be screened for nature values, human activities, pressures, management constraints and environmental context layers. These sources are especially useful in transboundary assessments because they often provide harmonised data products and standardised metadata. They may supply directly usable spatial layers, supporting context layers, or source data for the creation of derived layers. A more detailed overview of the most relevant portals for Baltic Sea and their potential contribution for different types of datasets relevant for CIA is provided in **Section 3.4**.
3. **Project reports, repositories** – Completed and ongoing projects should be reviewed because they may provide harmonised Baltic Sea scale datasets, modelled outputs, ecosystem service maps, metadata catalogues, or geoportals. These outputs are particularly valuable where standard databases do not provide the required variables in a directly usable form. However, project outputs vary considerably in format and accessibility, and some underlying datasets may need to be requested from project partners or host institutions. Some relevant examples are the Horizon Europe project PROTECT BALTIC that has produced high-resolution distribution models for hundreds of species at the Baltic Sea scale, or the Interreg project MAREA, which developed ecosystem functioning and services maps for the eastern Baltic Sea (Gulf of Finland, Estonia and Latvia).
4. **Built-in datasets and layers in Decision Support Tools** – Relevant activity and pressure layers, nature value layers, or sensitivity information may already be included in CIA decision support tools (e.g., PlanWise4Blue). These built-in resources should also be screened during data scoping, since they may provide a practical starting point for the assessment or shape the choice of the tool to be used. Built-in datasets and layers should always be checked for relevance, currency, scale and compatibility with the assessment needs defined in Step 1. An overview of the potential CIA tools is given in **Annex A**.

Fit-for-purpose assessment of candidate data

For each candidate dataset, it should be assessed whether it is suitable for the intended CIA task and compatible with relevant principles for spatially explicit datasets, particularly regarding spatial data quality, documentation, interoperability, and re-use. In the European context, these principles are supported by the INSPIRE Directive, which establishes an infrastructure for spatial information in the European Community to support environmental policies and policies or activities that may affect the environment [45]. INSPIRE is also closely aligned with FAIR data principles, which emphasise that data should be findable, accessible, interoperable, and reusable, although FAIR is a broader data-management framework and INSPIRE provides a more specific legal and technical framework for spatial datasets [46].

INSPIRE is therefore relevant for CIA because it promotes the harmonised documentation, accessibility, sharing, interoperability, and re-use of spatial data across sectors and countries.

The assessment should not be limited to confirming that a dataset exists or appears relevant. It should determine whether the dataset is appropriate for the specific analytical role it is expected to play in the CIA, for example as a nature value layer, activity layer, pressure layer, sensitivity layer, weighting input, validation source, background evidence.

The fit-for-purpose check should therefore examine the dataset in relation to the intended analytical question, spatial and temporal scale, required level of thematic detail, expected processing steps, and the other datasets with which it will be combined. Particular attention should be given to spatial, temporal and thematic mismatches, because these can affect comparability, reproducibility, model performance and interpretation of cumulative impact results. Where limitations are identified, the user should decide whether the dataset can be used directly, used after harmonisation or transformation, used only as supporting evidence, or excluded from the CIA workflow. The user should cover at least the following aspects:

a) **Geographic coverage and completeness**

Confirm that the dataset covers the full assessment area or, where relevant, the specific subarea for which it is needed. This check should include both the formal dataset extent and the actual presence of usable data within that extent. A dataset may technically cover the study area but still contain missing cells, unsurveyed zones, masked areas, incomplete national contributions or uneven representation across coastal, offshore or transboundary areas.

Check whether important subareas are missing, whether land-sea, coastal-offshore or transboundary zones are represented consistently, and whether gaps coincide with areas where cumulative effects are expected to be analysed. In a transboundary CIA, coverage should be checked separately for each country or planning area to avoid situations where apparent impact patterns simply reflect differences in data availability. If a dataset excludes areas of high expected pressure, sensitive nature values or key ecological connectivity zones (e.g., areas that help maintain ecological links between habitats, populations, or life-cycle stages), it may distort the assessment and should either be supplemented, gap-filled, or rejected.

The assessment should answer: Does the dataset cover the area needed for the specific CIA question, and would any missing or uneven coverage bias the result?

b) **Spatial resolution and scale**

Assess whether the spatial detail of the dataset is appropriate for the scale of the CIA. A very coarse dataset may be useful for regional assessment but not for localised planning decisions, while a very detailed dataset may be inconsistent with coarser layers used elsewhere in the assessment. The chosen resolution should allow meaningful interpretation of patterns without creating false precision.

The assessment should answer: Is the dataset's spatial resolution appropriate for the CIA task, and can it be combined with other layers without creating misleading spatial precision or bias?

c) **Temporal coverage, reference year and update status**

Check the time period represented by the dataset, the reference year (s) used, and whether the data are sufficiently up to date for the planning horizon and assessment scenarios. Some datasets describe a single point in time, while others reflect multi-year averages, historical conditions, or dynamic time series. The temporal characteristics should be appropriate for the intended use. A current-state assessment requires data that are recent enough to represent present conditions. A trend analysis requires comparable time steps or consistent observation periods. A scenario assessment requires inputs that are aligned with the planning horizon or scenario assumptions. A dataset representing a long-term average may be unsuitable for assessing short-term seasonal pressure peaks, while a single-year dataset may be unsuitable for representing stable baseline conditions.

There is also a need to verify whether the dataset's reference year aligns with other key layers. For example, combining a recent activity layer with an older nature value layers may create apparent changes or mismatches that are artefacts of different update frequencies. Seasonal misalignment should also be considered, especially where pressures or nature values vary strongly during the year, such as spawning areas, migratory routes, tourism intensity, nutrient loads, chlorophyll dynamics or seasonal fishing activity.

The assessment should answer: Does the dataset represent the right time period for the CIA question, and are its reference year, seasonality and update frequency compatible with the other selected datasets?

d) **Methodological consistency and production lineage**

Review how the dataset was produced and whether the method is internally consistent across the full assessment area. This includes the definitions, survey design, sampling density, modelling assumptions, classification rules, interpolation procedures, remote-sensing methods, expert judgement and validation approaches used to create the layers.

A dataset may be difficult to use in CIA if different methods were applied in different countries, sectors, years or subareas without clear documentation. Methodological differences can create patterns that appear ecologically or analytically meaningful but actually reflect changes in monitoring effort, model structure, data provider, or processing workflows. This is especially important in transboundary MSP, where national datasets may have different standards even when they appear to represent the same dimension. The assessment should check whether the dataset has a clear production lineage and whether any processing steps are reproducible. If the layer is derived, modelled or interpolated, the assumptions underlying the production should be understood before use. If methods differ across the study area, the dataset may still be usable, but the inconsistency should be documented and, where possible, corrected or accounted for in interpretation.

The assessment should answer: Was the dataset produced in a consistent and transparent way, and could methodological differences distort the CIA result?

e) **Thematic accuracy and relevance to the nature value, activity or pressure being represented**

Confirm that the dataset and layers to be used capture the variable required for the CIA with sufficient thematic precision. This criterion assesses whether the datasets and layers measure, map, or reasonably approximate the relevant nature value, activity, pressure, or sensitivity component. For example, a general habitat layer may be insufficient where the CIA requires information on specific spawning, nursery, or feeding areas. Similarly, a broad shipping-density layer may not adequately capture pressures such as underwater noise, collision risk, or seabed disturbance, which depend on different characteristics of vessel activity. Fishing activity data should contain sufficient detail on gear type, intensity, and spatial footprint when used to assess benthic abrasion. The assessment should distinguish between direct indicators and proxies. Proxy datasets may be acceptable where direct data are unavailable, but the logic of the proxy must be explicit and described. The assessment should clearly define the scope and limitations of the dataset, including any assumptions required for its use in the CIA.

The assessment should answer: Does the dataset represent the required CIA variable closely enough, or is it only a proxy requiring careful qualification?

f) **Comparability with datasets from other sectors or countries**

Assess whether the datasets and layers can be meaningfully combined with other selected datasets. This is particularly important in MSP and transboundary CIA, where datasets from different countries or sectors may differ in scale, spatial units, classification systems, update periods, data quality or access conditions. Datasets and layers do not need to be identical across sources or assessment areas, but they should be sufficiently compatible to allow meaningful comparison or transparent harmonisation. The assessment should identify what harmonisation would be required before use. This may include reprojecting, clipping, resampling, aggregating, reclassifying, converting units, aligning reference years, standardising attribute names, applying common thresholds. Special care is needed for cross-realm analysis, where terrestrial, freshwater, coastal and marine datasets often represent processes using different spatial units and assumptions. In such cases, integration may require an explicit analytical link, such as a shared pressure pathway, boundary condition or modelled relationship describing how a pressure is transferred from one area or realm to another, rather than simple spatial overlay.

The assessment should answer: Can this dataset be combined fairly with the other CIA inputs, and what harmonisation steps are needed before it can be used?

g) **Uncertainty and limitations**

Identify the main uncertainties associated with the datasets and layers and any limitations documented by the provider or apparent from the data itself. These may include incomplete coverage, sampling bias, low accuracy, modelling uncertainty, interpolation errors, classification errors, outdated inputs, uneven monitoring density, unknown representativeness or weak validation. The uncertainty assessment should be proportionate to the dataset's role in the CIA. A dataset or layers used to represent as a core nature value or pressure layer should be assessed more strictly than a dataset used only as background evidence. Where possible, the assessment should record whether uncertainty is spatially sensitive, for example, if it is higher in offshore areas, near borders, in shallow coastal areas or in poorly monitored sub-basins.

Uncertainty should determine how much weight a dataset is given in the CIA, rather than whether it is automatically excluded. If a dataset has important gaps, low spatial accuracy, outdated records, or uncertain classification, it may still help indicate where a pressure or receptor could occur. However, it should not be used as the sole basis for fine-scale prioritisation, quantitative comparison between areas, or conclusions that require a high level of confidence. Where such datasets are used, their limitations should be clearly stated and reflected in the interpretation of the results. The assessment should answer: What are the main uncertainties, how serious are they for the intended CIA use, and how should they be reflected in the analysis and reporting?

h) **Access, licensing and re-use conditions**

Check whether the dataset can be obtained, processed and reused for the assessment. Some datasets are openly downloadable, while others require permission, registration, data-sharing agreements, payment, or can only be applied with restrictions. These conditions should be clarified before the dataset is selected as a core input. The assessment should check whether the licence allows the intended use, including spatial analysis, modification, combination with other datasets, publication, sharing with project partners and inclusion in planning documents. If only restricted use is allowed, it should be specified whether derived outputs can be published and, if so, under what conditions, spatial resolution, or degree of aggregation.

The assessment should answer: Can the dataset legally and practically be used for the intended CIA workflow, outputs and reporting?

i) **Technical interoperability, including format, projection, coding and metadata availability**

Check whether the dataset can be integrated technically with the rest of the CIA workflow. This includes file format, coordinate reference system, spatial geometry, topology, raster grid alignment, attribute structure, coding conventions, units, naming consistency and compatibility with the selected GIS or modelling tools. A dataset may be thematically relevant but still difficult to use if it is poorly structured, lacks metadata, uses unclear codes, has invalid geometries, contains inconsistent attributes or is provided only in a non-standard format. Metadata should be sufficient to understand what the dataset represents, who produced it, when it was produced, what methods were used, what coordinate system and units apply, what limitations exist, and how it may be reused. The assessment should also check whether the dataset can be reproduced or traced after processing. Any transformations applied during CIA preparation, such as reprojection, resampling, aggregation, reclassification, or gap filling, should be documented to ensure that the final analytical information for a layer remains transparent.

The assessment should answer: Can the dataset be technically integrated, documented and reproduced within the CIA workflow?

The fit-for-purpose assessment should conclude with a clear decision on the dataset's role. Candidate datasets should not be treated as simply "accepted" or "rejected". Instead, each dataset should be assigned to one of the following categories:

- **Fit for direct use**: where the dataset is suitable for the intended CIA purpose with no major transformation beyond standard preparation.
- **Fit after harmonisation**: where the dataset can be used after documented processing, such as reclassification, temporal alignment, aggregation, resampling, format, or coordinate system conversion.
- **Fit only as a proxy**: where the dataset does not directly represent the required variable but can be used with explicit assumptions and limitations.
- **Fit only as supporting evidence**: where the dataset helps interpretation but should not be used as a core analytical layer.
- **Not fit for this purpose**: where limitations, incompatibilities or restrictions are too significant for the intended CIA.

Datasets that cannot be used directly should not automatically be discarded. Their limitations should be clearly documented and considered when deciding whether they can be harmonised, adjusted, modelled into a more suitable form or used as proxies. In many cases, a dataset that is not fit for direct use may still be valuable as background evidence, as an input to layer creation, or as a supporting source for interpretation. The final decision should always be linked to the intended CIA purpose, because the same dataset may be suitable for one analytical task but unsuitable for another.

Identification of data gaps and recommendations for addressing them

Data gaps, inconsistencies and limitations should be identified and recorded at an early stage of the assessment. This is important because missing, incomplete, outdated, incompatible or unevenly structured data can influence both the methodological choices made in later steps and the interpretation of the final CIA results. Gap recording should therefore not be treated as a minor technical note, but as an essential part of the assessment.

The fit-for-purpose assessment should provide the basis for identifying these gaps. Once a dataset has been reviewed, any limitation that affects its direct use in the CIA should be transferred into a gap and action record. This record should distinguish between cases where data are completely missing, cases where data exist but are not directly usable, and cases where data are usable only after proper processing. This distinction is important because different types of gaps require different actions.

For each important gap, inconsistency or limitation, a clear decision should be made on how it will be addressed in Step 3. Depending on the nature of the problem, this may include the following options:

a) Creation of new spatial data layers or derived layers

Where no directly usable layers exist, it may be necessary to create new ones from available data. This may involve interpolation, aggregation of point observations, modelling of species distributions, derivation of pressure layers from activity data, transformation of monitoring data into spatial surfaces, or other GIS-based processing methods.

This option should be used when the missing information is important for the CIA and when available input data are sufficient to produce a methodologically sound layer. The method used to create the layer should be documented, including input datasets, assumptions, spatial and temporal resolution, validation approach, and known uncertainties. Detailed descriptions of potential methodologies to create new or modify spatial data layers for nature values, human activities and pressures are provided in STEP 3 of the CIA process below.

b) Harmonisation of datasets from different sources

Where relevant data and layers exist but differ in format, scale, classification, spatial extent, coordinate reference system, attribute structure, or reference period, they may need to be standardised and aligned before they can be used together in the CIA. This is especially important in transboundary assessments, where national datasets often vary substantially in coverage, thematic classification, update frequency, and mapping methods.

Harmonisation may include reprojection, resampling, aggregation, reclassification and attribute standardization, temporal alignment, unit conversion, or the creation of a common spatial grid or assessment unit. The record should specify which harmonisation steps are required and whether they are expected to affect the interpretation of the data. For example, aggregation may reduce local detail, while reclassification may simplify important thematic distinctions.

c) Use of potential proxy datasets

Where direct data and layers are not available for specific nature values, human activities, and pressures, proxies may be used if the fit-for-purpose assessment has shown that it provides a scientifically meaningful approximation of the variable of interest. A proxy should be selected because it has a clear conceptual, ecological or pressure-related relationship to the missing variable, not simply because it is the only available dataset. For example, fishing vessel density may be used as a proxy for fishing intensity where direct fishing-pressure data are not available. Wide-scale habitat data, such as EMODnet seabed habitats [47], may be used as a proxy for the potential distribution of a prioritised species known to occur in specific habitat types, provided that the habitat-species relationship is sufficiently supported. Similarly, an activity layer may be used as a proxy for a pressure only where the link between activity and pressure is explicit and relevant to the CIA question.

The justification for the use of proxy should be documented clearly. The record should explain why the proxy is suitable for the assessment, what assumptions are involved, and how its limitations may influence the interpretation of results. Results based on proxy data should be distinguishable from results based on direct evidence.

Where suitable datasets or meaningful proxy layers are not available, structured expert assessments may be used as a complementary or alternative source of evidence. Expert assessments may help identify the presence, intensity, spatial extent, and/or relevance of a nature value, human activity, pressure, or pressure pathway, especially where information is held by national authorities, monitoring experts, sector specialists, local practitioners, or stakeholders rather than in standardised spatial datasets. Such assessment should be applied transparently, using a documented procedure that records who contributed, what evidence was considered, what assumptions were made, the level of confidence in the judgement, and how disagreement or uncertainty was handled. Where expert assessments are used to create or modify CIA input layers, the resulting outputs should be clearly distinguished from outputs based on direct monitoring data or validated modelled layers.

d) Unresolved gaps and improvement needs

Not all gaps can be resolved technically within the scope and with the resources of a given CIA process. Where the available evidence is too weak, too inconsistent or too restricted for reliable use, this should be acknowledged transparently. The assessment should state whether the limitation affects the full study area, a specific country, a particular subarea, a nature value, a pressure type or a time period. It should also explain how these limitations affect confidence in the results, including whether the evidence is sufficient to support spatial prioritisation, comparison between areas or alternatives, or decision-making, or whether it should be used only to identify issues that require further evidence.

Where a gap cannot be adequately resolved in the current assessment, the same record should include a recommendation for future data improvement. This may include targeted monitoring, improved metadata, more frequent updates, harmonised national and transnational reporting frameworks and the methods used for data and layer generation, common classification systems, access agreements, or development of shared transboundary datasets. In this way, the gap record serves both as a transparency tool for the current CIA and as a practical basis for improving future assessments.

Compilation of a transparent metadata inventory

In compliance with the MSP Data Framework (MSPdF) [48] and the metadata requirements established under the INSPIRE Directive [45,49], a transparent and structured data inventory should be compiled for all datasets considered within a CIA [50]. The purpose of the inventory is not only to list the datasets used, but also to document their origin, characteristics, processing history, limitations and role in the assessment. This is essential for transparency, reproducibility and later interpretation of results, especially where datasets from different sectors, institutions, or countries are combined. The inventory should include, for each dataset or spatial layer, at least the following metadata:

a) **Dataset / layer name:** The official title or a clear working name of the dataset or layer used in the assessment.

b) **Relevant MSPdF cluster:** The category under which the dataset is classified within the MSPdF structure, so that its role in the broader data framework is clear and datasets can be grouped consistently.

- Cluster 1: Marine & Coastal Environment - seabird distribution, benthic habitats, pelagic habitats, eutrophication indicators, contaminants, marine litter, underwater noise, seabed integrity.
- Cluster 2: Marine & Coastal Conservation and Designated Sites - marine protected areas, Natura 2000 sites, nationally designated protected areas, management zones, restriction zones, conservation objectives.
- Cluster 3: Oceanographic Characteristics and Climate - bathymetry, currents, waves, salinity, sea temperature, chlorophyll-a, oxygen, nutrients, sea-level trends, climate-related ocean indicators.
- Cluster 4: Coastal Land Use and Planning - coastal land use, land cover, ports, urban areas, coastal infrastructure, coastal plans, planned land-use zones.

- Cluster 5: Operative Maritime Activities and Planning - shipping, fisheries, aquaculture, offshore wind, cables and pipelines, dredging, tourism, military areas, maritime spatial plan zones.
- Cluster 6: Socio-economic Information - employment, income, gross value added, coastal population, sectoral economic activity, dependence on maritime sectors.
- Cluster 7: Governance Information - administrative boundaries, jurisdictional zones, competent authorities, legal restrictions, policy areas, management or regulation zones.

c) **Source**: The original source of the dataset or layer, such as the database, portal, institution, project repository or authority from which it was obtained. This should be specific enough for another user to locate the same dataset or layer.

d) **Publication date**: The date on which the dataset or product was published or made available, where known.

e) **Version**: The version number or release identifier of the dataset, where applicable, so that the exact dataset or layer used can be traced.

f) **Responsible institution**: The institution, agency, project or data provider responsible for producing or maintaining the dataset or layer.

g) **Geographic coverage**: The spatial extent covered by the dataset or layer, including whether it covers the full assessment area, only part of it, or a wider surrounding area.

h) **Spatial resolution**: The spatial detail of the dataset, such as grid size, scale, minimum mapping unit, or other relevant measure of spatial granularity.

i) **Coordinate reference system**: The coordinate reference system or map projection used by the dataset, which is essential for technical compatibility and harmonisation.

j) **Temporal coverage**: The period represented by the dataset, including the reference year, time range, averaging period, or update cycle where relevant.

k) **Key variable(s) and unit(s)**: The main variables contained in the dataset and the units in which they are expressed, so that their analytical meaning is clear.

l) **Pressure, nature value or sensitivity element represented**: A short statement of what the dataset represents within the CIA, for example whether it is used as a pressure layer, a nature value layer, a sensitivity input, or a supporting context layer (e.g. biological or environmental datasets or layers to be used in modelling workflows for the creation of new layers, or relevant administrative layers to provide relevant management context).

m) **Method of production / processing** (monitoring, modelled, interpreted, derived): A description of how the dataset was produced, for example, whether it is based on direct monitoring, expert interpretation, modelling, interpolation, or other derived processing.

n) **Aggregation or standardisation method used**: Where relevant, the inventory should record any aggregation, rescaling, reclassification, harmonisation or standardisation applied before the dataset was used in the CIA.

o) **Key assumptions**: The main assumptions associated with the dataset or its use in the assessment, including assumptions made during modelling, interpolation, use as a proxy, or conversion into analytical layers.

p) **Limitations (legal or technical) and uncertainty**: A short description of known limitations, including access restrictions, licensing issues, incomplete spatial coverage, scale mismatch, methodological uncertainty, or other relevant weaknesses that may affect interpretation.

q) **Fit-for-purpose decision**: Record the outcome of the fit-for-purpose assessment from the previous section "Fit-for-purpose assessment of candidate data". This should state whether the dataset is fit for direct use, fit after harmonisation, only as a proxy, or as supporting evidence, or not fit for this purpose.

The data inventory should be maintained as part of the formal assessment record and updated throughout the process whenever datasets are replaced, revised, further processed or supplemented. In this way, the inventory becomes a living record of the evidence used in the CIA and helps ensure that the assessment remains transparent, traceable and defensible during consultations, revisions and plan updates.

Tool selection based on technical requirements

Once data scoping is complete, a suitable spatially explicit CIA tool should be selected. Tools differ substantially in accessibility, user-friendliness, analytical scope and data needs, even when they are all described as CIA tools [51]. Some tools already include baseline datasets, pressure layers, nature-value layers, or sensitivity matrices, while others require users to prepare and upload most input data. Descriptions of selected CIA tools, including data availability and options for data incorporation, are provided in Annex A. For example, PlanWise4Blue and HELCOM SPIA provide Baltic Sea-oriented datasets and are therefore more immediately applicable for Baltic-focused assessments using existing regional data. By contrast, tools such as Symphony, Tools4MSP, and MYTILUS may offer greater flexibility for customized analyses, but they usually require more preparation of input layers, sensitivity matrices, and case-study settings. Interactive portals such as the MPA Solutions Hub (https://mpacommunity.network/tools-blueprints/) can help users identify suitable tools, including newly developed or improved applications.

Descriptions and locations of potential CIA tools relevant to the Baltic Sea, including HELCOM SPIA, PlanWise4Blue, Symphony, MYTILUS, and Tools4MSP, are provided in Annex A. The list should not be considered exhaustive. Rather, it presents examples of tools that could potentially be used for CIA in the Baltic Sea, depending on assessment objectives, data availability, technical capacity, and institutional needs.

In general, all CIA tools require three core input components. However, the technical requirements for these components vary between tools:

1. **Nature values**

Nature values are the ecosystem features for which potential cumulative effects are assessed. These may include species, habitats, ecological communities, ecosystem processes, and ecosystem services. In CIA tools, nature values are usually represented as gridded layers. Depending on data availability, these layers may describe presence or absence, probability of occurrence, habitat suitability, density, biomass, abundance, habitat extent, ecosystem processes such as carbon storage or sequestration, or the potential supply of provisioning, regulating, and cultural ecosystem services.

In many CIA tools that generate integrated assessment outputs, nature-value layers must be normalized before they can be combined. This is necessary because the original datasets may differ in units, classifications, spatial resolution, and value ranges. Normalizing layers to a common numerical scale, such as 0-1 or 0-100, allows different ecosystem components to be integrated consistently and helps prevent individual layers from contributing disproportionately to the final assessment simply because of differences in scale or value distribution. For example, fish biomass, bird abundance, benthic habitat suitability, and habitat area cannot be directly combined unless they are first transformed into comparable values. However, normalization also affects how the outputs should be interpreted. Once nature-value layers are transformed into comparable relative values, the resulting integrated outputs are best understood as indicators of cumulative impact risk. They can show where important nature values and pressures are likely to overlap and where cumulative impact risk may be higher, but they cannot be formally used to estimate expected change in habitat extent, biomass, abundance, density, or other quantitative dimensions of ecosystem features. In this sense, normalization approaches are generally more suitable for identifying relative spatial patterns of cumulative impact risk than for estimating actual ecological effects.

PlanWise4Blue differs in this respect because it operates with raw, quantitative layers and produces disaggregated outputs for different nature values, such as the density, biomass, abundance, or spatial extent of the distribution of species and habitats. This means that the tool assesses effects on individual nature values separately, rather than producing aggregated cumulative impact risk outputs. By combining input layers that retain their original quantitative meaning with expected effect magnitudes derived from empirical evidence, systematic reviews and meta-analytical approaches, or structured expert-based estimates, the tool can estimate potential changes in the amount or spatial distribution of nature values under different pressure scenarios.

When selecting a CIA tool, users should therefore consider whether the available nature-value data and the selected tool only support relative, aggregated risk outputs, or whether they allow effects to be assessed separately for individual nature values, formally estimating ecological effects.

2. **Human activities and pressures**

The second core input required for CIA is spatial information on human activities and the pressures they generate. Human activities may include, for example, shipping, fishing, aquaculture, offshore wind energy, sand extraction, dredging, coastal development (e.g., coastal protection, port construction and expansion), tourism, or military activities. Pressures describe the mechanisms through which these activities may affect nature values, such as seabed disturbance, underwater noise, nutrient input, hazardous substances, habitat loss, extraction of species, physical barriers, or changes in hydrological conditions. A distinction should be made between activity layers and pressure layers. Activity layers describe where and, where possible, how intensively human activities occur. Pressure layers describe the spatial distribution and intensity of the stressors generated by those activities. This distinction is important because the relationship between activities and pressures is not one-to-one. A single activity can generate multiple pressures, and the same pressure can be generated by several activities. For example, shipping may contribute to underwater noise, collision risk, pollution, and seabed disturbance from anchoring, while bottom trawling may contribute to seabed abrasion, habitat modification, and extraction of target or non-target species.

As was the case for nature values, CIA tools require activity or pressure data to be represented as gridded intensity layers. These layers are often standardised to a common scale, such as 0-1 or 0-100, where higher values indicate higher activity or pressure intensity. Standardisation is needed because different pressures are measured in different units and cannot be directly combined without transformation. For example, shipping density, fishing effort, and nutrient load represent different types of information and must be converted into comparable spatial representations before they can be used within a common cumulative impact framework. The preparation of pressure layers can range from relatively simple to highly interpretative. In some cases, an activity layer may already provide an acceptable proxy for pressure intensity, such as a gridded fishing-effort layer used to represent seabed abrasion. In other cases, activity data must be translated into pressure layers using assumptions about pressure generation, spatial spread, decay distance, duration, intensity, and ecological relevance. This step is technically important because it strongly influences the resulting assessment outputs. Poorly defined pressure layers may overestimate or underestimate potential impacts, particularly where pressures extend beyond the footprint of the activity or vary substantially in intensity over space and time. CIA tools differ in the extent to which they support this translation from activities to pressures. Some tools require users to provide pressure-ready layers, while others include functions for defining pressure weights, propagation distances, or scenario-specific pressure intensities. Tools4MSP, for example, allows users to define pressure weights and propagation distances, supporting explicit assumptions about how pressures spread from activity areas. HELCOM SPIA relies on pressure layers derived from harmonised regional Baltic Sea data layers, which cannot be adjusted for the inclusion of future scenarios within the tool. PlanWise4Blue allows users to adjust pressure intensity and add or remove spatial polygons, making it particularly useful for scenario testing involving planned developments, alternative spatial configurations, or management measures.

For tool selection, users should therefore assess whether they already have pressure-ready spatial layers or whether they need a tool that supports the translation of human activities into pressure layers. They should also consider how transparently the tool documents assumptions about pressure intensity, spatial extent, propagation, and standardisation, because these assumptions directly affect the interpretation of cumulative impact results.

3. **Sensitivity or effects matrix**

The third core input is a sensitivity or effects matrix. In practical terms, it describes how sensitive each nature value is to each relevant pressure or activity and provides the ecological link between spatial overlap and the interpretation of cumulative impact risk or potential ecological effects, depending on the analytical approach implemented by the tool. This link is critical because the spatial overlap alone does not indicate either impact risk or ecological effect. A pressure may overlap with a nature value, but the relevance of that overlap depends on whether the nature value is sensitive to the pressure and on the expected strength, direction, and severity of the response. Without this relationship, a tool can show where pressures and ecosystem components coincide, but it cannot meaningfully assess whether that overlap represents relevant cumulative impact risk or potential changes in the nature value.

A sensitivity or effects matrix assigns a value to each pressure-nature value combination. These values describe the expected response of a nature value to a given pressure, based on available evidence or expert judgement. Depending on the assessment approach, they may be expressed as semi-quantitative sensitivity scores or expected effect magnitudes. The way these values are used also differs between tools (Annex A). In some approaches, they are primarily used to weight the spatial overlap between pressures and nature values and generate relative cumulative impact risk outputs. In others, they support the estimation of potential changes in the amount, condition, or spatial distribution of individual nature values when combined with quantitative nature-value and pressure information.

The information used to populate sensitivity or effects matrices also varies between tools. Some tools rely primarily on expert-derived categorical scores, while others incorporate coefficients informed by scientific literature (through the usage of systematic reviews with meta-analyses), monitoring data, or other empirical evidence sources. For example, HELCOM SPIA includes a regional expert-based sensitivity matrix developed for cumulative impact assessment in the Baltic Sea. PlanWise4Blue includes effect coefficients informed by systematic reviews and meta-analytical approaches, supplemented by expert judgement where empirical evidence is limited.

Developing a sensitivity or effects matrix can be one of the most time-consuming and influential steps in a CIA. It requires clear definitions of pressures and nature values, a structured review of available evidence, use of existing regional or national sensitivity products where available, and expert judgement where empirical evidence is limited. Where possible, sensitivity values should also include information on confidence or uncertainty, because some pressure–nature value relationships are better documented than others. Details on creating a sensitivity or effects matrix are provided in next section “Selection and development of the sensitivity or effects matrix”.

Additional technical considerations for tool selection

In addition to these three core components, several practical and technical aspects should be considered before choosing a CIA tool.

First, users should consider the spatial resolution required for the assessment. HELCOM SPIA commonly uses a 1 km x 1 km grid (to be updated to 250 m x 250 m in August 2026), while Symphony has been applied at both 250 m x 250 m and 1 km x 1 km resolution. Tools4MSP and MYTILUS are more flexible and can work at different resolutions, depending on the input data and case-study setup. PlanWise4Blue typically uses 1 km x 1 km grids for standard assessments, but the effective resolution depends on the input layers.

Second, users should consider the level of technical expertise available. Web-based tools such as PlanWise4Blue, HELCOM SPIA, WIO Symphony, and the Tools4MSP geoplatform are generally easier to access and use. Desktop or stand-alone workflows, such as Symphony, MYTILUS, the HELCOM SPIA desktop version, and Tools4MSP, may require GIS skills, data processing experience, software installation, or scripting knowledge.

Third, users should consider whether the assessment requires scenario analysis. If the objective is to compare alternative planning options, planned developments, management measures, or future pressure intensities, the selected tool should support scenario creation and comparison. PlanWise4Blue, Symphony, Tools4MSP, and MYTILUS are particularly relevant for scenario-based applications, while HELCOM SPIA is especially useful for regional pressure and impact mapping based on standardized Baltic Sea assessment layers.

Fourth, users should consider the required output format. Some tools produce mainly map-based outputs, while others also provide tabular summaries, statistics, graphs, scenario comparisons, or GIS-exportable raster files. If results need to be used in further GIS analysis, exported to ArcGIS or QGIS, or included in reporting workflows, this should be checked before tool selection.

Finally, users should consider uncertainty and confidence reporting. Some tools provide quantitative confidence intervals or uncertainty analysis, while others provide qualitative confidence assessments or do not document confidence estimates separately. Where the results will support policy decisions, planning choices, or stakeholder communication, the ability to describe uncertainty clearly may be an important selection criterion.

Overall, the tool should be selected only after confirming that the available data match the tool's input requirements, that the tool can answer the assessment question, and that the users have sufficient technical capacity to prepare the data, run the analysis, interpret the outputs, and communicate the results.

The tool selection decision should be recorded to state explicitly:

a) Why the tool was chosen in relation to the assessment purpose, considering the series of aspects detailed in the previous sections.
b) Whether it already contains relevant datasets, pressure layers, nature value layers and sensitivity or effects matrices.
c) Whether built-in elements are suitable for the national or transboundary planning context, or instead need to be replaced, updated or complemented by national or regional data.
d) The specific data requirements for tool implementation

Selection and development of the sensitivity or effects matrix

The key practical question regarding the sensitivity or effects matrix is what type and level of information are required for the assessment, and how these values are used within the selected CIA framework. Depending on the assessment objective and data availability, matrices may include relatively simple sensitivity scores or more quantitative effect estimates. In general, simpler scoring approaches are often used to support relative cumulative impact risk assessments, while more quantitative information may help support interpretation of the potential magnitude or direction of ecological change. However, the distinction is not always strict, and many tools combine elements of both approaches.

Where a specific tool is selected for CIA implementation, the sensitivity or effects matrix should be developed or adapted to match the tool's methodological requirements, including its input format, scoring system, assumptions, and the way sensitivity or effect values are applied in the assessment. If the selected tool already includes a sensitivity or effects matrix (Annex A) with the required scores for the prioritised nature value and human activity or pressure combinations, this matrix may be used, provided that its suitability for the assessment context is confirmed and documented.

Two main approaches can be used to develop or refine these values: literature-based assessment and structured expert judgement. Some tools and assessments rely mainly on expert judgement, particularly where empirical evidence is limited or difficult to transfer to the assessment context. Where reliable quantitative evidence is available, it can be used to inform sensitivity scores or effect values, while expert judgement can be used to address remaining gaps, provided that assumptions and uncertainty are clearly documented.

1. **Literature-based approach**

In the literature-based approach, sensitivity or effects scores are based on documented evidence of how nature values respond to human activities or pressures. This approach uses published observational or experimental studies, monitoring data, or meta-analyses to estimate the sensitivity or effects of a pressure on a species, habitat, or ecosystem process.

This approach is strongest where there is enough reliable evidence to quantify the relationship between a pressure and a nature value. It can provide more transparent and reproducible sensitivity and effects scores than expert judgement alone, because each value can be traced back to published or observed evidence. It is especially useful when the aim is to estimate not only relative sensitivity, but also the potential magnitude or direction of change in a nature value. The approach generally involves three main steps:

a) Systematic literature review

Relevant scientific and technical evidence should be identified through a structured literature search performed in well-established academic search engines (e.g., Web of Science, Scopus). A search string should be designed combining, in the specific case of CIA, terms related to the nature value of interest, the relevant activities or pressure, and the response variable being assessed. For example, searches may combine terms related to a set of species, habitats, ecosystem processes, or ecosystem services with pressures such as seabed disturbance, underwater noise, nutrient enrichment, contamination, fishing pressure, offshore wind development, habitat loss, or other relevant stressors. The review should define clear inclusion and exclusion criteria before the evidence collection process begins. These criteria may include geographic relevance, ecological relevance, comparability of the assessed activity or pressure with the activities and pressures included in the CIA, study design, quality of evidence, response variable measured, temporal scale, or environmental context. Preference should generally be given to studies capable of establishing clear cause-effect relationships, such as controlled experiments, Before-After Control-Impact (BACI) studies, or time-series studies that allow comparison of conditions before and after the action of a specific activity or pressure.

Where available, the review should prioritize peer-reviewed scientific publications. However, valuable evidence may also be obtained from technical reports, long-term monitoring programs, environmental impact assessments, and other sources of grey literature, particularly when these provide information that is not available in the scientific literature. Regardless of the source, the quality, relevance, and transferability of the evidence to the assessment context should be critically evaluated and documented. The resulting evidence is used to derive sensitivity scores or effect values for the pressure-nature value combinations included in the assessment. Depending on the amount and quality of available evidence, this may involve a qualitative synthesis of findings, a quantitative synthesis using meta-analysis.

b) Extraction of relevant evidence

Relevant information is extracted from each study retained in the systematic review using a carefully designed data-extraction template. This step ensures that evidence from different sources can be consistently analyzed and, where appropriate, combined. Extracted information should include the nature value assessed, the activity or pressure considered, the pressure intensity or exposure level, the response variable measured, the spatial and temporal scale of the study, the implemented study design, and the direction and magnitude of the observed effect. The extracted information should include control and impact conditions, sample size, variability and measures of uncertainty, and an assessment of the quality of the study. Response variables may include, for example, changes in abundance, biomass, density, survival, reproduction, behaviour, habitat quality and area, probability of occurrence, ecosystem processes and services such as carbon storage and sequestration.

This information provides the basis for translating individual study results into sensitivity scores or effect values that can be used in the CIA matrix. It also helps identify where evidence is strong or uncertain, and where expert judgement may be needed to fill persisting gaps.

c) Calculation and translation of effect sizes

The extracted evidence is then converted into effect-size information. Effect sizes provide a standardized way to express the magnitude and direction of a response, allowing results from studies that use different units, scales, or response variables to be compared and, where appropriate, combined. For each nature value-pressure combination, an effect size value will be estimated. For continuous response variables, such as biomass, density, abundance, growth, or habitat area, effect sizes may be expressed using measures such as Hedges' g or log response ratios. Hedges' g is useful when comparing differences between control and impacted conditions in standard deviation units, while log response ratios are useful when the interest is in expressing proportional change between exposed and control conditions. For responses expressed as binary or frequency variables, such as survival or occurrence, odds ratios or related effect measures may be more appropriate.

Where several comparable studies are available, effect sizes can be synthesized using meta-analytical approaches to estimate an overall response for a given pressure-nature value relationship. The resulting estimate can provide information not only on the expected direction of change, but also on its magnitude and uncertainty. These values may then be used directly in tools that support quantitative effect coefficients, such as PlanWise4Blue, or translated into the scoring scale required by tools that operate with semi-quantitative sensitivity score classes.

2. **Expert-based approach**

In the expert-based approach, sensitivity scores are derived from the judgment of specialists with knowledge of the relevant species, habitats, pressures, and regional conditions. This approach is commonly used when scientific evidence is incomplete, difficult to compare, or not available at the required spatial or ecological scale. Expert-based assessments have already been carried out in several marine areas, including the Irish Sea, the Spanish Cetacean Migration Corridor, Burgas Bay in Bulgaria, and the Norwegian Raet National Park area. These have been developed through projects such as MSP4BIO [24], Blue Connect [26], and Blue4all [25], as well as through national initiatives. Where such matrices already exist, they can be reviewed and adapted rather than creating a new matrix from the beginning. In the Baltic Sea, an expert-based sensitivity matrix has been developed for the human pressures and ecosystem components prioritised in HOLAS [43]. This provides a useful regional example of how expert scores can be generated in a structured way: experts assessed pressure and ecosystem-component combinations using categories for tolerance or resistance, recoverability, sensitivity, impact distance, impact type and confidence, and the qualitative sensitivity categories were transformed into numerical scores for use in the Baltic Sea Impact Index. The approach also included a confidence assessment based on the number of expert replies, variability among responses and expert self-evaluated confidence. The resulting scores provide a regional basis for estimating the potential sensitivity of HOLAS ecosystem components to different human pressures and can therefore be used as a starting point for Baltic Sea CIA, provided that the pressure categories, nature values, scoring logic, and confidence levels are suitable for the specific assessment context.

An expert-based approach usually follows a structured process:

a) Define the human activity/pressures-nature values relationships to be assessed

Before the expert elicitation begins, the assessment team should define the exact pressure-nature value combinations to be scored. These combinations should be aligned with the spatial layers decided to be used and the pressure pathways defined for the CIA to be performed. If the assessment is based on pressure layers, experts should score the effect of each pressure on each nature value, rather than scoring broad human activities. As has been mentioned before, this is an important distinction since a single activity can generate several pressures with different ecological consequences.

b) Select and brief experts

Experts should be selected to cover the main ecological, technical, and regional dimensions of the assessment. Depending on the scope of the CIA, this may include specialists in benthic habitats, fish, seabirds, marine mammals, habitat mapping, fisheries, pollution, offshore infrastructure, and maritime spatial planning (among others). The expert group should collectively understand both the nature values being assessed and the pressures represented in the spatial analysis. Before the scoring begins, experts should receive clear guidance on the purpose of the matrix, the definitions of each nature value and pressure, the spatial and temporal assumptions of the assessment, and the meaning of each of the elements to be scored. This helps ensure that scores are assigned consistently and that experts are evaluating the same pressure-nature value relationships. Using several experts is important as individual interpretations may differ. Thus, a broader expert group helps reduce individual bias, capture different types of knowledge, and improve the credibility and robustness of the final matrix.

c) Sensitivity or effects scores

Experts are usually asked to score the sensitivity or expected response of each nature value to each activity or pressure using a predefined scoring system and considering the activity or pressure in high intensity. In many assessments, a simple ordinal scale is used, such as a Likert 0-5 scale, where 0 indicates no relevant interaction between the nature value and the activity or pressure, and 5 indicates a very strong expected effect (Table 3, [26]). Such scales are primarily designed to represent the relative sensitivity or vulnerability of nature values and are commonly used in cumulative impact risk assessments. Alternative approaches may use scores that represent expected effect magnitudes more directly. For example, the matrix architecture used in PlanWise4Blue expresses each pressure nature value interaction on a 0.0–1.0 scale, interpreted as the proportion of the nature value expected to remain after the pressure effect is applied. A value of 1.0 indicates no expected loss, while progressively lower values indicate stronger effects. For example, a score of 0.9 implies that 90% of the nature value is expected to remain and 10% is expected to be lost, whereas a score of 0.8 implies a 20% reduction. A value of 0.0 represents complete loss of the nature value. This approach allows scores to be interpreted as expected proportional changes in the nature value, rather than only as relative classes of sensitivity.

Regardless of the scoring system used, experts should also be encouraged to provide confidence scores, comments, references, or explanations supporting their judgements. This additional information is particularly valuable for documenting uncertainty, identifying areas of disagreement, and distinguishing well-supported assessments from those based on limited evidence.

Table 3. An example of sensitivity score levels, based on Blue Connect Deliverable 3.1 [26].

Score	Description
0	Not relevant for this nature value - The activity or pressure does not interact with this nature value.
1	Marginal effect on the nature value - Negligible or barely detectable impact on the nature value. No measurable changes expected.
2	Low effect on the nature value - Activity/pressure has minor impact with only limited or localized effects. In general, the ecological subject remains largely unaffected.

3	Medium effect on the nature value - Activity/pressure has moderate impact with some visible consequences on the nature value population or habitat integrity.
4	Strong effect on the nature value - Activity/pressure has a strong impact with substantial visible consequences on the nature value population or habitat integrity.
5	Very strong effect on the nature value - Activity/pressure has removed the nature value or caused a substantial decline in population size or habitat area.

d) Review and combine expert scores

After scoring, the results should be reviewed for consistency. Large differences between experts should be discussed, especially where scores strongly influence CIA results. The final score may be calculated as an average, median, mode, or agreed consensus. The selected aggregation method should be documented. Where experts provide confidence scores, these can be used to identify uncertain pressure-nature value combinations. Low-confidence scores should not necessarily be removed, but they should be highlighted and, where possible, checked against available literature.

Combining the two approaches

In many CIA applications, the most practical solution is to combine both approaches. Scientific evidence should be used wherever sufficient and relevant data are available. Expert judgement can then be used to interpret mixed evidence, fill evidence gaps, adapt scores to local conditions, or validate scores derived from literature.

A combined approach may follow a tiered process:

1. Use existing tool-specific or regional sensitivity matrices where they are available and suitable.
2. Review scientific evidence for the most important or uncertain nature value-pressure relationships.
3. Use expert judgement to fill missing combinations and adapt scores to the assessment context.
4. Document confidence levels and evidence sources for each score.
5. Test how sensitive the CIA results are to uncertain or high-influence scores.

This combined approach is often the most realistic for Baltic Sea CIA, because some pressure-nature value relationships are well documented, while others remain uncertain or context-dependent.

Preparing the sensitivity or effects matrix for the selected tool

The sensitivity or effects matrix created or identified in Step 2 should also be prepared for implementation in the selected tool or workflow. Where a sensitivity matrix is already included in the selected tool, its suitability should be confirmed before use. This includes checking whether the matrix covers the nature values, human activities, pressures, and spatial context of the assessment. Any adjustments should be documented.

Where an external or newly developed matrix is used, it should be reformatted and harmonised to match the structure and scoring requirements of the selected analytical approach. This may include:

- Aligning nature value, activity, and pressure categories with the datasets used in the assessment.
- Checking whether the tool requires sensitivity scores by activity, by pressure, or by activity-pressure combination.
- Completing missing combinations where there is a justified interaction pathway.
- Marking non-relevant combinations clearly, rather than treating them as missing data.
- Standardising terminology, codes, taxonomic names, pressure names, and habitat classifications.
- Converting categorical scores into a numerical scale as required by the tool.
- Normalising or rescaling sensitivity values, for example from 0-5 to 0-1 where required.
- Documenting whether scores represent impact vulnerability/sensitivity or actual magnitudes of effects.
- Recording the evidence source, expert source, confidence level, and any assumptions for each score.

All adjustments should be clearly recorded, because the sensitivity matrix is a critical determinant of CIA results. Even small changes in sensitivity scores can influence which areas appear as cumulative impact hotspots and which activities are identified as major contributors. Therefore, the final matrix should be treated as a core assessment product, not only as a technical input file.

STEP 3: Preparation of layers for CIA

The purpose of Step 3 is to transform the data decisions made in Step 2 into a complete, harmonised, and tool-ready input package of layers for CIA implementation (Figure 2). Step 2 identified which datasets are suitable, which gaps remain, which datasets require harmonisation, which proxy datasets may be acceptable, and which inputs need to be created or adapted. Step 3 implements these decisions into practice.

Addressing data gaps through the creation of new or derived layers

The first task in Step 3 is to address the gaps identified during Step 2. Where Step 2 concluded that no directly usable layer exists, but sufficient supporting data are available, a new or derived spatial layer should be created. New or derived layers should only be created where there is both a clear analytical need and a scientifically sound method to produce them. The method for producing the layers should be transparent, reproducible and well documented, including the input data, assumptions, processing steps, validation approach and uncertainty.

Methods for generating nature value layers

Before developing new spatial layers for nature values, users should first assess whether suitable datasets already exist in global, regional, or national repositories (see paragraph 3.4, for a detailed overview of potential data sources) that can provide an ecologically meaningful representation of the nature value for the purposes of the CIA. This assessment should consider whether the available data are sufficiently complete, up to date, spatially resolved, and free from major sampling biases to represent the nature value at the scale and level of detail required by the assessment. If these conditions are met, additional modelling, refinement, or development of new layers may be possible.

Species distribution models (SDMs) provide the foundation for developing many biodiversity-related nature-value layers used in CIA, particularly those representing species, habitats, ecological communities, and other derived nature value layers, such as for ecosystem processes and services, that depend on information about species or habitat distributions. These approaches use biological observations together with environmental predictors to estimate the likely distribution, habitat suitability, abundance, or biomass of nature values across space, depending on the biological data available [52–55]. Depending on the available data and modelling objectives, methods such as Generalized Linear Models, Generalized Additive Models, Random Forests, Boosted Regression Trees, XGBoost, or MaxEnt may be applied [54,56–62]. The environmental variables required for these models are increasingly available through global, regional, and national environmental data repositories, including Copernicus and EMODnet marine related data services. Common predictors include depth, salinity, temperature, substrate type, oxygen concentration, hydrodynamic conditions, and other variables known to influence species and habitat distributions. Where both biological observations and environmental predictors are available, SDMs can generate ecologically meaningful spatial layers at resolutions suitable for spatial planning and cumulative impact assessment. Regardless of the modelling technique used, model performance, uncertainty, sampling bias, and ecological plausibility should be carefully evaluated [54,55,63]. At the Baltic Sea scale, substantial progress has recently been made through the Horizon Europe project PROTECT BALTIC, which generated harmonized distribution layers for hundreds of species and habitats across the region. These products provide an important starting point for CIA applications by making harmonized nature-value layers available for direct use or adaptation, while also supporting more consistent and coordinated assessments across countries. This is particularly important in transboundary and Baltic Sea-scale applications, where using a shared spatial evidence base can both reduce duplicated modelling efforts and improve the comparability of CIA results. However, their suitability should still be assessed in relation to the specific planning question, assessment scale, and nature values considered.

Some nature values, particularly ecosystem processes and ecosystem services, require modelling approaches that go beyond traditional SDMs. While building on species and habitat distribution layers, they also require integrating empirical observational and experimental evidence on the processes represented or using process-based and biogeochemical models to estimate ecosystem functions and services such as nutrient regulation, carbon storage and sequestration, water purification. The Interreg Central Baltic project MAREA (www.bef.lv/projekti/marea-en/) provided a relevant workflow and Baltic Sea examples for developing ecosystem-service layers by building on distribution models and incorporating quantitative process-based evidence for the spatial quantification of ecosystem functioning and service provision [64]. In relation to cultural ecosystem services, MAREA further provides examples of how participatory approaches can support the mapping of leisure activities, perceived coastal values, and their contributions to human well-being [65].

Methods for generating human activity and pressure layers

Human activity and pressure layers are needed to represent the spatial distribution and intensity of pressures caused by human uses of the sea. As has been mentioned in previous sections, in the frame of CIA, it is important to distinguish between activity layers and pressure layers. In many cases, available data represent only the location of infrastructure, events or activity records, rather than the full spatial extent of the associated pressure. For example, pipeline data may be provided as lines, discharge outlets as points, and port infrastructure as polygons. These geometries do not automatically represent the ecological influence area of the activity. It is therefore often necessary to derive pressure-relevant layers from more limited activity data.

1. **Footprint-based mapping**

The simplest approach is to use the directly affected area of the activity or infrastructure as the pressure layer. This is appropriate only when the pressure is expected to remain largely confined to the area physically occupied, removed, or structurally modified by the activity. Clear examples include permanent habitat loss under built infrastructure, seabed removal within an extraction area, or direct seabed disturbance within a dredging area. In these cases, the pressure layer should be based on the mapped activity area or on technical information describing the actual area affected, such as the dimensions of the structure, installation corridor, excavation area, or modified seabed.

2. **Buffer-based pressure mapping**

Buffering is used when the pressure extends beyond the location of the activity, but where a relatively simple representation of an influence zone is sufficient (e.g., pipelines and cables, aquaculture sites, dredging and disposal sites). A buffer creates a defined area around a point, line or polygon feature. Buffering can represent either the estimated activity footprint or the wider pressure influence area, depending on the case. For example, a narrow buffer around a pipeline may be used to estimate the area of physical loss or disturbance, while a wider buffer around a dredging site may be used to represent potential sediment resuspension or disturbance. Buffer distances should not be selected arbitrarily. They should be based on a clear rationale that combines the technical characteristics of the activity with the best available evidence on how the pressure behaves in the environment. Where evidence is limited, expert judgement may be used, provided that the assumptions are clearly documented.

For the Baltic Sea, HOLAS 3 [27] provides useful regional examples of how activity and pressure layers can be prepared and harmonised for cumulative impact assessment, including aggregated pressure layers derived from multiple human activities and spatial datasets. Earlier HELCOM BSII work also provides methodological examples of applying spatial extent assumptions, impact distances, decay patterns and weighting when transforming activity data into pressure-relevant layers [43]. These values can be used as a starting point, but they should be checked for suitability in the local context before being applied.

3. **Spatial modelling of pressure propagation**

Explicit modelling of pressure propagation is a more advanced approach than representing pressure only through a fixed activity footprint. It is used when the pressure can extend beyond the area where the activity occurs and when its intensity is expected to change with distance or environmental conditions. This approach is particularly relevant for the spatial representation of pressures such as underwater noise, sediment plumes, nutrient inputs, contaminants, or other pressures that spread through the marine environment.

Several methods can be used to model the propagation of pressures in space. The simplest approaches assume that the pressure intensity decreases with distance from the source, for example through distance-decay functions or concentric zones of influence with progressively lower intensity. Classic approaches use kernel or distribution functions to represent gradual spatial spreading around the source. In situations where propagation is influenced by environmental conditions, process-based approaches may be more appropriate. These can account for factors such as currents, waves, wind, depth, or habitat-specific attenuation, allowing pressure propagation to follow ecologically meaningful pathways rather than simple distance relationships. Some tools include built-in functions for this type of processing. For example, Tools4MSP allows users to generate propagated pressure layers using predefined spreading and decay functions [2]. The selected propagation method should be consistent with the ecological and environmental characteristics of the pressure and supported by available evidence. Assumptions regarding the extent of propagation, the shape of the decay function, and the factors influencing pressure spread should be clearly documented, as they can strongly influence the resulting pressure layer and subsequent CIA outputs.

4. **Density surfaces for mobile activities**

Mobile activities (e.g., shipping, fishing, recreational boating) often require a different approach because the pressure is generated by repeated movement rather than by fixed infrastructure. In these cases, density surfaces or heatmaps can be used to represent relative activity intensity. Density surfaces can be created from AIS data, VMS data, logbooks, route data, surveillance records, and repeated observations.

Common methods include grid-based counting, line-density analysis, kernel density estimation, or aggregation of effort values into a regular assessment grid. For fisheries, VMS and logbook data are commonly used to estimate fishing intensity or swept-area ratio, while AIS can support finer-scale mapping but should be checked for coverage gaps and biases [66,67]. This method is useful where the aim is to identify hotspots, corridors, concentration areas or relative differences in activity intensity across the assessment area.

5. **Scenario modification of existing layers**

For CIA scenarios to be assessed, it may be necessary to modify existing human activity or pressure layers rather than create entirely new ones. This is relevant when assessing planned developments, management measures, future activity levels or mitigation options.

Scenario modification can include:

- adding planned infrastructure, such as the incorporation of new wind farms or aquaculture sites,
- removing activities from conservation or exclusion areas,
- reducing activity intensity in selected areas or increasing it according to future development assumptions,
- changing buffer distances or influence zones, or
- applying mitigation coefficients.

These modifications can be carried out in GIS software by editing features, adding or removing polygons, masking areas, changing raster values, or adjusting pressure intensity in selected grid cells. Some CIA tools, such as PlanWise4Blue, already include built-in functions for modifying activity and pressure layers directly within the tool environment.

Addressing remaining gaps using proxy layers

Where direct or derived layers remain unavailable after the data screening and layer-development steps, proxy layers may be used only if they were identified as fit for purpose in Step 2 or can be justified through the same criteria. The proxy should have a clear ecological, physical, or mechanistic relationship with the missing nature value, activity or pressure, and its use should not be based on data availability alone [68]. Any proxy layer retained for CIA should be clearly documented, including the rationale for its selection, the assumptions made, the expected direction and strength of the relationship, and the implications for interpreting the results [68]. Where no proxy or expert-based approximation is available, the gap should be reported transparently rather than filled with a weak or misleading layer.

Harmonisation, standardisation, and processing of available, new, proxy, and built-in layers

Once data gaps have been addressed and the required spatial layers have been gathered or created, all layers should be processed so that they can be coherently implemented and integrated within a common CIA. This step should include all layers that will enter the assessment, including:

- layers selected directly from the data inventory generated in Step 2,
- newly created human activity, pressure or nature-value layers,
- proxy layers used where direct data or layers were unavailable,
- built-in layers provided by the selected CIA tool (where possible), and
- supporting administrative or management layers, where these are used in the analysis or interpretation.

Harmonisation is especially important in transboundary assessments, where datasets from neighbouring countries may differ in coordinate reference system, spatial resolution, classification, format, temporal coverage, update cycle or level of detail. Without harmonisation, differences in data structure may be misinterpreted as real spatial differences in pressure or ecosystem sensitivity. The aim of this step is therefore to ensure that all layers are spatially, temporally and thematically compatible, and that their values are expressed in a form suitable for the selected CIA tool.

The harmonisation process may include:

- **Aligning coordinate reference systems**: All spatial layers should be transformed into the same coordinate reference system before analysis. This ensures that features are correctly positioned relative to one another and provides a consistent basis for subsequent spatial processing and analysis.
- **Converting layers to a common grid structure**: CIA tools usually require input layers to be represented using the same spatial units, such as a common grid, planning units, or polygon structure. This step allows nature values, activities, and pressures to be spatially aligned, compared, combined, and analysed consistently within the assessment.
- **Clipping or extending layers to the agreed assessment area**: Layers should be clipped to the agreed boundary of the assessment areas so that calculations are carried out only within the relevant area. In some cases, layers may also need to be extended beyond the assessment boundary, for example, where pressures originate outside the area but may influence nature values within it.
- **Harmonising classification systems, codes, and naming conventions**: Datasets from different sources may use different categories, codes or names for the same activity, pressure, or nature

value. These should be harmonised so that equivalent classes are treated consistently across the assessment.

- **Standardising units**: Input layers should be checked to ensure that values are expressed in the correct and intended units before analysis. Where the same type of variable is represented using different units, these should be converted to a consistent unit. For example, fishing effort may need to be harmonised across hours, days, or swept-area ratio; biomass may need to be converted to a common unit per area; and habitat extent may need to be expressed consistently as area or percentage cover. This step ensures that equivalent variables are interpreted and processed consistently before any further standardisation, rescaling, or integration.
- **Aligning temporal reference periods where needed**: Layers should represent comparable time periods where possible. For example, it may be misleading to combine recent shipping data with outdated habitat or fishing data without noting the temporal mismatch. Where different time periods must be used, this should be clearly documented and considered when interpreting results.
- **Converting vector layers to raster format where required by the tool**: Some CIA tools require raster inputs, even when the original data are points, lines or polygons. In such cases, vector layers need to be rasterised using appropriate rules, such as presence/absence, area covered per cell, length per cell or intensity per cell.
- **Capping and transforming skewed datasets:** Some layers may require additional processing to remove extreme values. This is especially relevant for skewed datasets, such as activity-density surfaces or pressure proxies, where a few very high values or extreme hotspots could otherwise dominate the CIA calculation. In such cases, log-transformation or other scaling methods may be used to reduce the influence of very high values while retaining the overall pattern of the dataset. In some datasets, extreme values may result from measurement error, inconsistent reporting, one-off events, or highly localised anomalies. In these cases, outlier removal or value capping may be justified, for example by defining a threshold above which the pressure is treated as maximum intensity. However, this should be done carefully and transparently, because genuine hotspots or high-intensity activity areas may be ecologically meaningful and should not be removed or capped without clear justification.
- **Normalising values to the scale required by the selected tool, such as 0–1 or 0–100**: Depending on the CIA tool selected, the input layers may require to be normalized to a common value scale. This allows datasets with different original units, ranges, or measurement methods to be used together in the same assessment framework.

Updating the metadata inventory and layer processing record

The metadata inventory created in Step 2 should be updated throughout Step 3 to record how each layer was prepared for use in the selected CIA tool. Rather than creating a new inventory, this step should extend the existing documentation by capturing any modifications made during layer preparation and gap filling. For each final tool-ready layer, the updated inventory should record the source data, main processing steps, assumptions, parameter choices, spatial and temporal settings, normalisation or rescaling methods, and any limitations or uncertainties. It should also indicate whether the layer was used directly, derived, modelled, harmonised, standardised, represented through a proxy, or adapted from a built-in tool layer. This record is essential because the robustness of the CIA depends not only on the selected tool, but also on the transparency and comparability of the inputs used within it.

Final verification of selected data inputs for implementation

The final task in Step 3 is to verify that the complete set of prepared input layers is ready for implementation in the selected CIA tool or workflow. This verification should take place after gap filling, proxy selection, layer development, harmonisation, standardisation, and metadata updating have been completed. Whereas the Step 2 determines whether candidate datasets and layers are suitable for the intended CIA purpose, the Step 3 verification confirms that the final prepared layers function together as a coherent, tool-ready input package.

The verification should cover the following points:

- **Completeness of the tool-ready input package**: Check that all datasets selected in Step 2, including any gap-filling layers, proxy layers, newly created layers, built-in tool layers, and sensitivity inputs, are included in the final input package.
- **Consistency between layers and the sensitivity matrix**: Check that nature-value names, activities and pressure names, codes and groupings match the categories used in the sensitivity matrix. This ensures that each spatial layer is linked to the correct sensitivity score and that no pressure-nature value relationship is misassigned because of inconsistent terminology or coding.
- **Compatibility with the selected tool's input structure**: Check that all layers meet the technical input requirements of the selected CIA tool or workflow. This includes file format, attribute fields, value ranges, no-data values, folder structure, parameter files and any tool-specific input requirements. The purpose is to confirm that the layers can be uploaded, read and processed by the selected tool without additional technical adjustment.
- **Final spatial alignment check**: Confirm that the harmonisation carried out earlier has been correctly applied across the full layer set. All layers should share the required coordinate reference

system, assessment extent, grid resolution cell alignment, among others. The aim is to detect remaining persisting errors in the spatial definition of the layers.

- **Final temporal consistency check**: Confirm that the prepared layers represent the intended baseline period, season, planning or scenario horizon, checking whether the final input package is temporally coherent as a whole. Particular attention should be given to cases where recent activity layers are combined with older nature-value layers, where seasonal pressures are assessed against annual ecosystem layers, or where future scenario layers are compared with current-state baseline layers. Any remaining temporal mismatch should be documented and carried forward into the interpretation of CIA results.
- **Consistent value ranges and interpretation**: Check that the values in each layer have the meaning expected by the selected CIA tool. For example, confirm whether higher values indicate higher pressure intensity, higher ecological importance, higher probability of occurrence, higher biomass, higher sensitivity, etc. This check should also confirm that layers have not been accidentally inverted, double-normalised, or capped incorrectly.
- **Scenario consistency**: Check that all alternatives and scenarios use comparable input sets and that differences between scenarios reflect intentional scenario assumptions. Differences should not result from unintended changes in data source, processing methods, reference years, spatial extent and resolution, or normalisation. This is particularly important when comparing baseline, planned development, mitigation or alternative management scenarios.
- **Metadata and processing documentation:** Check that the final version of each layer is accompanied by sufficient metadata and processing documentation. This should include the original source, processing steps, assumptions, transformations, normalisation method, scenario modifications, limitations and final file name. This ensures that the final input package is transparent, reproducible, and interpretable between ongoing and future CIA, MSP iterations and in the frame of transboundary consultations.
- **Test run or import check**: Where possible, carry out a small test import or trial run in the selected CIA tool before starting the full assessment. This can help identify technical problems such as missing fields, incorrect file names, unsupported formats, no-data handling errors, unexpected value ranges or processing failures.

STEP 4: CIA implementation

The purpose of Step 4 (Figure 2) is to implement the CIA using the selected tool. The required nature-value layers, human activity and layers, and the sensitivity matrix have been prepared, harmonised, standardised and verified in Step 3.

Tool set-up and input integration

Before running the CIA, the selected tool should be configured according to its technical requirements. This may include installing the desktop version of the tool, creating a web-user account, setting up a workspace, defining the assessment extent, selecting the required coordinate system, uploading the prepared input layers, importing the sensitivity matrix, and setting the model parameters. All inputs used in the run should correspond to the final tool-ready input package verified in Step 3.

Tool implementation of CIA for the agreed baseline, MSP plan alternatives, and additional scenarios

The selected CIA tool should be applied to the agreed baseline and all MSP plans or additional scenarios identified during the scoping phase. Step 4 should ensure that the correct input layers (prepared in Step 3) is used for each run and that each run is executed using comparable settings. Differences between scenario outputs should reflect the planned scenario assumptions, not unintended changes in tool settings, data format, spatial extent, normalisation or input selection.

Documentation of implementation settings and assumptions

All implementation settings should be recorded clearly so that the results can be traced, reproduced and interpreted.

The implementation record should include, where relevant:

- Tool name, version and access mode, for example desktop, web-based or scripted workflow.
- Date of implementation.
- Assessment extent and spatial resolution used in the run.
- Baseline, alternative plans, and scenario used.
- Nature-value layers, pressure layers and sensitivity matrix applied.
- Model settings, weighting rules, aggregation rules or calculation options.
- Any deviations from the planned input package.
- Technical warnings, errors or processing constraints encountered.
- Limitations that may affect comparability between outputs.

Technical quality check of model runs

After each run, the outputs should be checked before they are used for interpretation. This is a technical quality-control step, not yet an assessment of environmental significance.

The quality check should confirm that:

- Output maps cover the expected assessment area.
- Output values fall within the expected range.
- No-data areas are treated correctly.
- Land, sea, coastal and transboundary areas are represented as intended.
- Cumulative impact hotspots are not caused by obvious technical artefacts.
- All expected pressures and nature values contributed to the calculation.
- Outputs for different MSP plan alternatives and additional scenarios are comparable.
- Unexpected gaps, sharp borders or extreme values can be explained.

A visual inspection in GIS or in the tool interface is recommended. Many implementation errors, such as shifted rasters, missing coastal cells, incorrect masks, inverted values, or artificial national borders, are easier to identify on maps than in tables. Results that diverge from reasonable ecological or spatial expectations should be treated as potential warning signals. For example, the apparent absence of impacts in clearly impacted areas, or unexpectedly high impacts in areas with limited activity, may indicate issues in the input data, assumptions, or model implementation. Such cases should be investigated before the outputs are used for interpretation or decision-making. Depending on the source of the problem, this may require correcting the input layer package in Step 3, adjusting tool settings, or re-running the CIA.

Compilation and organisation of outputs

The outputs generated by the selected tool should be compiled and organised in a form suitable for Step 5, where they will be interpreted in relation to likely significant effects, scenario comparison and mitigation needs.

Depending on the selected tool and CIA method, outputs may include:

- cumulative impact maps for each nature value assessed in each scenario,
- maps showing differences between plan alternatives,
- summary tables by assessment area, planning unit, country, sub-basin or management zone, including descriptions of each human activity contribution to the cumulative effects, if provided by the tools, and
- uncertainty or confidence layers, where available.

Post-processing of outputs

Some outputs may require post-processing before they can be interpreted or reported. Post-processing should be limited to technical preparation and should not alter the meaning of the CIA results unless this is clearly justified and documented.

Post-processing may include:

- converting outputs to formats required for further analysis,
- clipping outputs to reporting units or management zones,
- summarising values by, for example, subarea, country, habitat type or protected area,
- calculating differences between current state and plan alternatives outputs,
- preparing map layouts for review, or
- creating simplified outputs for later communication and consultation.

Any post-processing should be documented so that future users can distinguish between the original tool outputs and derived summaries. This is especially important where outputs are aggregated, classified into hotspot categories, or summarised by management areas.

Output package for Step 5

Step 4 should result in a complete and traceable CIA output package. This package should include the outputs for the current state, plan alternatives, and additional scenarios, together with the implementation record and any post-processing notes.

The output package should be ready to support Step 5, where the results are interpreted in relation to:

- Spatial distribution of cumulative effects.
- Differences between plan alternatives and additional scenarios.
- Affected nature values.
- Pressure and activity contributions.
- Uncertainty and limitations.

STEP 5: Interpretation of CIA outputs

The purpose of this step is to move from technical CIA outputs, such as cumulative impact and hotspot maps and summary tables, towards an assessment of what the results mean for the MSP process, the SEA environmental report, and planning decisions. CIA outputs should be interpreted as estimates of relative cumulative pressure, impact, or risk, rather than as direct measurements of realized ecological damage.

The results therefore need to be interpreted in relation to the assumptions, input data, sensitivity or effects matrix, tool settings, and assessment context used to generate them [27,32,43].

The interpretation should be based on the outputs generated in Step 4, together with the current-state assessment. The current-state assessment provides the environmental baseline for understanding the significance of the CIA outputs, including whether predicted effects occur in areas already under pressure, affect nature values that are already vulnerable, intensify existing environmental problems, or introduce new pressures into relatively less affected areas.

Comparison of outputs across plan alternatives

The documented tool outputs should be compared across the MSP plan alternatives and additional scenarios against the current-state assessment, which may represent a without-plan situation or the continuation of an already existing plan. This comparison should support the SEA requirement to assess reasonable plan alternatives and should help clarify:

- which plan alternatives are associated with higher or lower cumulative effects,
- which nature values or areas are most affected under each option,
- whether effects are concentrated in hotspots, dispersed across a wider area, shifted from one area to another, or reduced compared with the current state assessment, and
- where trade-offs arise between development objectives and environmental protection.

Where possible, the comparison should include both absolute and relative information. Absolute outputs show where cumulative effects are highest within each assessment case. Relative outputs, such as plan-alternative comparison maps, show where the proposed plan alternative increases, decreases, or redistributes cumulative effects compared with the current-state assessment or another alternative. When interpreting differences between alternatives, the user should also check whether the differences reflect actual planning assumptions, such as new activities, relocated uses, mitigation measures or changed pressure intensity, rather than differences caused by inconsistent input data, reference years, spatial extent, normalisation, or tool settings. Scenario-based spatial CIA has been widely used to support this type of comparison in MSP and marine management contexts [2,69].

Identification of likely significant effects

The CIA results should be used to support the identification of effects that may be significant in SEA terms. A CIA score should not automatically be treated as a significance threshold. Instead, significance should be judged using clear and transparent criteria, combining the CIA outputs with ecological sensitivity, policy objectives, spatial context and expert judgement [44,70].

Likely significant effects may be identified by considering whether the plan alternative:

- causes a clear increase in cumulative impact compared with the baseline, especially in areas already under high pressure,
- affects sensitive, rare, declining, protected or functionally important species, habitats or ecosystem services,
- affects protected areas, restoration areas, critical habitats, spawning areas or other areas of recognised ecological importance,
- may prevent progress towards environmental objectives, such as Good Environmental Status, water quality targets, conservation targets or national threshold values,
- affects a large area, or a large proportion of the local or regional distribution of a nature value,
- results in long-term, repeated, frequent, irreversible or difficult-to-mitigate effects,
- adds to existing pressures in a way that increases cumulative risk has a transboundary dimension or affects ecosystem components shared between countries, or
- involves high uncertainty but potentially serious consequences for sensitive receptors, requiring a precautionary interpretation.

The interpretation should also consider what is driving the likely significant effect. A high cumulative impact score may be caused by many moderate pressures, a small number of high-intensity pressures, high sensitivity of the affected nature value, strong spatial overlap between pressures and nature values, or a combination of these factors. Where the tool allows, pressure and activity contribution outputs should be used to identify which activities, pressures or pressure pathways are most responsible for the result. This is important for linking the CIA outputs to realistic mitigation, management and monitoring options [27,43,71].

Uncertainty and confidence assessment

The interpretation should explicitly consider uncertainty. CIA outputs may be influenced by data gaps, proxy layers, sensitivity-score uncertainty, spatial resolution, tool assumptions, normalisation methods, scenario assumptions and incomplete knowledge of pressure-receptor relationships. These uncertainties should not be treated only as a technical limitation but should be carried into the interpretation of the results and the conclusions drawn for SEA [43,44,72]. For example, results based on strong spatial data, well-supported sensitivity scores, and consistent scenario assumptions can support more robust conclusions. Results based on weak proxy data, uncertain sensitivity scores, or incomplete pressure pathways should be reported more cautiously.

First, uncertainty may arise from the quality and completeness of the input data. Nature-value layers may be based on incomplete observations, modelled distributions, uneven monitoring effort, proxy layers, outdated surveys, or data with different levels of spatial accuracy. Pressure layers may represent activity intensity rather than the actual ecological pressure, and may differ in temporal coverage, resolution or national data quality. Areas with low apparent impact should therefore not automatically be interpreted as low-risk areas if spatial data on relevant pressures and/or nature values are missing or poorly resolved. This is especially important in transboundary assessments, where data availability and mapping methods may differ between countries, sub-basins, coastal and offshore areas [27,43].

Second, uncertainty may arise from the sensitivity or effects matrix. Expert-based matrices, literature-derived scores or effect-size relationships may differ in their confidence levels depending on the amount of supporting evidence, agreement among experts, regional relevance of the evidence, and match between the assessed pressure and nature value. Low-confidence pressure-nature value combinations should be highlighted, especially where they strongly influence the final CIA result. If confidence values are available, they should be reported together with the interpretation. Where formal confidence values are not available, the report should provide a qualitative statement on the reliability of the most influential sensitivity or effect relationships. This follows the logic used in HELCOM cumulative impact assessment, where confidence was assessed through the quality of underlying spatial layers and the confidence in sensitivity scores [43].

Third, uncertainty may arise from assumptions about the future. MSP plan alternatives and additional scenarios often depend on assumptions about future activity levels, technology developments, climate change, management measures, ecological responses, and socio-economic development. These assumptions should be clearly documented. The interpretation should distinguish between results that are relatively robust across alternatives and results that depend strongly on uncertain future conditions. This is particularly important where the CIA compares long-term plan alternatives, because differences between alternatives may reflect both planning decisions and assumptions about future pressures or ecosystem sensitivity.

Where possible, sensitivity checks should be used to test how strongly the results depend on uncertain inputs and assumptions. This may include comparing outputs with and without low-confidence layers, testing alternative pressure weights or sensitivity scores, applying different standardization approaches, or comparing alternative future assumptions. Where formal sensitivity testing is not feasible, qualitative confidence statements should still be provided for the main findings. The final interpretation should clearly state what can be concluded with reasonable confidence, what remains uncertain, and which results should be treated as indicative rather than definitive.

Development of mitigation measures and planning recommendations

The interpreted results should then be translated into planning recommendations and possible mitigation measures. The aim is to identify how the MSP plan or alternatives could be adjusted to avoid, reduce or manage likely significant adverse effects, while also supporting environmental objectives and ecosystem-based planning. CIA results can help identify where mitigation may be needed, which pressures or activities should be targeted, and where further assessment or monitoring is required, but the final selection of measures should be developed through the wider SEA, MSP, and consultation process.

Mitigation and planning recommendations may include:

- avoiding allocation of new activities in highly sensitive or high-impact areas,
- relocating planned activities away from cumulative impact hotspots,
- excluding or limiting specific uses in protected areas, restoration areas, spawning areas, nursery areas or migration corridors,
- applying spatial buffers around sensitive receptors or high-risk activities,
- introducing seasonal restrictions where effects are linked to breeding, spawning, migration or other critical periods,
- reducing the intensity of specific activities in areas where cumulative pressure is already high,
- applying coexistence rules or operational conditions to reduce pressure overlap,
- phasing development to avoid simultaneous pressure peaks,
- prioritising restoration or compensation measures in areas where cumulative pressure cannot be fully avoided, or
- identifying areas where further project-level assessment, monitoring or adaptive management will be required.

In the SEA context, priority should be given to plan-level avoidance and spatial alternatives, because these are usually more effective than attempting to mitigate impacts later at project level.

Where the selected tool and available resources allow, it may be useful to test revised scenarios or mitigation options through additional CIA runs. However, such additional iterations should be treated as a return to Step 4, because they require the implementation of a revised input package or revised tool settings. Step 5 should document why such an iteration is needed and what planning question it is intended to answer.

STEP 6: CIA report to inform the environmental report

The final technical step is to ensure that the interpreted CIA results are clearly reported and fully integrated into the SEA documentation and follow-up system. The purpose of this step is to present the results of the CIA process in a transparent, traceable and accessible form that supports consultation, decision-making and later monitoring.

This step should build directly on the outputs documented in Step 4 and their interpretation in Step 5. It should show how the selected tool was used, what outputs it generated, how those outputs were interpreted, what conclusions were drawn for the comparison of plan alternatives and likely significant effects, and what mitigation and monitoring implications follow from the assessment. The reporting should be proportionate to the purpose of the CIA and the level of detail required in the SEA, while still documenting the main assumptions, limitations and uncertainties clearly enough for authorities, stakeholders, and other users to understand and scrutinise the results [16,27,43,44].

Reporting of methods, outputs, and mitigation measures

The CIA results report should provide a clear and structured account of:

a) the selected tool or analytical workflow used,
b) the datasets, built-in tool layers and sensitivity information applied,
c) the main methodological settings and assumptions,
d) the outputs generated for each plan alternative and additional scenario,
e) the main limitations, uncertainties and warnings documented during implementation, and
f) the interpretation of those outputs in relation to likely significant effects and scenario comparison.

This is necessary to ensure transparency and to allow the assessment to be understood and scrutinised by authorities, stakeholders and other users.

Contribution to monitoring design

The CIA results should inform the monitoring framework by identifying which effects, locations or receptors require follow-up after plan adoption, which indicators are most relevant, and where unforeseen adverse effects may be most likely to emerge.

This creates the link between the technical CIA workflow and the post-adoption stages of the SEA process, ensuring that the assessment contributes not only to plan preparation and decision-making, but also to the design of the subsequent monitoring and adaptive management.

Monitoring should be targeted to the main findings and uncertainties of the CIA. It may focus, for example, on cumulative impact hotspots, sensitive or highly exposed nature values, areas where new activities are introduced, areas where impacts are expected to decrease due to mitigation, or locations where transboundary effects may occur. The monitoring framework should also consider whether the assumptions used in the CIA remain valid over time, including assumptions about activity intensity, pressure propagation, sensitivity of nature values, effectiveness of mitigation measures and future environmental change.

Where possible, monitoring should build on existing national and regional monitoring systems to avoid duplication. However, existing monitoring should be checked to ensure that it is sufficient to test the key assumptions and conclusions of the CIA. The monitoring design should specify which indicators or criteria will be followed, what data sources will be used, how often monitoring will occur, what thresholds or trigger values may indicate concern, and how monitoring results will feed back into MSP plan review, SEA follow-up or adaptive management. This is consistent with the SEA requirement to monitor significant environmental effects of plan implementation and to identify unforeseen adverse effects at an early stage [16].

Preparation of simplified material for consultation and communication

Material suitable for consultation should also be prepared, including:

- simplified maps and figures,
- non-technical explanations of the main findings,
- concise summaries of plan alternative differences and likely significant effects, and
- evidence summaries that can be understood by authorities, stakeholders and the public.

This helps ensure that CIA findings are not only technically robust, but also accessible and usable within the wider SEA consultation process.

3.4 Data sources overview

HELCOM Map and Data Service (MADS)

HELCOM's data services (https://maps.helcom.fi/website/mapservice/) are among the most important regional sources for Baltic Sea CIA because they provide harmonised, assessment-oriented datasets compiled across Contracting Parties. According to HELCOM's current data page, the HELCOM data system includes the Map and Data Service (MADS), Metadata Catalogue, BASEMAPS, Biodiversity data portal, Shipping data platform, HELCOM MPA Portal, the Ballast Water Decision Support Tool, and links to thematic databases hosted via ICES, including oceanographic data, hazardous substances monitoring data, biological community data, impulsive noise, and the Pollution Load Compilation (PLC) database. HELCOM states that MADS contains the geospatial data used in HELCOM assessments and reports and is linked directly to the Metadata Catalogue, which provides documentation of the datasets and databases.

The main value of HELCOM is that it offers regionally coherent baseline layers that are already structured for Baltic-wide environmental assessment and transboundary comparison. This is especially important in MSP because national datasets could differ in scale, format, classification, update cycle or accessibility. HELCOM products can therefore be used as a common regional reference when the assessment covers more than one country, when cross-border comparability is needed, or when national data are incomplete.

HELCOM data can support CIA in several different ways:

a) Regional baseline layers for nature values and ecosystem components

HELCOM provides biodiversity-related resources through the Biodiversity data portal and assessment-linked geospatial products in MADS. The Biodiversity database contains macrospecies observations made available by HELCOM Contracting Parties, and the wider HELCOM system includes biodiversity records, protected-area information, and assessment-ready ecosystem component layers. These can be used to identify and map species and habitat distributions, support screening of priority nature values, and provide regional background layers for transboundary assessments. However, occurrence data should not automatically be treated as complete distribution maps; they may need further processing, interpolation, or species distribution modelling before they are suitable as CIA receptor layers.

b) Protected areas, management constraints and administrative context

The HELCOM MPA Portal provides information on Baltic Sea protected areas, while BASEMAPS provides access to maritime spatial planning data, including input data services and MSP plan outputs on sea uses. These resources are useful for identifying legal and management constraints, existing protected-area networks, designated zones, and cross-border planning context. In CIA, these layers can be used to define screening constraints, interpret potential conflicts with conservation objectives, and compare scenario results against existing management designations.

c) Human activities and pressure layers

HELCOM's MADS includes human activity and pressure datasets used in HELCOM assessments, while the Shipping data platform provides access to shipping-related data gathered through HELCOM working groups and projects. HELCOM also provides or links to datasets on nutrient inputs, hazardous substances, impulsive noise, and pollution loads. These datasets are directly relevant to CIA because they can be used either as pressure layers themselves or as inputs for deriving pressure layers. For example, shipping-related datasets may support the creation of traffic intensity, collision-risk or disturbance proxies; nutrient and contaminant datasets may support eutrophication and pollution-pressure mapping; and impulsive-noise data may help identify noise exposure hotspots.

d) Assessment-ready Baltic Sea products

HELCOM data are especially valuable because many of them have already been assembled for Baltic-wide assessment products such as the Baltic Sea Impact Index (BSII) and related HELCOM holistic assessments. In the Pan Baltic Scope project work, the Baltic-wide cumulative impact approach used 18 spatial pressure layers and 36 ecosystem component layers, combined through a sensitivity matrix, and the inputs were handled as GIS rasters at 1 × 1 km resolution. This means that HELCOM products are not only raw data sources but also a practical starting point for CIA workflows, especially where the chosen tool builds on the BSII or similar cumulative impact logic.

e) Gap-filling and transboundary harmonisation

HELCOM data are particularly useful where national datasets are missing, inaccessible, or not directly comparable. They can be used to fill data gaps, to provide a common regional layer where national methods differ, or to create a first Baltic-wide screening before replacing or refining the analysis with better national data. This is often preferable to combining several incompatible national datasets at the outset. In transboundary CIA, HELCOM layers can therefore function as the common denominator for early screening, consistency checking, and plan alternative comparison.

f) Metadata, documentation and machine access

HELCOM's Metadata Catalogue is important because it provides dataset documentation, while the data services also support download and machine-to-machine access. HELCOM describes these services as standards-compliant interfaces for GIS professionals, developers and researchers, and notes that datasets are accessible through MADS, metadata records, and ArcGIS REST-based services. For CIA, this is useful because it supports reproducible workflows, allows easier import into GIS or modelling environments, and makes it possible to document exactly which version of a dataset was used.

European Marine Observation and Data Network (EMODnet)

EMODnet (https://emodnet.ec.europa.eu/en) is one of the most useful European-scale data infrastructures for CIA because it provides a single access point to free marine data, metadata, and data products across seven thematic areas: Bathymetry, Geology, Physics, Chemistry, Biology, Seabed Habitats, and Human Activities. It is the European Commission's in situ marine data service and is designed to make marine data more findable, accessible, interoperable, and reusable across European sea basins. For CIA purposes, its main strength is not that it replaces national datasets, but that it provides a harmonised, cross-border starting point for assembling environmental baseline layers, human-use layers, and supporting context data in a consistent format.

For data scoping, EMODnet is especially valuable because it functions as an umbrella source. Instead of searching separately through many unrelated repositories, the assessment team can use the EMODnet Portal, Map Viewer, and Product Catalogue to identify relevant datasets, inspect coverage, review metadata, and download layers or connect to services. This is particularly helpful in transboundary MSP and CIA, where assessments often require comparable data from several countries or from an entire sea basin. EMODnet therefore works well as an early screening source, a gap-filling source, and in many cases a direct source of assessment-ready regional layers.

For CIA, the most relevant EMODnet thematic portals are usually the following:

EMODnet Bathymetry provides harmonised seabed depth information, including its flagship European marine Digital Terrain Model (DTM), which is regularly updated and available for viewing, download, and OGC web services. In CIA, these data can be used to define bathymetric context, derive slope or terrain variables, support habitat interpretation, and provide the physical base layer for hydrodynamic, dispersion, exposure, or pressure-propagation modelling. Bathymetry is also essential for interpreting ecological patterns and for modelling pressures such as noise propagation, sediment plumes, and hydrodynamic change.

EMODnet Biology provides interoperable marine biodiversity data and products on the temporal and spatial distribution of marine species and on species traits. Its coverage includes major taxonomic groups such as benthos, fish, birds, mammals, macroalgae, angiosperms, phytoplankton and zooplankton. In CIA, these data can be used for species occurrence screening, receptor identification, biodiversity baseline mapping, and in some cases trait-based interpretation of ecological sensitivity. However, many biology datasets are occurrence records or monitoring observations rather than complete distribution surfaces, so they may need additional processing, filtering, or modelling before they can be used directly as receptor layers.

EMODnet Chemistry focuses on four main themes: eutrophication, ocean acidification, contaminants, and marine litter. These products are highly relevant for CIA where chemical status, nutrient enrichment, pollution pressure, or litter-related effects are part of the impact pathway. In practice, EMODnet Chemistry can support the creation of baseline environmental-condition layers, pressure indicators, and trend layers for contamination or eutrophication-related analysis. It is particularly useful where national water-quality data are fragmented or difficult to compare across borders.

EMODnet Physics provides access to oceanographic observations and, in some cases, gridded and reanalysis products. These are relevant for CIA because physical and dynamic conditions often determine how pressures move through the system and where receptors are exposed. For example, physics layers can support the interpretation of salinity, temperature, currents, sea-level conditions, and other oceanographic variables that influence habitat suitability, connectivity, transport pathways, and the spread of pollutants or suspended material. These datasets are therefore particularly important where Step 1 has identified pressure pathways that depend on circulation or water-mass dynamics.

EMODnet Seabed Habitats provides seabed habitat data for Europe, including the broad-scale seabed habitat map EUSeaMap, habitat maps from surveys, habitat observations, and some habitat distribution modelling outputs. EUSeaMap is especially useful in CIA because it offers a free, harmonised, ready-to-use broad-scale map of physical habitats across European seas. In practical terms, these products can be used to identify habitat receptors, map broad habitat patterns consistently across jurisdictions, support screening of ecologically valuable areas, and provide a first receptor layer where national habitat mapping is incomplete. EMODnet notes that EUSeaMap is predictive and broad-scale, so it is highly useful for strategic screening and regional comparison, but finer national or site-scale habitat maps should be preferred where a more detailed assessment is needed.

EMODnet Human Activities is one of the most directly useful portals for CIA because it provides harmonised geographic information on a wide range of marine and maritime uses across Europe. The portal states that it offers data on the geographical position, spatial extent, temporal variation, and intensity attributes of activities, and currently provides access to datasets including aggregate extraction, algae production, aquaculture, cables, cultural heritage, dredging, fisheries, hydrocarbon extraction, ports, pipelines, shipping density, waste, and wind farms, among others. In CIA, these data can be used directly as human-use layers, as inputs for plan alternative comparison, or as proxies for pressure generation where direct pressure layers are not yet available. Historical or time-series information, where available, is particularly useful for understanding trends and for distinguishing existing from planned or emerging pressures.

EMODnet Geology, although not always mentioned first in planning workflows, can also be very useful for CIA. The geology theme includes harmonised offshore data on sea-floor geology, seabed substrates, coastline migration, geological events and probabilities, mineral resources, and submerged landscapes. These layers can support interpretation of seabed sensitivity, geomorphological context, substrate-related habitat mapping, and assessment of pressures that depend on sediment type or geological setting, such as dredging, extraction, seabed disturbance, or cable burial feasibility.

In practice, EMODnet data can be used in CIA in four main ways. First, they can be used as direct assessment layers, for example bathymetry, habitat maps, shipping density, or wind farm locations. Second, they can be used as input data for derived layers, such as pressure proxies, habitat suitability models, or context variables for spatial interpretation. Third, they can be used for transboundary harmonisation, where national datasets from different countries are too inconsistent to combine at the outset. Fourth, they can be used for gap-filling, especially in early screening, when national data are incomplete or not yet accessible.

EMODnet is particularly strong for strategic and regional-scale CIA, but it should still be checked carefully for fitness for purpose. Coverage, resolution, update date, and thematic detail differ between portals and datasets. Some layers are observations, some are modelled products, and some are aggregated or generalised to improve harmonisation. This means EMODnet is often excellent for screening, baseline building, cross-border comparison, and broad-scale scenario work, but for local-scale assessment it may need to be complemented by finer national, sectoral, or project-specific datasets. The official portal and product pages provide metadata, and those metadata should always be reviewed before use to check spatial coverage, date, access conditions, and methodological limitations.

Copernicus Marine Service

For oceanographic and environmental context, Copernicus Marine Service (https://marine.copernicus.eu/) is highly relevant because it provides free, open and regularly updated reference information on the physical, sea-ice and biogeochemical state of European regional seas, including the Baltic Sea. This makes it useful for variables such as temperature, salinity, currents, sea level and chlorophyll, and for producing baseline or trend layers where national monitoring is incomplete. For land–sea interaction and coastal context, Copernicus Land Monitoring Service and its Coastal Zones product can support analyses of coastal land cover, land use and land-use change along European coasts.

Copernicus Marine Service is one of the most useful sources for CIA when the assessment needs environmental baseline, physical and biogeochemical context, recent conditions, or long-term marine time series. It provides free and open information on the physical ("blue"), sea-ice ("white"), and biogeochemical ("green") ocean state, variability, and dynamics across the global ocean and European regional seas. Its products are built from satellite observations, in situ observations, and numerical models, which makes it especially valuable where CIA needs not just static maps, but dynamic marine conditions and model-based environmental layers.

For data scoping, Copernicus Marine is particularly useful because it provides harmonised regional and basin-scale products rather than only raw observations. The service covers seven main geographical areas: Global Ocean, Arctic Ocean, Baltic Sea, Atlantic North West Shelf Seas, Iberia-Biscay-Ireland Regional Seas, Mediterranean Sea, and Black Sea. This makes it well suited to CIA in MSP, especially where assessments are transboundary or where national physical and oceanographic datasets are difficult to combine consistently.

In practice, Copernicus Marine provides several different product types, and these differences matter for CIA. Its modelling products include forecast, hindcast, analysis, and reanalysis products. It also distinguishes between NearRealTime (NRT) and MultiYear (MY) datasets. NRT products describe the recent state of the ocean, are updated regularly, and for some models include forecasts of up to about 10 days; MY products provide longer historical records, often spanning 10, 20, 30 years or more. Older NRT data are generally transferred into the associated MY archive. For CIA, this means NRT products are useful for characterising present-day conditions, while MY products are better for baseline setting, climatology, long-term trend interpretation, and historical context.

For CIA, Copernicus Marine data are most useful in the following ways:

a) Physical and oceanographic context layers

Copernicus Marine is especially strong for physical marine variables such as temperature, salinity, currents, sea level, mixed-layer depth, and in some products waves and sea-ice parameters. For example, its global physics analysis and forecast products includes daily, monthly and hourly fields for temperature, salinity, currents, sea level, mixed layer depth, and sea-ice variables through the full water column. These kinds of layers are highly relevant for CIA because they help define the environmental setting in which pressures propagate and nature values are exposed. They are therefore useful as context layers for interpreting ecological patterns, exposure conditions, connectivity, and transport pathways.

b) Hydrodynamic and pathway-related inputs

Copernicus Marine is particularly valuable where Step 1 has identified pressure pathways that depend on movement through the marine system, such as sediment plumes, contaminant transport, salinity-driven ecological change, underwater noise propagation context, larval dispersal, oxygen depletion, or hydrodynamic alteration. In such cases, Copernicus Marine products can provide current fields, temperature and salinity structure, water-column stratification, sea-level conditions, and sometimes wave or Stokes drift information that support modelling or interpretation of exposure pathways. These products are therefore often used not as direct CIA pressure layers, but as inputs for the derivation or interpretation of pressure propagation.

c) Biogeochemical baseline and pressure-relevant environmental conditions

Copernicus Marine also provides biogeochemical information such as oxygen, pH, chlorophyll, nutrients, primary production, and related variables, depending on region and product. For example, the Baltic biogeochemistry analysis and forecast product includes nitrate, phosphate, chlorophyll-a, ammonium, dissolved oxygen, pH, zooplankton, phytoplankton, silicate, dissolved inorganic carbon, and net primary production. In CIA, these layers can be used to characterise existing ecosystem condition, identify areas already under environmental stress, and support interpretation of pathways related to eutrophication, hypoxia, acidification, or productivity change.

d) Recent conditions, baselines, and historical context

One of Copernicus Marine's main strengths is that it offers both short-term and long-term products. NRT products are useful for describing recent marine conditions and current background variability, while MY and reanalysis products are useful for constructing a historical baseline, exploring variability across seasons and years, and identifying long-term trends. This is important for CIA because cumulative effects should be interpreted in relation to the state of the system into which new pressures are introduced. MY products can therefore support baseline characterisation, while NRT products can help interpret present-day exposure conditions.

e) Regional products for sea-basin assessment

Copernicus Marine is especially helpful where CIA is carried out at Baltic, North Sea, Mediterranean, Black Sea, Arctic, or wider sea-basin scale. For example, Baltic regional products include physics reanalysis, physics analysis and forecast, biogeochemistry analysis and forecast, wave hindcasts, and various climate indicators. These regional products are often more relevant than global products for MSP-related CIA because they provide better resolution and are tailored to the dynamics of the regional sea.

f) Support for derived indicators and climate-oriented interpretation

Copernicus Marine also provides climate and monitoring products, including some Ocean Monitoring Indicators and long-time series. These can be useful where CIA needs to consider future-oriented or climate-sensitive criteria, for example changing temperature, sea-level trends, marine heat anomalies, or long-term oxygen and productivity patterns. In this sense, Copernicus Marine can help place CIA within a wider environmental-change context rather than treating cumulative effects as if they occur on a static baseline.

At the same time, Copernicus Marine should not be treated as a complete CIA data source on its own. Its main strength is environmental and ocean-state information, not direct mapping of human uses and pressures. It can support some surface wind products, but for full atmospheric pressure and wind data the service itself directs users to Copernicus Atmosphere (CAMS) or WEkEO. Likewise, Copernicus Marine usually needs to be combined with sources such as national databases, HELCOM, EMODnet, sectoral datasets, or project repositories for human activity layers, planning constraints, and direct pressure layers.

Global Fishing Watch

Global Fishing Watch (https://globalfishingwatch.org/map) is a useful complementary source for fisheries and vessel-activity proxies because it provides an open-access map platform, downloadable datasets, and APIs for analysing vessel-based human activity at sea. Its public apparent fishing-effort products are based primarily on AIS data processed with Global Fishing Watch algorithms, and the current downloadable static dataset covers 2012–2024. This makes it particularly useful in CIA where a broad, harmonised proxy for fishing intensity is needed across large marine areas or across borders.

In practical terms, Global Fishing Watch data can be used to create screening layers for fishing pressure, identify spatial hotspots of fishing activity, compare the relative intensity of vessel use across plan alternative, and provide a first approximation of exposure where official fisheries-pressure layers are not yet available. However, because these products are AIS-based, they should normally be treated as broad proxy layers rather than definitive regulatory datasets. Where the CIA requires finer or management-grade fisheries assessment, the AIS-based layers should, where possible, be checked against national VMS, logbook, or fisheries-administration data.

ICES data portals

ICES (https://www.ices.dk/data/Pages/default.aspx) is an important complementary source for CIA because it provides a range of official fisheries, biodiversity, spatial reference, and survey datasets relevant to European and North Atlantic marine assessments. Its data infrastructure includes maps and spatial information, the ICES Spatial Facility, VMS and Logbook data services, DATRAS trawl survey data, metadata catalogues, and dedicated thematic portals such as the VME portal. ICES also maintains standard spatial reference systems such as ICES statistical rectangles, which are widely used in fisheries and ecosystem assessment.

For CIA, ICES data are especially useful for fisheries reference layers, survey-based species information, spatial reporting units, and cross-border harmonisation. DATRAS can support fish-related receptor layers or survey context; ICES statistical rectangles and related geospatial layers can help standardise assessment units; and the VME portal can support screening of vulnerable seabed features. ICES spatial fisheries data can also support effort and pressure interpretation, but some data products are restricted or sensitive, including certain VMS/logbook and VME datasets, so access conditions and licensing need to be checked early in Step 2.

Global Biodiversity Information Facility (GBIF)

GBIF (https://www.gbif.org/) is a major international biodiversity infrastructure that provides open access to occurrence data for all types of life, including marine taxa. GBIF states that occurrence datasets are the core of the platform and represent evidence that a taxon occurred at a particular place on a particular date. This makes GBIF a useful supplementary source in CIA where broader occurrence evidence is needed for species screening, receptor identification, or distribution modelling support.

In practical use, GBIF is best treated as a supporting occurrence source, especially for gap filling, broad biodiversity screening, and additional evidence for species distribution modelling. Because GBIF data are occurrence-based rather than ready-made distribution surfaces, they are usually more suitable as modelling inputs or corroborating evidence than as final receptor maps without further processing. Before use in CIA, GBIF records should be screened for sampling bias, duplication, uneven coverage, taxonomic quality, and fitness for purpose, particularly where the assessment depends on spatial completeness or abundance interpretation.

Ocean Biodiversity Information System (OBIS)

OBIS (https://obis.org/) is a global, marine-focused biodiversity system and is one of the most useful complementary portals for CIA where a specifically marine occurrence data source is needed. OBIS harvests occurrence records from thousands of datasets and makes them available as a single integrated marine biodiversity dataset, accessible through search tools, a mapper, APIs, and full downloads. The OBIS manual states that the system now provides access to more than 100 million marine records, and it applies quality control checks including taxonomic matching and validation of required fields.

For CIA, OBIS is particularly useful for marine species screening, receptor support, transboundary occurrence analysis, and marine-only biodiversity searches. It can complement HELCOM, EMODnet Biology, and national biodiversity sources where additional marine occurrence data are needed. As with GBIF, OBIS data are most useful as occurrence evidence and modelling support, not automatically as final receptor distribution layers. They should therefore be screened for coverage, duplication, temporal relevance, and spatial bias before being incorporated into the assessment.

European Environment Agency (EEA)

EEA-hosted Natura 2000 data (https://natura2000.eea.europa.eu/) are essential for CIA wherever the assessment needs to reflect EU protected-site boundaries, legal conservation context, and overlaps with protected areas. The Natura 2000 Viewer and EEA data pages provide access to the European database of Natura 2000 sites, which is the core protected-area network established under the Birds and Habitats Directives. These layers are particularly important in SEA-linked CIA because they help identify where plan alternatives intersect with protected sites and where further scrutiny may be needed in relation to legal obligations and conservation objectives.

In practical terms, Natura 2000 layers can be used to map site boundaries, legal constraints, conservation context, and receptor screening areas. They are also useful when comparing plan alternatives against protected-area networks, identifying potential conflicts with site integrity or conservation objectives, and contextualising cumulative effects within the wider protected-area system. In Baltic Sea work, these layers should be used together with the HELCOM MPA Portal and relevant national protected-area data, since those sources provide complementary regional and site-specific context.

Marine Regions

Marine Regions (https://www.marineregions.org/) is a valuable source for administrative and reference geography because it provides a standardised marine gazetteer and downloadable geospatial layers for maritime boundaries, EEZs, sea areas, and related marine regions. It integrates geographic information from the VLIMAR Gazetteer and the MARBOUND database and offers downloadable maritime-boundary products, including the Maritime Boundaries Geodatabase and derived EEZ layers.

For CIA, Marine Regions is especially useful for harmonising assessment extents, defining reporting units, checking EEZ and sea-area boundaries, and supporting transboundary comparisons. These layers are often not impact layers in themselves, but they are extremely important for making sure that datasets from different countries are clipped, compared, and reported consistently. They are therefore best used as reference geography layers in the data inventory and GIS workflow, particularly in transboundary MSP assessments.

Copernicus Land Monitoring Service (CLMS)

Copernicus Land Monitoring Service (https://land.copernicus.eu/en) is a useful complementary source for CIA where land–sea interaction, coastal land cover, coastal land use, or coastal change need to be considered. CLMS provides geographical information on land cover, land-use change, water-cycle variables, vegetation state, and related land-monitoring products. Of particular relevance to coastal and marine planning is the Coastal Zones product, which provides detailed land cover and land use information for Europe's coastal regions, including status layers and change layers.

For CIA, CLMS Coastal Zones data can be used to represent coastal land-use pressures, shoreline-adjacent development, estuarine and coastal context, and land–sea interaction variables. The Coastal Zones product covers European coastal territory with detailed land cover/land use classes, extends landward to around 10 km inland, and includes status and change layers for 2012 and 2018. In practice, these datasets are useful where marine impacts are influenced by ports, coastal urbanisation, tourism development, coastal protection structures, estuarine modification, or land-based pressure pathways. They can therefore complement Copernicus Marine, which is stronger on ocean-state conditions than on land–sea interface mapping.

References

1. HELCOM. Thematic assessment of cumulative impacts on the Baltic Sea 2011–2016. Baltic Sea Environment Proceedings No. 159. (2018).
2. Menegon, S. *et al.* Addressing cumulative effects, maritime conflicts and ecosystem services threats through MSP-oriented geospatial webtools. *Ocean Coast. Manag.* **163**, 417–436 (2018).
3. Hammar, L. *et al.* Cumulative impact assessment for ecosystem-based marine spatial planning. *Science of The Total Environment* **734**, 139024 (2020).
4. Depellegrin, D. *et al.* Current status, advancements and development needs of geospatial decision support tools for marine spatial planning in European seas. *Ocean Coast. Manag.* **209**, 105644 (2021).
5. Kirkfeldt, T. S. & Andersen, J. H. Assessment of collective pressure in marine spatial planning: The current approach of EU Member States. *Ocean Coast. Manag.* **203**, 105448 (2021).
6. Kusters, J. E. H., van Kann, F. M. G., Zuidema, C. & Arts, J. SEAs for seas: Strategic environmental assessment for more strategic and environmentally-oriented marine spatial planning processes. *Environ. Sci. Policy* **162**, 103920 (2024).
7. Stelzenmüller, V. *et al.* From plate to plug: The impact of offshore renewables on European fisheries and the role of marine spatial planning. *Renewable and Sustainable Energy Reviews* **158**, 112108 (2022).
8. HELCOM. *State of the Baltic Sea. Third HELCOM Holistic Assessment 2016-2021. Baltic Sea Environment Proceedings N°194.* (2023).
9. Lees, L. *et al.* Comparative analysis of top-down and bottom-up approaches in maritime spatial planning. *Reg. Stud. Mar. Sci.* **88**, 104257 (2025).
10. Zaucha, J. *et al.* Implementing the EU MSP Directive: Current status and lessons learned in 22 EU Member States. *Mar. Policy* **171**, 106425 (2025).
11. Gutierrez, D. *et al.* Sustainable solutions: exploring trade-offs in marine protected areas from six European case sites. *npj Ocean Sustainability* **4**, 68 (2025).
12. Ehler, C. & Douver, F. *Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-Based Management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. IOC Manual and Guides No. 53, ICaM Dossier No. 6. Paris: UneSCO.* (2009).
13. Flannery, W., Healy, N. & Luna, M. Exclusion and non-participation in Marine Spatial Planning. *Mar. Policy* **88**, 32–40 (2018).
14. Flannery, W. *et al.* Exploring the winners and losers of marine environmental governance/Marine spatial planning: *Cui bono*? *Planning Theory & Practice* **17**, 121–151 (2016).

15. Flannery, W., Clarke, J. & McAteer, B. Politics and Power in Marine Spatial Planning. in *Maritime Spatial Planning* 201–217 (Springer International Publishing, Cham, 2019). doi:10.1007/978-3-319-98696-8_9.

16. European Parliament and Council. *Directive 2001/42/EC of 27 June 2001 on the Assessment of the Effects of Certain Plans and Programmes on the Environment. Official Journal of the European Communities, L 197, 30–37.* (2001).

17. Pinkau, A. & Schiele, K. S. Strategic Environmental Assessment in marine spatial planning of the North Sea and the Baltic Sea – An implementation tool for an ecosystem-based approach? *Mar. Policy* **130**, 104547 (2021).

18. HELCOM-VASAB. *Regional Maritime Spatial Planning Roadmap 2021-2030*. (2021).

19. United Nations Economic Commission for Europe (UNECE). *Convention on Environmental Impact Assessment in a Transboundary Context (Espoo Convention). Espoo, Finland.* (1991).

20. Moodie, J. R., Kull, M., Morf, A., Schrøder, L. & Giacometti, A. Challenges and enablers for transboundary integration in MSP: Practical experiences from the Baltic Scope project. *Ocean Coast. Manag.* **177**, 1–21 (2019).

21. Bergström, L. et al. *Cumulative Impact Assessment for Maritime Spatial Planning in the Baltic Sea Region. Pan Baltic Scope.* (2019).

22. European Parliament and Council. *Directive 2014/89/EU Establishing a Framework for Maritime Spatial Planning. Official Journal of the European Union, L 257, 135–145.* (2014).

23. Cambra, E. *et al. Guidance for Including Climate Change Scenarios in Protection and Prioritization Strategies for Marine Protected Areas Development. Deliverable D3.3, under the WP3 of MSP4BIO Project (GA N° 101060707)* . (2024).

24. Kotta, J. *et al. Ecological Toolkit (ESE1) for MPAs Prioritization and Networking (No. Deliverable 3.4). MSP4BIO Horizon Europe Project.* (2024).

25. Nurkse, K. *et al. 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. Deliverable – D3.3 under WP3 of the Blue4all Project (GA N° 101094014).* (2025).

26. Mestdagh, S. *et al. Towards Conservation Measures and Actions Required at Local or Regional Scale to Mitigate Environmental Risks to MPAs. Deliverable - D3.1 under the WP 3 of the BLUE CONNECT Project (GA N° 101156759)*. (2026).

27. HELCOM. *HELCOM Thematic Assessment of Spatial Distribution of Pressures and Impacts 2016-2021. Baltic Sea Environment Proceedings No. 189.* (2023).

28. Raymond, C. M., Brown, G. & Weber, D. The measurement of place attachment: Personal, community, and environmental connections. *J. Environ. Psychol.* **30**, 422–434 (2010).

29. Margules, C. R. & Pressey, R. L. Systematic conservation planning. *Nature* **405**, 243–253 (2000).

30. CBD. *Decision IX/20: Marine and Coastal Biodiversity. Annex I: Scientific Criteria for Identifying Ecologically or Biologically Significant Marine Areas in Need of Protection in Open-Ocean Waters and Deep-Sea Habitats. Convention on Biological Diversity.* (2008).
31. Yamakita, T., Sudo, K., Jintsu-Uchifune, Y., Yamamoto, H. & Shirayama, Y. Identification of important marine areas using ecologically or biologically significant areas (EBSAs) criteria in the East to Southeast Asia region and comparison with existing registered areas for the purpose of conservation. *Mar. Policy* **81**, 273–284 (2017).
32. Halpern, B. S. *et al.* A Global Map of Human Impact on Marine Ecosystems. *Science (1979).* **319**, 948–952 (2008).
33. Garcia, C. *et al. T5.1 Report Ecological Climate Risk Assessment. FutureMARES Project Deliverable Report*. (2023).
34. Pressey, R. L. & Bottrill, M. C. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. *Oryx* **43**, 464–475 (2009).
35. Galparsoro, I. & Borja, Á. Defining Cost-Effective Solutions in Designing Marine Protected Areas, Using Systematic Conservation Planning. *Front. Mar. Sci.* **8**, (2021).
36. Adem Esmail, B. & Geneletti, D. Multi-criteria decision analysis for nature conservation: A review of 20 years of applications. *Methods Ecol. Evol.* **9**, 42–53 (2018).
37. OSPAR Commission. *Quality Status Report: Cumulative Effects Assessment and DAPSIR Framework.* (2023).
38. European Environment Agency. *Environmental Indicators: Typology and Overview. Technical Report No. 25/1999. Copenhagen: European Environment Agency.* (1999).
39. Elliott, M. *et al.* “And DPSIR begat DAPSI(W)R(M)!” - A unifying framework for marine environmental management. *Mar. Pollut. Bull.* **118**, 27–40 (2017).
40. Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K.-N. & Smith, C. J. DPSIR—Two Decades of Trying to Develop a Unifying Framework for Marine Environmental Management? *Front. Mar. Sci.* **3**, (2016).
41. Knights, A. M., Koss, R. S. & Robinson, L. A. Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. *Ecological Applications* **23**, 755–765 (2013).
42. Goodsir, F. *et al.* A spatially resolved pressure-based approach to evaluate combined effects of human activities and management in marine ecosystems. *ICES Journal of Marine Science* **72**, 2245–2256 (2015).
43. HELCOM. *The Assessment of Cumulative Impacts Using the Baltic Sea Pressure Index and Baltic Sea Impact Index: Supplementary Report to the First Version of the HELCOM “State of the Baltic Sea” Report 2017. Helsinki Commission.* (2017).

44. Judd, A. D., Backhaus, T. & Goodsir, F. An effective set of principles for practical implementation of marine cumulative effects assessment. *Environ. Sci. Policy* **54**, 254–262 (2015).

45. European Parliament and Council. Directive 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Official Journal of the European Union, L 108, 1–14. (2007).

46. Wilkinson, M. D. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data* **3**, 160018 (2016).

47. EMODnet Seabed Habitats. *EUSeaMap 2023 Broad-Scale Predictive Habitat Map for Europe. EMODnet. Licensed CC BY 4.0.* (2023).

48. Abramic, A. *et al. Maritime Spatial Planning Data Framework (MSPdF). How to Structure Input Data for MSP Process, Monitoring & Evaluation. Produced by Technical Expert Group (TEG) on Data for MSP. Supported by CINEA and DG MARE (EC)*. (2023).

49. European Commission. *Commission Regulation (EC) No 1205/2008 Implementing Directive 2007/2/EC as Regards Metadata. Official Journal of the European Union, L 326, 12–30.* (2008).

50. Barboza, F. R. *et al. Repository Integrating Relevant Knowledge, Data and Tools for Assessing Linkages between ES and Eutrophication Dynamics across Realms. Deliverable – D1.1 under WP1 of the CREATE Project (Grant Agreement N°101060874).* (2026).

51. Barboza, F. R. *et al. 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).* (2025).

52. Melo-Merino, S. M., Reyes-Bonilla, H. & Lira-Noriega, A. Ecological niche models and species distribution models in marine environments: A literature review and spatial analysis of evidence. *Ecol. Modell.* **415**, 108837 (2020).

53. Guisan, A. & Zimmermann, N. E. Predictive habitat distribution models in ecology. *Ecol. Modell.* **135**, 147–186 (2000).

54. Elith, J. & Leathwick, J. R. Species Distribution Models: Ecological Explanation and Prediction Across Space and Time. *Annu. Rev. Ecol. Evol. Syst.* **40**, 677–697 (2009).

55. Guisan, A., Thuiller, W. & Zimmermann, N. E. *Habitat Suitability and Distribution Models*. (Cambridge University Press, 2017). doi:10.1017/9781139028271.

56. Hastie, T. & Tibshirani, R. Generalized Additive Models. *Statistical Science* **1**, (1986).

57. Elith, J., Leathwick, J. R. & Hastie, T. A working guide to boosted regression trees. *Journal of Animal Ecology* **77**, 802–813 (2008).

58. Phillips, S. J. & Dudík, M. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* **31**, 161–175 (2008).

59. Breiman, L. Random Forests. *Mach. Learn.* **45**, 5–32 (2001).

60. Chen, T. & Guestrin, C. XGBoost. in *Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining* 785–794 (ACM, New York, NY, USA, 2016). doi:10.1145/2939672.2939785.

61. Wood, S. N. *Generalized Additive Models*. (Chapman and Hall/CRC, 2017). doi:10.1201/9781315370279.

62. Valavi, R., Guillera-Arroita, G., Lahoz-Monfort, J. J. & Elith, J. Predictive performance of presence-only species distribution models: a benchmark study with reproducible code. *Ecol. Monogr.* **92**, (2022).

63. Araújo, M. B. & Guisan, A. Five (or so) challenges for species distribution modelling. *J. Biogeogr.* **33**, 1677–1688 (2006).

64. Forsblom, L. *et al. High-Resolution Maps on the Intensity and Extent of Ecosystem Services Supply in the Transnational Pilot Area (D.T1.1.1. under the Interreg MAREA Project).* (2022).

65. Reke, A. *et al.* Linking coastal cultural ecosystem services to human well-being and leisure preferences: insights from the Baltic Sea region. *Ecosystems and People* **21**, (2025).

66. Hintzen, N. T. *et al.* VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data. *Fish. Res.* **115–116**, 31–43 (2012).

67. Shepperson, J. L. *et al.* A comparison of VMS and AIS data: the effect of data coverage and vessel position recording frequency on estimates of fishing footprints. *ICES Journal of Marine Science* **75**, 988–998 (2018).

68. Stephens, P. A., Pettorelli, N., Barlow, J., Whittingham, M. J. & Cadotte, M. W. Management by proxy? The use of indices in applied ecology. *Journal of Applied Ecology* **52**, 1–6 (2015).

69. Gușatu, L. F. *et al.* Spatial and temporal analysis of cumulative environmental effects of offshore wind farms in the North Sea basin. *Sci. Rep.* **11**, 10125 (2021).

70. Willsteed, E. A. *et al.* Advances in cumulative effects assessment and application in marine and coastal management. *Cambridge Prisms: Coastal Futures* **1**, e18 (2023).

71. Korpinen, S., Meski, L., Andersen, J. H. & Laamanen, M. Human pressures and their potential impact on the Baltic Sea ecosystem. *Ecol. Indic.* **15**, 105–114 (2012).

72. Halpern, B. S. & Fujita, R. Assumptions, challenges, and future directions in cumulative impact analysis. *Ecosphere* **4**, 1–11 (2013).

73. Vaher, A. *et al.* Assessing cumulative impacts of human-induced pressures on reef and sandbank habitats and associated biotopes in the northeastern Baltic Sea. *Mar. Pollut. Bull.* **183**, 114042 (2022).

74. Kotta, J. *et al.* Assisting Coastal and Marine Governance: Enhancing Decision Support Through Digital Tools for Cumulative Impact Assessment. *Ocean and Society* **2**, (2025).

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

76. Menegon, S. *et al.* A modelling framework for MSP-oriented cumulative effects assessment. *Ecol. Indic.* **91**, 171–181 (2018).

77. Bonnevie, I. M., Hansen, H. S., Schrøder, L. & Armoškaitė, A. Utilising MYTILUS for Active Learning to Compare Cumulative Impacts on the Marine Environment in Different Planning Scenarios. *Sustainability* **14**, 12606 (2022).

78. Hansen, H. S. Cumulative Impact of Societal Activities on Marine Ecosystems and Their Services. in *Computational Science and Its Applications* (ed. Misra, S. , et al.) vol. 11621 577–590 (Springer, Cham., 2019).

Annex A. Potential cumulative impact tools for the Baltic Sea, their characteristics and implementation specifics

Table 4. Potential cumulative impact tools for the Baltic Sea, their characteristics and implementation specifics.

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
Acronym	PlanWise4Blue	HELCOM SPIA	Symphony	Tools4MSP	Mytilus
Brief description	Web-based planning tool developed by the University of Tartu, Estonian Marine Institute. It combines spatial data on nature assets, environmental conditions, and human uses with evidence-based cause–effect relationships. The tool supports assessment of individual and cumulative impacts on nature values and presents results in user-friendly maps and summaries. It has been used in the Estonian maritime spatial planning process.	A tool for assessing spatial pressures and cumulative impacts on Baltic Sea ecosystem components. It combines activity, pressure, ecosystem-component, and sensitivity data to estimate where impacts are likely to be highest.	Model-based framework developed for ecosystem-based maritime spatial planning in Sweden. It combines pressure maps, ecosystem-component maps, and sensitivity scores to identify impact hotspots and compare planning options. The related WIO Symphony platform provides a web-based version for the Western Indian Ocean.	Open-source geospatial modelling suite for maritime spatial planning and marine environmental assessment. It supports cumulative effects assessment, maritime use conflict analysis, and scenario-based spatial analysis.	Open-source tool developed by Aalborg University within the BONUS BASMATI project. It assesses cumulative environmental impacts and interactions between maritime activities, including potential conflicts and synergies.
Location	**Web version**: https://gis.sea.ee/bluebiosites/	**Desktop version:** https://github.com/helcomsecretariat/Cumulative-impact-Assessment-Toolbox	**Desktop version** (Symphony): https://github.com/havochvatten/MSP-Symphony **Web version** (WIO Symphony): https://www.nairo	**Web version**: https://geoplatform.tools4msp.eu/ **Desktop version**: https://github.com/CNR-ISMAR/tools4msp	**Desktop version**: Acquired through email by contacting Professor Henning Sten Hansen at Aalborg University

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
			biconvention.org/wio-symphony/		Copenhagen (hsh@plan.aau.dk)
Developer	Estonian Marine Institute, University of Tartu	HELCOM	Swedish Agency for Marine and Water Management	Italian National Research Council - Institute of Marine Sciences	Aalborg University, Denmark
Year of development	2020	2019	2017	2014	2019
Updates	Continued updates and developments	Web-tool is currently under maintenance until August 2026	Continued updates and developments	Continued updates and developments	Unclear
Examples of the tool usage (see reference list)	73–75	1,8,27,43	3	2,4,76	77,78
Where has the tool been applied?	Across the entire Baltic Sea, with a particular focus on Estonia, and complemented by case studies from the BlueGreen Governance and Blue4All projects covering major European seas.	Entire Baltic Sea; first applied in the Initial HELCOM Holistic Assessment and further developed in HOLAS 2 and HOLAS 3.	Swedish MSP process; WIO Symphony has been applied in various contexts within the Western Indian Ocean region to aid maritime spatial planning and management.	Northern Adriatic Sea; Adriatic Sea; Italian Adriatic Sea	Pan-Baltic Sea, with documented demo/training use in the Bornholm Basin; it has also been tested with Swedish MSP/Symphony data.
Platform type	Web-based platform.	Web-based tool and downloadable desktop toolbox.	Desktop tool; WIO Symphony is web-based.	Web-based platform and downloadable desktop version.	The tool is desktop-based and requires installation
How the tool calculates cumulative effects?	Combines spatial layers of human uses, environmental conditions, and nature assets with impact coefficients. The coefficients are mainly derived from scientific literature and	Uses a “sum of impact” approach. For each grid cell, pressures are combined with ecosystem-component distributions and sensitivity scores, then summed to produce cumulative impact	Uses a Halpern-style additive model. Normalized pressure layers and ecosystem-component layers are combined through a pressure–ecosystem sensitivity matrix.	Converts human-use layers into pressure layers using pressure weights and propagation distances. These are combined with environmental-component layers and sensitivity scores. Optional	Applies an additive cumulative impact model adapted from Halpern et al. Pressure, ecosystem-component, and sensitivity layers are multiplied and summed in raster format.

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
	observational data, with expert judgement used where evidence is limited. The tool calculates changes in each nature value amount or distribution.	values. As a result, cumulative impact risk for the ecosystem is calculated		processing includes normalization, filtering, reclassification, and Gaussian convolution.	
Built-in data in tool	A wide range of spatial data is already available in the tool for the Baltic Sea, the North Sea, and pan European analyses. For the Baltic Sea in particular, the tool provides ready to use datasets that generally include national and international administrative boundaries, at least 19 human activities and pressures, and several hundred nature asset layers. The exact spatial coverage and availability of individual layers should be checked in the tool's Input Layers section, as datasets are continuously updated through ongoing projects such as Protect	Approximately 30 human-activity datasets are collected through HELCOM annual reporting programmes, open sources, data requests to other organisations, and national data calls, then aggregated into 17 pressure layers current SPIA/BSII setup uses 17 pressure layers, 737 ecosystem components, and 969 sensitivity scores. In the downloadable toolbox, BSII runs on ecosystem-component and pressure grid layers plus a sensitivity matrix, while BSPI runs on pressure grid layers; the package includes default Baltic Sea regional layers and	The tool does not provide built-in data for the Baltic Sea, but the data layers used for the Swedish case study could be repurposed for other areas (the model included 37 human pressures and 33 ecosystem components, adapted to Swedish North Sea and Baltic Sea conditions: https://www.havochvatten.se/data-kartor-och-rapporter/rapporter-och-andra-publikationer/publikationer/2018-04-10-symphony---integrerat-planeringsstod-for-statlig-havsplanering-utifran-en-ekosystemansats.html)	The deplatform provides direct access to more than 1,000 geospatial layers and follows a case-study-driven approach, where each case study is a pre-configured and consistent set of input data with defined spatial domain, time reference, and resolution. For CEA, users configure human uses, environmental components, and pressures through the GUI; advanced setup allows Python-based preprocessing expressions such as filtering, normalization, logarithmic scaling, and Gaussian convolution. A demo Adriatic case	MYTILUS can be operated with pre-installed demonstration datasets, including Baltic Sea human-pressure layers, ecosystem-component layers, and expert-derived sensitivity scores. Public documentation describes use with pan-Baltic HELCOM Data and Map Service layers, including data for the Bornholm Basin demonstration case. The tool can also use datasets derived from Swedish MSP/Symphony applications. Built-in data availability appears to depend on the version or training package provided, and additional user datasets can be

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
	Baltic, BlueGreen Governance, Obama-Next and others.	users can replace them with their own data.		study is included in the package, and the stand-alone workflow loads human-use, pressure, environmental-component, sensitivity, and other input-parameter layers from the predefined case study.	imported for customized analyses.
Steps for user input data to use the tool	To use user-supplied data in PlanWise4Blue, users need to contact the tool support team, automatic upload option is currently under development. User data should be prepared as spatial layers that match the tool's assessment structure. The main input needs are: 1) gridded human activity or pressure layers, preferably standardized between 0 and 1, where 1 represents the highest intensity; 2) gridded nature-value layers, such as biomass,	To use user-supplied data in the HELCOM SPIA/BSII toolbox, users need to prepare pressure layers, ecosystem-component layers, and a sensitivity matrix in a format compatible with the assessment grid. Human activity data usually first need to be translated or aggregated into pressure layers, for example by converting shipping, fishing, nutrient input, or seabed-use data into spatial pressure intensity maps. Pressure layers and ecosystem-component layers	To use Symphony with user-supplied data, users need to prepare three main input groups: pressure layers, ecosystem-component layers, and a pressure–ecosystem sensitivity matrix. First, spatial data are collected or modelled for each human pressure and ecosystem component. These data should be converted into gridded map layers covering the same assessment area. Second, layers are transformed where necessary. In the Swedish case, most pressure layers	To use Tools4MSP with user-supplied data, users first need to define a case-study structure, including the study area, coordinate system, spatial resolution, and assessment grid. Input data should then be prepared as harmonized geospatial layers. The main data requirements are: 1) human-use layers, such as fishing, shipping, aquaculture, energy, or coastal infrastructure; 2) environmental-component layers, such as habitats, species distributions, or other ecological	To use MYTILUS with user-supplied data, users need to provide spatial pressure layers, ecosystem-component layers, and pressure–ecosystem sensitivity scores. Pressure layers should represent the intensity or distribution of human-induced pressures, while ecosystem-component layers should represent habitats, species, ecosystem services, or other ecological features being assessed. The input layers need to be spatially compatible, meaning they

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
	abundance, density, probability of occurrence, habitat suitability, or distribution of ecosystem components; and 3) sensitivity or impact-response scores linking each activity or pressure to each affected nature value. If suitable sensitivity relationships already exist in the tool, users may only need to provide the spatial layers. For scenario testing, users can adjust pressure intensity values or add/remove polygons representing planned activities, developments, or management measures.	should be harmonized to the same coordinate system, spatial extent, and grid resolution, normally 1 km x 1 km or 250 m x 250 m. Pressure values are then normalized (1-100) where needed so they can be compared across pressure types. Users also need a pressure–ecosystem sensitivity matrix showing how strongly each ecosystem component is affected by each pressure. Once these inputs are prepared, they can be used in the toolbox to calculate pressure indices and cumulative impact indices. Default Baltic Sea layers can be replaced by user datasets if the new data follow the required structure.	were used without transformation before normalization, but some layers, such as bottom-trawling-related habitat loss, were log-transformed to better represent nonlinear ecological responses. Some ecosystem data, especially species abundance layers, were also standardized and log-transformed. Third, all pressure and ecosystem-component layers are normalized to a common scale, usually 0–100, where 0 represents no exposure or no value and 100 represents a high-value threshold while reducing the influence of extreme outliers. Finally, users need to build or adapt a sensitivity matrix linking each pressure to each ecosystem component. In the Swedish application, this	features; 3) pressure definitions showing which pressures are generated by each human use; 4) pressure weights and propagation distances, which describe the strength and spatial spread of each pressure; and 5) sensitivity scores linking pressures to environmental components. Layers must be aligned to the same spatial extent, projection, and grid resolution before analysis. Depending on the case study, users may also need to configure preprocessing steps such as filtering, normalization, logarithmic transformation, reclassification, or Gaussian convolution. These settings can be managed through the web interface for standard workflows or	should use the same coordinate system, extent, and raster resolution or be converted before analysis. Pressure values are typically normalized (1-100), following approaches similar to HELCOM BSII/BSPI, so that different pressure types can be combined. The sensitivity matrix defines how each ecosystem component responds to each pressure. In the Baltic Sea demonstration, MYTILUS used pan-Baltic HELCOM layers and expert-derived sensitivity scores. In practice, users first inspect the individual pressure and ecosystem maps, then calculate cumulative impact indices, review outputs for the full study area or selected sub-areas, and export raster results for

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
			matrix was developed mainly through expert judgement and checked against published sensitivity information where available.	through the stand-alone/Python workflow for more advanced case-study setup.	further GIS processing.
What does the tool allow?	Users can define an assessment area, select human activities or pressures, choose nature assets, and run cumulative-effect analyses through a guided web interface. The tool supports scenario testing by changing the intensity or spatial extent of built-in pressures, including planned developments or management measures. Users can compare how different scenarios affect nature values amount and distribution and view the results as maps and summary indicators. It can also support combined analyses where additional pressures, such as oil-spill footprints,	Users can calculate and map Baltic Sea Pressure Index and Baltic Sea Impact Index results. The tool allows users to analyse different combinations of pressures and ecosystem components, identify areas with high pressure or impact, and examine how much different pressure–ecosystem combinations contribute to the total impact. In the desktop toolbox, users can replace default layers with compatible user datasets and produce both spatial grid outputs and statistics matrices.	Users can view pressure and ecosystem-component layers, create or select analysis areas, run cumulative-impact assessments, and compare planning scenarios. The tool is especially useful for testing how alternative planning options may change environmental impacts. WIO Symphony additionally allows users to visualise data, create maps, calculate cumulative environmental impact, test scenarios, and compare different ocean-use options through a web interface.	Users can run cumulative effects assessment, maritime use conflict analysis, and marine ecosystem-services threat assessment. The platform supports case-study-based analysis, visualisation of geospatial datasets, configuration of analysis workflows, and publication or sharing of outputs. It can be used to identify cumulative-impact hotspots, explore conflicts between maritime uses, and assess threats to ecosystem services.	Users can calculate spatial distributions of pressures and cumulative impacts using datasets at different spatial scales. The tool supports comparison of cumulative impacts between planning scenarios and can also assess possible conflicts or synergies between maritime activities. It is suitable for exploring how alternative planning choices affect ecosystem components and for communicating trade-offs between planning options to stakeholders.

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
	are included alongside existing human pressures.				
Spatial resolution	Typically uses a 1 km x 1 km grid for standard assessments. The effective resolution depends on the resolution of the input layers, and some computations can be performed at finer scales where suitable data are available.	The new desktop tool version uses 250m x250m layers. The user can upload their own data in any resolution, but the tool checks that all layers are spatially compatible before the analysis.	Resolution depends on the implementation. The Swedish Symphony application has used both 250 m x 250 m and 1 km x 1 km grids, depending on the dataset and assessment need. Input layers should be harmonized to a common grid before analysis.	Spatial resolution is user-defined and depends on the case-study setup and input data. The public Adriatic example uses a 500 m grid, but other resolutions can be used if all input layers are harmonized.	Spatial resolution is scale-dependent and can vary according to the input datasets. Public documentation indicates that MYTILUS can work with datasets at different spatial scales, provided that layers are converted to a compatible grid before analysis.
Output type	Map-based and tabular outputs	Map-based outputs	Map-based and tabular outputs	Map-based outputs	Map-based outputs
Output confidence estimates	The tool generates quantitative confidence intervals for its outputs.	Qualitative confidence evaluation provided — HELCOM evaluates confidence qualitatively, including confidence in sensitivity scores and the quality of the underlying spatial layers; it does not report statistical confidence intervals.	No explicit output confidence estimate documented in the standard outputs; confidence is handled mainly through the expert-based sensitivity assessment rather than separate confidence intervals/maps.	Tools4MSP incorporates uncertainty analysis and sensitivity analysis rather than simple confidence intervals. Its sensitivity framework can include an expert-derived confidence value, and published applications describe spatial uncertainty analysis to show the variation and robustness of cumulative-impact results.	No Confidence Estimates Provided - The tool does not offer any form of confidence estimates or indicators for its outputs. Example: Results are presented without any indication of reliability or uncertainty, leaving confidence in results open to user interpretation.

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
Accessibility	Open access	Open access	Open access	Open access	Available upon request
Usage time	The web tool can generally be learned and used within a few hours. Where additional user supplied data need to be uploaded or configured, the preparation phase may take longer due to the need for coordination with the tool developers. Scenario analyses themselves usually take only a few minutes, although analyses covering larger regions may take substantially longer.	The web tool with its preexisting datasets can be learned and used within a few hours. The desktop-based toolbox can be learned and used in the QGIS environment depending on previous use of the platform.	Few weeks for symphony; Few Days for WIO Symphony	Few Weeks - The tool requires a few weeks to become proficient in its use.	Few Days - The tool requires a few days to learn and effectively use.
Technical expertise	Web-version easy to use.	The desktop version relies on previous experience with QGIS.	Symphony requires advanced expertise to install and process and upload the needed data. WIO symphony is easier to use with the built in Indian Ocean datasets but require collaborations with tool developments to adapt to the Baltic SEA.	Mixed / moderate expertise required — the webtool is designed for non-technical users and a broad stakeholder community, but full case-study setup and advanced analyses require administrator/technical skills, including configuration of datasets and Python-based	Basic to moderate expertise — MYTILUS is intended for experts and planners, including users with less GIS knowledge. It is described as easily accessible when operated with pre-installed data layers, while more advanced use allows users to add their own data layers.

	PlanWise4Blue	HELCOM Spatial Pressure and Impact Assessment tool	Symphony	Tools4MSP	Mytilus
				preprocessing expressions; the stand-alone package supports advanced geospatial and statistical analysis.	
Training manual or help guide	The portal provides a comprehensive manual and video guide, offering detailed instructions and user support. The updated manual will be available August 2026.	User manual available: https://stateofthebalticsea.helcom.fi/wp-content/uploads/2017/09/HELCOM_The_assessment_of_cumulative_impacts_Supplementary_report_first_version_2017.pdf. An updated manual will be available August 2026.	WIO Symphony has a public user manual and a tutorial; the Symphony codebase/documentation is also public on GitHub.	The public GitHub repository includes a docs folder, a README describing the 4-step workflow, and a demo case study for testing; the published paper also documents the GUI workflow and stand-alone example.	No training manual or help guide is provided with the tool to our knowledge
User support	User support is provided via email, with contact information available within the portal.	User support is available, with contact information provided for email assistance.	User support is available, with contact information provided for email assistance.	No, the tool does not offer any user support.	No, the tool does not offer any user support.