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SATURN Deliverable 6.4

Report describing the methodology to insert underwater noise into Marine Spatial Planning tools

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Executive Summary

The present document describes a step-by-step approach and an upgraded and integrated combination of Decision Support Tools (DST) capable of supporting identification and evaluation of optimal mitigation measures to balance development demands with marine ecosystem protection within a Maritime Spatial Planning (MSP) context. The upgraded DSTs consists of several components and modules (toolkit) for collecting and visualizing geospatial data, and quantitative/analytical modules for assessing soundscapes and management measures. It considers present and future soundscapes, distribution of environmental receptors, impact/risk maps, and mitigation measures.

The tools are integrated and combined into a structured framework called "A step-by-step approach for incorporating URN in MSP". This approach, grounded in risk-based assessment principles and adopts a spatially explicit Cumulative Effects Assessment (CEA) methodology as the main analytical module for investigating and profiling the vulnerability of multiple human activities and pressures on the targeted environmental receptors.

The approach is structured into six main steps:

- **MSP-based Context Definition** – Defining the context using a Maritime Spatial Planning (MSP)-oriented approach. This step highlights key aspects related to URN, such as legislation, policy solutions, and ecosystem-based management.
- **URN Modeling – Current Conditions** – Using the existing **Quonops** tool (available online) to model URN under present conditions, focusing specifically on marine traffic and fishing activities.
- **URN Cumulative Effects Assessment (CEA) – Current Conditions** – Applying the Tools4MSP CEA tool (available online) to spatially assess the risk posed by URN on target environmental components. This analysis also integrates risks from other anthropogenic pressures (e.g., litter, abrasion) caused by multiple uses (e.g., fishing, aquaculture, land-based activities). As part of this project, CEA Tools4MSP has been enhanced with new functionalities, allowing for more detailed URN pressure inputs, incorporating multiple frequency bands to better align with different environmental receptors. One of the key aspects of applying CEA in this context is the development of a dedicated index for underwater noise, the Anthropogenic Noise Pressure Index (ANPIndex), which provides a structured approach to quantifying and assessing noise-related pressures.
- **Scenario Development** – Constructing spatially explicit scenarios for multiple uses through a participatory process involving stakeholders. As part of this project, a dedicated **sea-sketching tool** has been implemented and tested within the Tools4MSP Geoplatform (accessible online).
- **URN Modeling – Scenario-based** – Using the **OceanPlanner** web platform to model new spatiotemporal distributions of URN sources based on the developed scenarios, update noise maps, and assess differences across study areas. The OceanPlanner web tool has been developed and implemented within this project.
- **URN Cumulative Effects Assessment (CEA) – Scenario-based** – Leveraging scenario-based URN modeling and the projected configuration of anthropogenic uses to assess variations

in cumulative risk and impacts caused by the developed scenarios. This analysis considers both URN and other anthropogenic pressures.

The proposed approach can be adopted even in situations with limited knowledge allowing for assessment despite poor understanding of ecological effects or the absence of dose-response curves for target species in the study area. Two different versions of the new developed index named Anthropogenic Noise Pressure Index (ANPIndex) for assessing URN Pressure and related Effects/Impacts are provided: a) Simplified Version: Utilizes pressure maps based on the ANPIndex; b) Targeted Version: Uses pressure maps (ANPIndex) calculated for individual species, based on the measured Maximum Tolerable Level (MTL).

The integrated tools are web-based and interactive, allowing decision-makers to identify and explore future scenarios, assess risks, analyse options, and transparently evaluate solutions based on scientific knowledge. This development built upon existing platforms such as Quonops Online Services (QO) and Tools4MSP-CEA (CNR) also integrates data from external Spatial Data Infrastructure and EU programs like Copernicus and EMODnet Marine Services.

Starting from background information on Maritime Spatial Planning (MSP) and Underwater Radiative Noise (URN) the report also provides general overview on the development of scenarios and mitigation measure adopted in Europe.

To conclude, the proposed approach developed a methodological workflow to evaluate MSP-URN processes using an integrated model composed of multiple specialized tools (toolkit), which are accessible via web through the Quonops and Tools4MSP platforms for registered users. This results in a versatile solution that can support complex decision-making process exploring the effect of management scenario and mitigation actions. The developed approach and tools are designed for use in various case studies, regardless of the availability of data. They are adaptable to both data-rich and data-poor conditions. At the time of writing this report, the approach and tools are being applied in the North Adriatic case study. This will provide valuable insights into their applicability and help in further refining the methodology.

List of Acronyms

Abbreviation	Definition
ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area
AIS	Automatic Identification System
ANPIndex	Anthropogenic Noise Pressure Index
API	Application Programming Interface
ATBAs	Areas To Be Avoided
BRD	Bycatch Reduction Devices BRD
CEA	Cumulative Effects Assessment
CMS	Content Management System
CNR-ISMAR	National Reseach Council – Institute of Marine Sciences
CZM	Coastal Zone Management
D4Science	Organization offering a Data Infrastructure since 2014
DST	Decision Support Tool
EBA	Ecosystem-Based Approach
EEA	European Environment Agency
EIA	Environmental Impact Assessments
EEZs	Exclusive Economic Zones
EMODnet	European Marine Observation and Data Network
GES	Good Environmental Status
GFCM	General Fisheries Commission for the Mediterranean
GIS	Graphical Information System
GUI	Graphical User Interface
HELCOM	Baltic Marine Environment Protection Commission / Helsinki Commission
HILUCS	Hierarchical Land Use Classification System
ICES	International Council for the Exploration of the Sea
IExI	Integrated Excess Index
IMO	International Maritime Organization
MPAs	Marine Protected Areas
MRU	MSFD - Marine Reporting Unit
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning

MSPdF	MSP Data Framework
MSPD	Maritime Spatial Planning Directive
MTL	Maximum Tolerable Level
MUC	Maritime Use Conflict Analysis
OECD	Organisation for Economic Co-operation and Development: Sustainable Development
OGC	Open Geospatial Consortium
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PMAR	Pressure Assessment for Marine Activities
PSSAs	Particularly Sensitive Areas
QO	Quiet-Oceans
SATURN	Solutions AT Underwater Radiated Noise
SDI	Spatial Data Infrastructure
SEA	Strategic Environmental Assessment
SES	Social-Ecological System
TG Noise	MSFD Technical Group on Underwater Noise
UNCLOS	United Nations Convention on the Law of the Sea
URL	Universal Resource Locator
URN	Underwater Radiated Noise
VMS	Vessel Monitoring Systems
VRE	Virtual Research Environment
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WP	Work Package

1 Introduction

Since the last century, human activities have significantly ensonified underwater soundscapes with negative impacts on marine life (Duarte et al 2021). Nowadays underwater noise pollution has been recognized as a threat to marine ecosystems by international bodies (Lewandowski & Staaterman 2020), including the EU Marine Strategy Framework Directive (MSFD), the first legislation focusing on underwater noise pollution explicitly. As a result, from the first decade of the century several joint acoustic programmes have been developed in Europe (Merchant et al 2022). In this context, the SATURN project, which stands for Solutions @ Underwater Radiated Noise, is a collaborative effort spearheaded by a consortium of leading experts across diverse fields. It aims to address the pressing issue of underwater radiated noise and its detrimental impacts on aquatic species. By leveraging the collective expertise of specialists in bioacoustics, population biology, marine mammal and fish biology, maritime engineering, policy, and stakeholder engagement, SATURN seeks to achieve a comprehensive understanding of the underwater noise pollution and develop effective solutions.

At its core, SATURN endeavours to identify the specific sounds that pose the greatest threat to aquatic species, how these sounds are generated and transmitted, and the short-term and long-term consequences they inflict on key groups of marine life. This multifaceted approach allows for a holistic assessment of the issue, considering both immediate and cumulative impacts on various species in both river and ocean environments.

Moreover, the project aims to pioneer innovative methods for measuring and mitigating the negative effects of ship noise, offering practical solutions applicable to current and future vessels. By establishing standards for terminology and methodology, SATURN ensures consistency and reliability across different disciplines engaged in underwater radiated noise research.

Central to SATURN's approach is the establishment of an inclusive community comprising researchers, practitioners, regulatory authorities, maritime operators, industry stakeholders, and NGOs. This collaborative network ensures that the project's outputs are tailored to meet the diverse needs of stakeholders and maximize their real-world impact. Through this concerted effort, SATURN seeks to address the complex global challenge of underwater radiated noise in a transdisciplinary manner that prioritizes the well-being of aquatic ecosystems, and the interests of all stakeholders involved. Specifically, the work Package 6 (WP6) of the SATURN project is dedicated to maximizing the impact of the project's scientific, technical, and stakeholder-based expertise. It aims to engage stakeholders effectively, synthesize project findings for policy implications, and support the development and implementation of noise-based marine planning decision tools for policymakers.

As part WP6 the primary goal of Task 6.5 was to develop an upgraded and integrated combination of Decision Support Tools (DST) capable of identifying optimal mitigation measures to balance development demands with marine ecosystem protection. This tool aimed to guide decision-makers through the MSP process, collecting and visualizing geospatial datasets, analysing soundscapes and cumulative effects, and evaluating the efficiency and costs of different management measures (scenario comparison).

The upgraded DSTs consists of several components, including a general conceptual framework derived from Task 6.4 guidelines, modules for collecting and visualizing geospatial data, and quantitative/analytical modules for assessing soundscapes and management measures. It considers present and future soundscapes, distribution of environmental receptors, impact/risk maps, and mitigation measures.

The integrated tool is interactive, allowing decision-makers to identify and explore future scenarios, assess risks, analyse options, and transparently evaluate solutions based on scientific knowledge. This development built upon existing platforms such as Quonops Online Services (QO) and Tools4MSP-CEA (CNR) also integrates data from external Spatial Data Infrastructure and EU programs like Copernicus and EMODnet Marine Services.

The report begins with a Background chapter (Chapter 2), which provides essential information on the Marine Spatial Planning (MSP) process. It explains how Underwater Radiated Noise (URN) is currently addressed in MSP processes, particularly in Europe. The chapter also outlines the main scenarios and mitigation measures related to the management of URN in planning processes.

Following the Background chapter, Chapter 3 focuses on the primary web tools that have been adopted and developed within the SATURN project. This chapter describes how these tools have been integrated and designed for ease of use by users.

Finally, this report focuses on detailing a “step-by-step approach for incorporating URN into MSP” (see Chapter 4). The methodology employs a Risk-based Cumulative Effects Assessment (CEA) approach as the primary analysis framework, consisting of six main steps:

- MSP-based Context Definition: Setting the context using Marine Spatial Planning (MSP).
- URN-modelling - Current Conditions: modelling current conditions of the Underwater Radiated Noise.
- URN CEA - Current Conditions: conducting a Cumulative Effects Assessment (CEA) combining URN pressure with other MSFD pressures exerted by multiple anthropogenic uses.
- Scenario Development: creating future scenarios for analysis. This step also includes a methodology for stakeholders' engagement to support explicit spatial identification of future scenarios.
- URN-modelling - Scenario-based: modelling the URN under different scenarios.
- URN CEA - Scenario-based: conducting a CEA on the URN based on the developed scenarios and perform scenario comparisons.

For each step, the methodology provides: i) a general description; ii) the types of inputs and outputs; iii) the specific tools used to support that step.

Thus, instead of creating a single, all-encompassing Decision Support Tool (DST), the proposed approach focuses on creating an integrated model composed of multiple specialized tools. Each of these tools is designed to address specific aspects or steps of the methodology. Thus, the result is a more adaptive and versatile solution that can better support complex decision-making processes across different stages of the methodology

Note that in this report underwater acoustical terminology follows ISO 18405:2017, while vessel acoustical and bioacoustical terminology follow the SATURN terminology standard (June 2024).

2 Background

This chapter provides an overview of Maritime Spatial Planning (MSP), emphasizing how various countries and the European Union are integrating underwater noise (URN) considerations into the MSP process. It highlights the importance of managing underwater noise to ensure sustainable maritime activities and protect marine ecosystems. Additionally, the chapter will present the possible mitigation measures that an MSP planner typically has available in their portfolio for use during the planning process. Furthermore, the chapter explains how current MSP plans are addressing the issue of underwater noise.

2.1 Maritime Spatial Planning

Maritime Spatial Planning (MSP) is a comprehensive and proactive approach to managing human activities in the marine environment to achieve ecological, economic, and social objectives. It is a tool that enables sustainable development, conservation of marine biodiversity, and efficient use of marine resources. MSP integrates various sectors such as shipping, fisheries, tourism, energy, conservation, and recreation, aiming to balance their competing demands and minimize conflicts.

General Definition

Maritime Spatial Planning can be defined as the process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives (Ehler & Douvere, 2009). It involves stakeholders' engagement, data collection, analysis, decision-making, and implementation of plans and measures to ensure sustainable use of marine resources and protection of marine ecosystems.

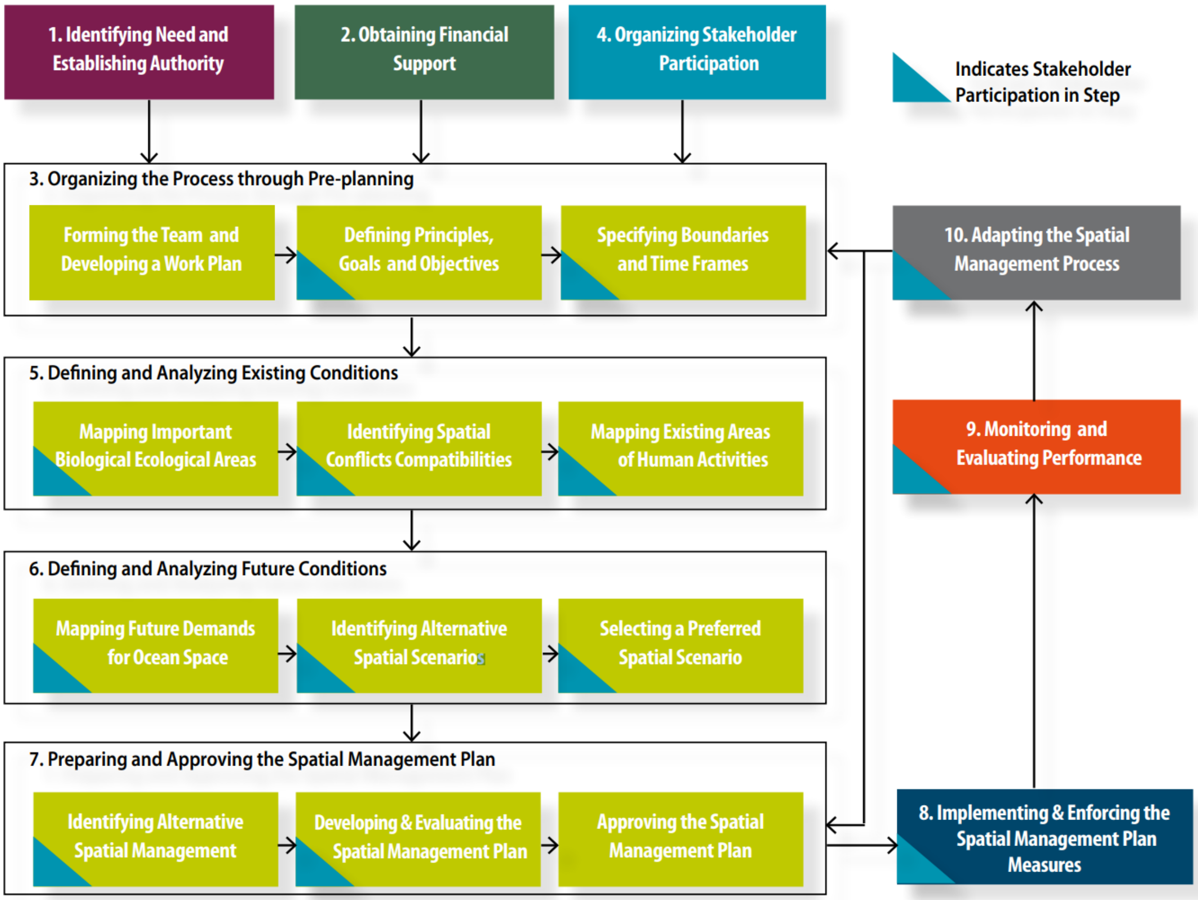

Figure 1: A Step-by-Step Approach to Marine Spatial Planning (Ehler & Douvere, 2009).

The MSP process unfolds through a series of ten steps (see Fig. 1; Ehler & Douvere, 2009):

- Identifying Need and Establishing Authority: Recognize the necessity for MSP and determine the responsible authorities to oversee the planning process.
- Obtaining Financial Support: Secure funding to support the MSP process, including research, stakeholder engagement, and plan implementation.
- Organizing the Process through Pre-planning: Develop a clear process for MSP, including timelines, milestones, and responsibilities.
- Organizing Stakeholder Participation: Identify and engage relevant stakeholders to ensure their input and cooperation throughout the MSP process.
- Defining and Analyzing Existing Conditions: Collect and analyze data on current environmental, economic, and social conditions within the marine area.
- Defining and Analyzing Future Conditions: Use scenario building to predict future conditions and impacts, guiding the development of the MSP.
- Preparing and Approving a Marine Spatial Plan: Draft the MSP document, incorporating stakeholder feedback, and obtain the necessary approvals.
- Implementing and Enforcing the Plan: Put the approved MSP into action, ensuring that its provisions are followed by all users of marine space.

- Monitoring and Evaluating MSP Performance: Continuously monitor the outcomes of the MSP and evaluate its effectiveness against set goals.
- Adapting the Process (Revision): Be prepared to revise and adapt the MSP based on monitoring results, new scientific knowledge, or changes in conditions.

EU Directive

The European Union (EU) has been at the forefront of promoting Maritime Spatial Planning through the adoption of the Directive 2014/89/EU, also known as the Maritime Spatial Planning Directive (MSPD). This directive establishes a framework for MSP within EU Member States' marine waters and seeks to ensure coordinated and coherent planning across borders. The MSPD requires Member States to develop and implement maritime spatial plans that promote sustainable development, environmental protection, and socio-economic benefits. It emphasizes the importance of ecosystem-based approaches and cross-sectoral cooperation in planning processes.

The MSPD outlines key principles and objectives for MSP, including:

- Integration: MSP should integrate environmental, economic, and social considerations to achieve sustainable development goals.
- Stakeholder Engagement: MSP processes should involve relevant stakeholders, including government agencies, industries, environmental organizations, and local communities, in decision-making processes.
- Coordination: MSP should ensure coordination and cooperation among relevant authorities and stakeholders at national, regional, and local levels.
- Ecosystem-based Approach: MSP should adopt an ecosystem-based approach that considers the interdependencies and interactions between marine ecosystems and human activities.
- Cross-border Cooperation: MSP should facilitate cooperation and coordination across maritime borders to address shared challenges and opportunities.

Ecosystem-based Approach in MSP

An ecosystem-based approach to MSP recognizes that marine ecosystems are complex and interconnected systems influenced by natural processes and human activities. It seeks to maintain the health, resilience, and biodiversity of marine ecosystems while supporting sustainable use and development (Langlet et al., 2019). This approach emphasizes understanding ecosystem dynamics, identifying ecosystem services, and integrating this knowledge into planning and decision-making processes (European Commission, 2021).

Ecosystem-based MSP considers the following principles:

- Ecological Connectivity: Recognizing the interconnectedness of marine ecosystems and the importance of maintaining ecological connectivity to support biodiversity and ecosystem functioning.

- Cumulative Effects Assessment: Assessing the cumulative impacts of multiple human activities on marine ecosystems to identify potential synergies, trade-offs, and areas of conflict.
- Adaptive Management: Adopting adaptive management strategies that allow for flexible and iterative decision-making based on new information, monitoring data, and changing environmental conditions.
- Habitat and Species Protection: Prioritizing the protection and restoration of critical habitats and species to maintain biodiversity and ecosystem resilience.
- Sustainable Use: Promoting sustainable use of marine resources that ensures long-term ecological, economic, and social benefits while minimizing adverse impacts on ecosystems.

By integrating an ecosystem-based approach, stakeholder engagement, and cross-border cooperation, MSP can play a crucial role in identifying areas vulnerable to underwater noise pollution, establishing measures to mitigate its impacts, and promoting the conservation of marine habitats and species affected by noise disturbances. Through strategic planning and coordination of human activities in marine environments, MSP can help by reducing noise emissions from shipping, construction, and other anthropogenic sources, thus safeguarding marine ecosystems' health and resilience. Emphasizing the importance of MSP in supporting underwater noise mitigation efforts underscores its significance as a tool for achieving environmental sustainability and ensuring the well-being of marine life and coastal communities.

As highlighted below the Cumulative Effects Assessment (CEA) is one of the essential analytical tools for integrating an ecosystem-based approach into the planning and management of marine areas, among other contexts. The CEA is a key component of the approach presented in this report, and it will be explained in more detail in Sub-section 3.2.3.

2.2 Mitigation scenarios

For the development of potential mitigation scenarios, we reference the findings of the SOUNDSCAPE project (see Farella et al., 2021). This project proposes a portfolio of measures that can be implemented in the Marine Spatial Planning (MSP) context to mitigate the effects of URN on marine ecosystems. Specifically, 26 measures are proposed, categorized into six groups (see Table 1).

Main Measures (Directly Affecting Noise Emissions):

- Strategic Measures
- Spatial-Temporal Measures: Regulating activities in specific areas and/or periods.
- Behavioral Measures: Promoting good practices to minimize environmental impacts.
- Technical and Technological Improvements: Improving ships and their components, navigation methods, tools, devices, products, processes, and any elements that enhance the sustainability of activities.

Support Measures (Facilitating the Implementation of Main Measures):

- Monitoring, Control, and Surveillance: Measuring underwater soundtrends and marine ecosystem characteristics.
- Economic, Financial, and Other Measures: Encouraging active participation in decision-making and management processes, addressing economic aspects (including taxation), identifying financial resources to support activities, and providing training for operators on specific technical topics.

For each measure, the following attributes were defined:

- Typology: Categorized as governance, technical (permanent), or operational (temporary).
- Description: Detailed explanation of the measure.
- Applicability: How the measures can be applied to different ship types (e.g., cargo, tankers, cruises, passenger, fishing, touristic vessels) in both new builds and retrofit projects, considering the specifics of Adriatic fleets.
- Possible Implementation Issues: Challenges such as time, cost, effectiveness uncertainty, enforcement, and voluntary approaches.
- Examples, Experiences, and Good Practices: When available, examples of implementation, experiences, and best practices are provided.

The catalogue of measures was compiled by considering:

- Existing strategies (e.g., EU policies, IMO agreements, ACCOBAMS reports).
- Results from relevant international projects (e.g., AQUO, SONIC, JOMOPANS).
- An extensive review of scientific literature.

Table 1. Synthesis of the possible mitigation measures for each category and typology (SOUNDSCAPE Project, Farella et al. 2021).

Type of measure	Code	Name	Short/Medium/ Long Term (S/M/L)
Strategic	1a	Include specific noise mitigation objectives within maritime plans	M
	1b	Coordinated port development plans in the whole area	M / L
	1c	Dynamic Ocean Management of maritime traffic	M
Spatial-Temporal	2a	Rerouting	S
	2b	Establish “Particularly Sensitive Sea Areas” (PSSAs)	S / M
	2c	Establish “Areas To Be Avoided” (ATBAs)	S / M
	2d	Limitations to recreational boating	S
Behavioural	3a	Speed reduction	S

	3b	Convoy	S
	3c	Using Tugs	M
	3d	Optimize Ship Handling	S / M
	3e	Regular hull and propeller maintenance polishing	S
Technical/ Technological	4a	Install ducted propellers	M
	4b	Install skewed propellers	M
	4c	Reduction of propeller speed per Knot (TPK)	M
	4d	Install water jets or pump jets	M
	4e	Install CLT propellers	M
	4f	Electric machinery	M / L
	4g	Machinery treatments	M
	4h	New hulls designs	L
Monitoring, control and surveillance	5a	Live mapping of underwater noise sources and intensity	S / M
	5b	Development of a pilot registration system through transparent management and live use of AIS data for all the vessels (including leisure boats).	S / M
	5c	Better knowledge Continuous mapping of the distribution of target species, their variability and their life cycle, and understanding of their responses to noise exposure	S / M
Economic, financial and other supporting measures	6a	Promote and finance innovative technologies geared to noise emission reduction	S / M
	6b	Offer best practice training programs to shipping companies	S
	6c	Literacy and awareness raising (e.g. local communities, nautical sector, citizens)	S

Please refer to the Farella et al, 2021 report for a detailed description of the measures listed. A more comprehensive presentation of the mitigation scenarios is also present in the Deliverable D6.3 (Folegot et al., 2024).

2.3 The role of MSP in addressing underwater noise in Europe

To gain a better understanding of how the tools presented in Chapter 3 and the approach presented in Chapter 4 efficiently support the planning process, a systematic review of existing policy around underwater noise in 11 European countries, covering marine areas in the Mediterranean, Baltic and North Sea, was carried out as part of the SATURN project.

The review considered Maritime Spatial Plans (MSP), Strategic Environmental Assessments (SEAs), National Marine Strategies, MSFD reports and direct input of local MSP Competent Authorities from the following European countries: Finland, Sweden, Germany, Denmark, The Netherlands, France, United Kingdom (England and Scotland, here considered separately as they have separate MSPs), Ireland, Portugal, Spain, Italy.

The results were published in a paper titled “Is Maritime Spatial Planning a tool to mitigate the impacts of underwater noise? A review of adopted and upcoming maritime spatial plans in Europe” (Bosi et al., 2023) and form a baseline for the design of Decision Support Tools for underwater noise within the SATURN project.

A comprehensive description of the methodology and results can be found in Deliverable D6.3 (Folegot et al., 2024). Differently, the current report highlights the most significant elements, focusing especially on supporting the development of a step-by-step approach and the associated tools for incorporating URN into MSP

2.3.1 Review background

Increasing awareness around the negative impacts of underwater noise on the marine environment has made it the subject of ongoing research in recent years. Noise emissions are produced by a variety of human activities at sea, from the continuous noise caused by marine traffic to the impulsive emissions generated by different types of construction activities carried out underwater (e.g., cables and pipelines, offshore wind farms, etc.). Moreover, a wide range of sea creatures, from marine megafauna to plankton, depend on noise for a number of life functions such as communication or reproduction, all of which are potentially disrupted when in contact with anthropogenic noise emissions. Many of the species manifesting negative effects due to underwater noise are highly mobile and several significant sources of underwater noise are of transboundary dimension. Moreover, sound travels long distances underwater, making its inclusion in MSP a complex and transboundary issue. It thus comes as no surprise that underwater noise made the list of the 11 descriptors identified by the Marine Strategy Framework Directive (MSFD, 2008/56/EU) for the achievement of Good Environmental Status (GES). As many European countries are currently approaching their second cycle of MSP, and after the recent release in November 2022 of new guidelines by the Technical Group on Underwater Noise (TG Noise), a conscious and effective inclusion of noise in all phases of MSP is as crucial as timely.

2.3.2 Methods and results

According to a recent review of existing policy around underwater noise in 11 European countries, covering marine areas in the Mediterranean, Baltic and North Sea, there is a discrepancy between the perceived importance of the inclusion of underwater noise in MSP and the implementation of measures acting towards this goal (Bosi et al., 2023).

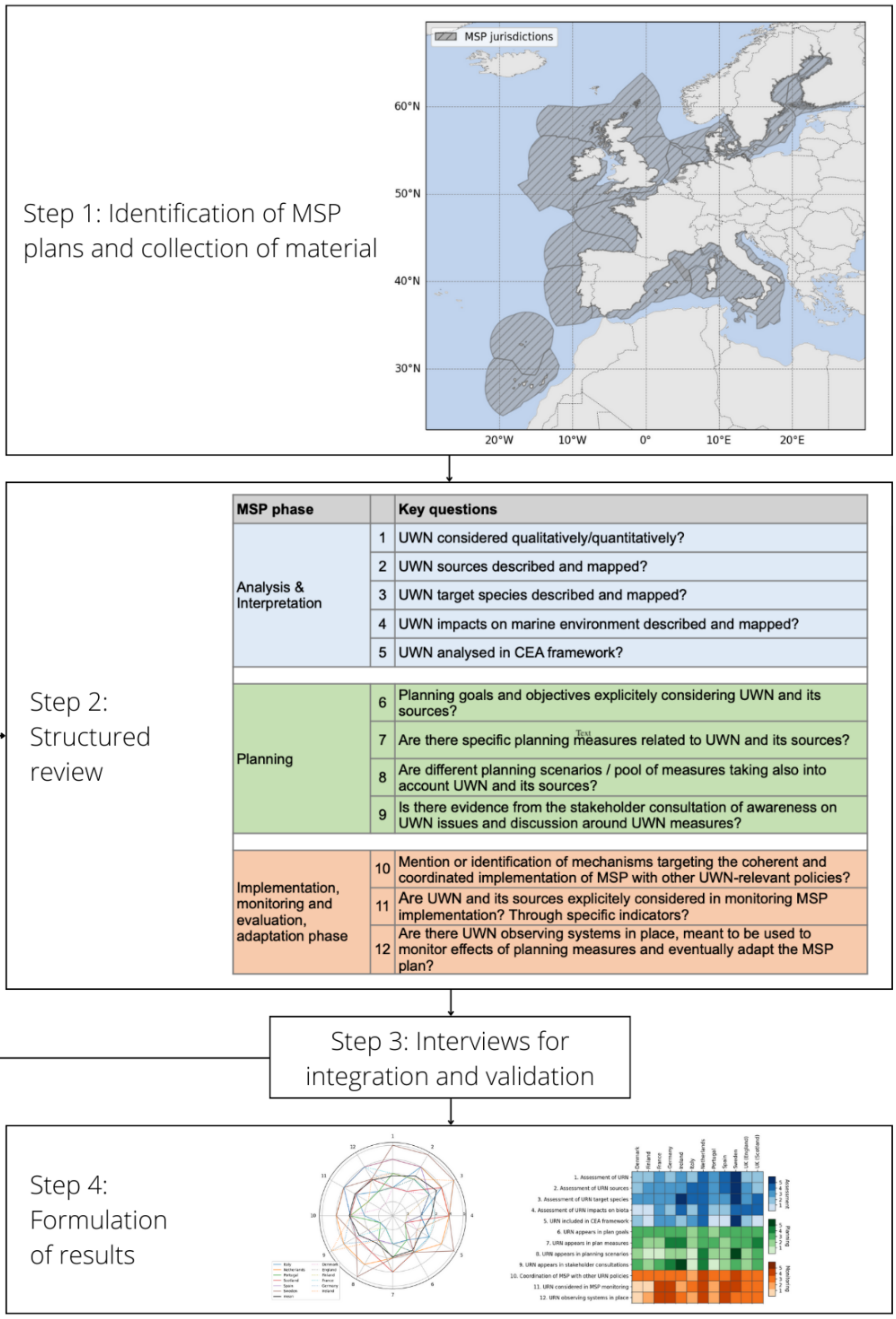

Figure 2: Methodology adopted by Bosi et al., 2023, for the review and analysis of the maritime spatial plans and related materials of 11 different countries and their approach in managing underwater noise through MSP. UWN is short for underwater noise, here.

The review was caried out in four steps. First, MSP plans from 11 European countries were collected to form a sample that is considered representative in spatial coverage, numerosity and distribution. The grey areas on the map in Fig. 2 show the considered MSP jurisdictions. All MSP plans were at the time either approved or under finalization.

For each country, a structured review of the plans and related materials (such as SEAs, MSFD reports, national marine strategies, etc.) was performed, attempting to answer key questions regarding URN in the three phases of a typical MSP process: i) analysis and interpretation, ii) planning, iii) monitoring and implementation (see step 2 in Fig. 2). The review was validated via one-to-one meetings with MSP competent authorities from each of the countries. This often led to a further iteration of step 2, where new material provided during the interviews served as an integration of the analysis. Once the review was finalized and approved by the competent authorities, a semi-quantitative score was given to the answers to the key questions, with the same criteria applied to all countries, and three main planning approaches for underwater noise were identified.

The study found that most countries include a qualitative assessment or at least a general description of underwater noise as a significant pressure in the marine environment. This is especially true when MSP is a direct implementation of MSFD guidelines. However, quantitative or geospatial analyses of underwater noise in relation to its sources and impacts are rare.

The human activities causing the most concern as noise sources, according to this sample, are maritime traffic (for continuous noise) and offshore wind (mainly for impulsive noise). Only in a handful of plans and SEAs is the spatial distribution of these activities mapped out in space to inform the analysis. Maps of distribution of target species (i.e. marine organisms negatively impacted by URN) are equally as uncommon and a list of target species is simply provided in most cases. Marine mammals, such as porpoises, dolphins, whales and seals are often mentioned as the main victims of physical injuries leading to increased mortality, disturbance, masking of communication and behavioural changes due to exposure to noise emissions. However, awareness is growing regarding impacts on other taxa, such as fish, seabirds, reptiles and invertebrates.

URN is known to act in combination with other anthropogenic pressures and contribute to cumulative impacts. However, only one of the sampled countries includes noise in a systematic Cumulative Effects Assessment (CEA). Similar methodologies are being developed in other countries at a local level but were not included in the plans at the time. Noise is included in high-level strategic goals on conservation and protection of marine biodiversity and good environmental status, particularly in reference to MSFD-D11. Where noise-specific planning objectives are present, impulsive noise is often better addressed than continuous noise.

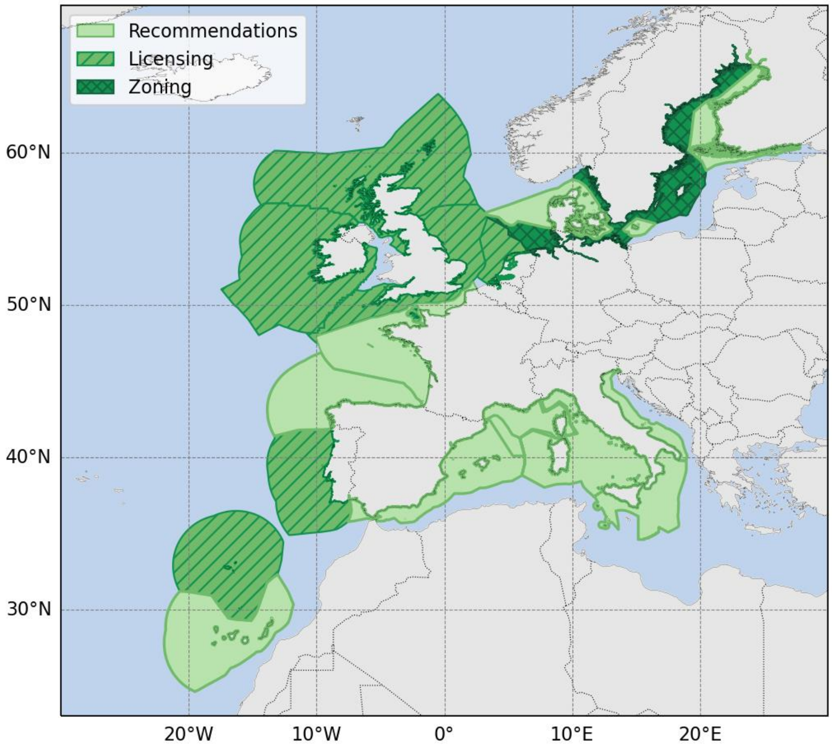

Figure 3: Planning approaches adopted in relation to underwater noise. Polygons represent the planning domains of MSP plans considered in this study. The green shading refers to the chosen approach, from a list of recommendations (lighter shading) to particular attention being given to underwater noise in the guidelines on how to perform EIAs and apply for licensing (medium shading), to a more spatial approach where underwater noise influences the allocation of human uses to marine areas (darkest shading). The planning approaches are to be understood as overlapping layers, i.e., countries shown here to have adopted a "zoning" approach may also provide recommendations, but not vice versa. From Bosi et al., 2023.

Fig. 3 shows the spatial distribution of three main planning strategies identified by this study, titled “recommendations”, “licensing” and “zoning”. All countries present recommendations on how to best manage, minimize or mitigate the negative impacts of anthropogenic noise on marine biota. This is the most common and most lenient approach, as these recommendations are not legally binding. In a handful of cases, a licensing process is added to these recommendations, whereby noise-producing activities require special permits that are released following a thorough Environmental Impact Assessment (EIA). Finally, only two of the sampled countries adopt a “zoning” approach, such that the results of the analysis on the impacts and spatial distribution of URN are explicitly taken into consideration when allocating uses to marine areas in an ecosystem-based management process. Strong awareness emerges from stakeholders during the consultation phase, during which, particularly NGOs, urge to consider existing scientific evidence on the negative effects on species other than marine mammals and to expand research on the role of URN in a cumulative impact framework. In terms of monitoring, the MSFD requires programs for both impulsive and continuous noise. Indeed, these are adopted by around half of the sampled countries, which consider both socioeconomic and environmental indicators. In addition, existing sources of noise-related data are capitalized on to contribute to national and transnational sound registries, which are useful for monitoring. For instance, instruments like Automatic Identification Systems (AIS) or Vessel Monitoring Systems (VMS), while not strictly designed for underwater noise detection, are often used to map noise emissions from shipping.

2.3.3 Discussion and conclusion

Overall, MSP is considered a useful tool to address the negative impacts of URN in a systematic way and the results of this study suggest a general tendency towards including URN in all steps of the MSP process. However, significant knowledge gaps still exist surrounding the impacts on marine biota, especially at population level and on species other than marine mammals. Further research in this sense would facilitate the creation of quantitative and spatially explicit assessments needed to inform spatial planning. Equally, capitalizing on existing research projects at the local level would help fill some of these gaps. The transboundary nature of URN needs to be addressed with a systematic and informed cooperation between neighbouring countries, who may adopt common approaches for assessment and planning by agreeing on shared targets, thresholds and indicators. Finally, as maritime spatial plans are expected to coordinate or refer to other policies to manage the effects of URN, significant effort should be made on the harmonization of existing policies and their implementation at the regional, national and international level. Involved countries would benefit from dedicated guidelines for "noise-proof" MSP, covering all aspects and phases of the process in a full MSP framework which would include noise experts from the very beginning.

Existing planning measures consist mainly of voluntary-based recommendations for the avoidance, reduction or mitigation of noise impacts and – with a few exceptions– virtually no mandatory or spatial measures are taken. However, according to the SOUNDSCAPE report on mitigation measures (Interreg Italy-Croatia SOUNDSCAPE, Deliverable Number D5.4.1, final version 20/10/2011) underwater noise mitigation may require a wide and diversified range of actions to be fulfilled. The report identifies two main categories of planning measures in this context: main measures and support measures. The former are measures that affect noise emissions in a direct way and can be further subdivided into strategic, spatial-temporal, behavioural or technological improvement measures. The latter are measures that do not directly decrease noise emissions but support the implementation of the main measures. Monitoring strategies, aimed at measuring trends of noise emissions over time, but also financial incentives towards activities implementing noise mitigation, belong to this realm. It is important to note that estimating the effectiveness, costs and applicability of mitigation measures through monitoring, scenario analysis and comparison is equally as important as their implementation.

3 Upgrade the MSP tools: development, implementation and testing

This chapter presents the web software solutions Quonops©[1], OceanPlanner©i[2], and Tools4MSP[3], along with the specific modules developed as part of the SATURN project, which are designed to integrate URN aspects into MSP processes.

3.1 Development of OceanPlanner

OceanPlanner© is an operational service available 24/7 that provides:

- a detailed regional analysis of the maritime baseline in relation with shipping and underwater sound,
- an assessment of the effectiveness of management measures in response to IMO guidelines or EU/MSFD Descriptors
- an assessment of the costs for the shipping industry.

The tool is generic and operational on all the seas and oceans of the Europe (Fig. 4) and provides relevant insight to answer the following questions:

- What are the shipping activities that may contribute the most to the regional underwater noise?
- How many vessels contribute collectively to the regional distribution of underwater noise?
- How will the distribution of underwater sound across an area be modified management measures were put in place?
- How effective would such a management measure be in reducing underwater noise?
- What is the most efficient management measure to apply that would minimize the impact and the cost for the maritime sector in a sensitive marine region?
- How good is the balance between the environmental benefit and the impact on the maritime business of such a management measure?

[1] Quonops Online Services: https://qos.quiet-oceans.com/

[2] OceanPlanner: https://ocean-planner.com/

[3] Tools4MSP Geoplatform: https://geoplatform.tools4msp.eu/

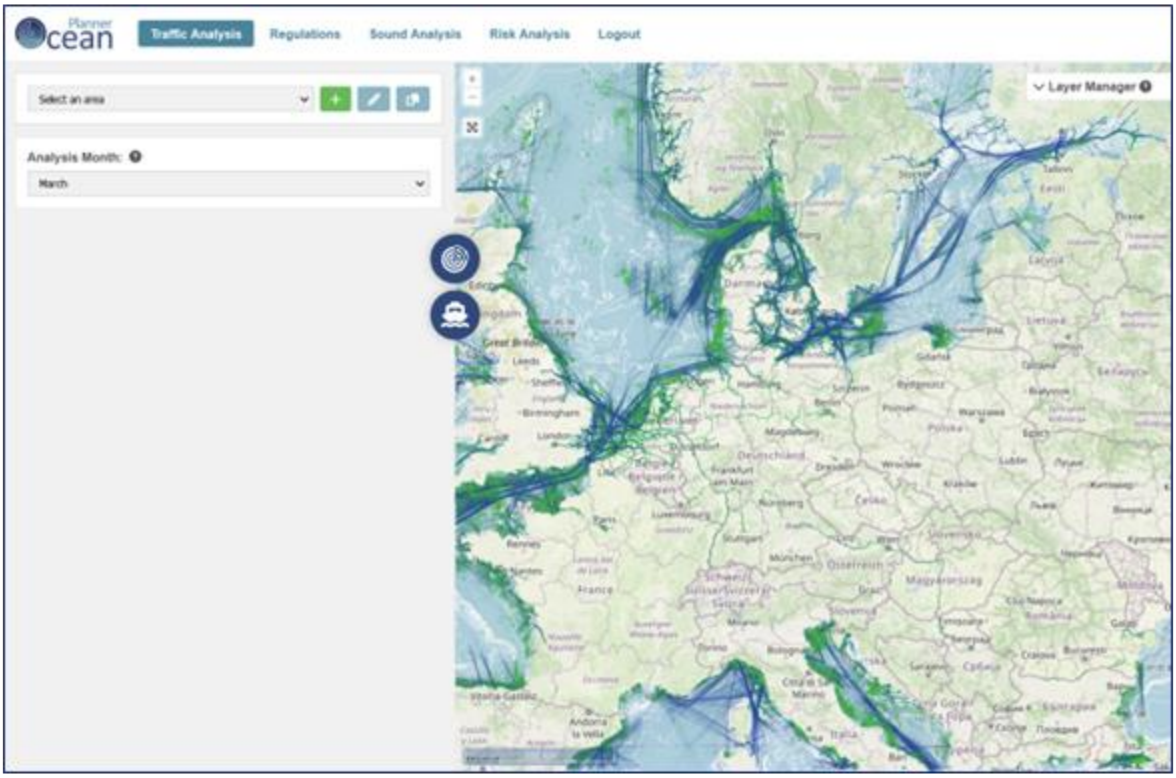

Figure 4: Illustration of the front page of OceanPlanner platform showing the geographical interface and the shipping data in Europe. The user can change the view to zoom in or out and cover other regions of the world.

3.1.1 Targeted audience

OceanPlanner© is designed to address the needs for Marine Spatial Planning on underwater noise pressures by governmental agencies, maritime authorities, marine protected area and Natura2000 (in EU) managers, international regional conventions, and harbour managers. The tool provides tangible assessment on the actual status and on the key characteristics of the shipping (baseline). It can provide a ranking of both the activities and the places where actions shall be considered in priority and inform the national and regional roadmaps relating to the preservation of the marine environment.

By providing both the economic consequences and the environmental benefits of any regulation scenario, OceanPlanner© aims to facilitate the dialogue between regulators and the marine stakeholders, especially in the context of Particularly Sensitive Sea Areas (PSSA). The tool provides tangible and objective assessment of key metrics to help finding the best acceptable balance between the environmental benefit and the cost for the shipping sector.

3.1.2 Overview

OceanPlanner© is an operational online service for assessing current environmental risks and helping to define future management measures for shipping. Based on a methodology developed in a previous study (Jakob et al., 2016), Automated Identification System (AIS) data serves as reference of the actual maritime situation and input to the algorithms that analyse the environmental and shipping characteristics in any user defined area. Shipping characteristics are among ship density, cumulative travelled distances, average and median speeds as summarized in Table 2.

OceanPlanner© provides an analysis of the environmental and economic consequences of the following maritime management measures:

- Speed limit: geographical area in which the speed is limited;
- Exclusion area: area prohibited to navigation;
- One way: traffic separation scheme;
- Limited Access: access allowed only to vessels that comply with given standards;
- Shipping trend: evolution of shipping (growth or decrease). Shipping trend are not a management measure per se, but enable to anticipate the effects of the evolution of shipping on the environment

The platform offers a friendly graphical user interface to any user to define management measures and can also be operated automatically through APIs (Application Programming Interface). Local (such as Marine Protected Areas) or regional regulated areas (such as Economical Ezone (EEZ), maritime regions, marine sanctuaries, etc.) can be geographically defined. Seasonal, temporary, or permanent regulation, partial (applied to part of the maritime activities) or total regulation are supported by the tool to quantify, by modelling, the differences between the actual sound of an area and the resulting sound after application of these management measures.

The analysis is based on the application of a single or a combination of the management measures listed above and has the form of the following information (Table 2):

- Delays: quantification of the delays induced by the management rules;
- Over-consumption/fuel savings induced by rerouting or speed reduction;
- Changes in the distribution of underwater noise;

The assessment provided by the platform are in forms of maps that can be visualized on the graphical interface, and detailed reports that can be downloaded. The assessment is made globally and separately for groups of activities along 10 categories (Passenger, Roll-on Roll-off, Container ship, Cargo, Tanker, Cruise, Pleasure, Working Vessel, Fishing, and other vessels).

Table 2: Overview of the shipping and environmental analysis performed by OceanPlanner.

	Baseline	Management scenario
Shipping		
Ship density	X	X
Travelled distance	X	X
Mean/Median speed	X	X
Fuel over-consumption or saving		X
Delays		X

Marine environment		
URN (Underwater noise)	X	X

3.1.3 Definition of areas in OceanPlanner

OceanPlanner defines different types of zones (see Fig. 5), each playing a specific role in the calculation and visualization of maritime regulations:

- Reference Zone: All processing, analysis and calculation will be done and visualized along this user-defined rectangular zone,
- Interest Zone: Automatically generated by OceanPlanner, this rectangular zone is contained into the Reference zone and corresponds to the smaller area that contains all regulation polygons defined by the user in the same scenario.
- Regulated Polygon: Defined by the user, this polygon establishes a specific area where a given regulatory measures, such as speed limits or exclusions, are defined for one or more categories of vessels.
- Influence Zone: This user-configurable area expands the regulated polygon with a buffer to determine the geographical extent where a regulatory starts its influence. For example, if there is a speed limit area, it is likely that the vessels would start to slow down before entering the regulated area, or accelerate after transiting into the regulated area, or changing heading to avoid an exclusion area. In the influence zone, trajectories start to be altered, anticipating the behavior of the vessel to meet the coming regulation. The extension is identical toward the North, the East, the South and the West.

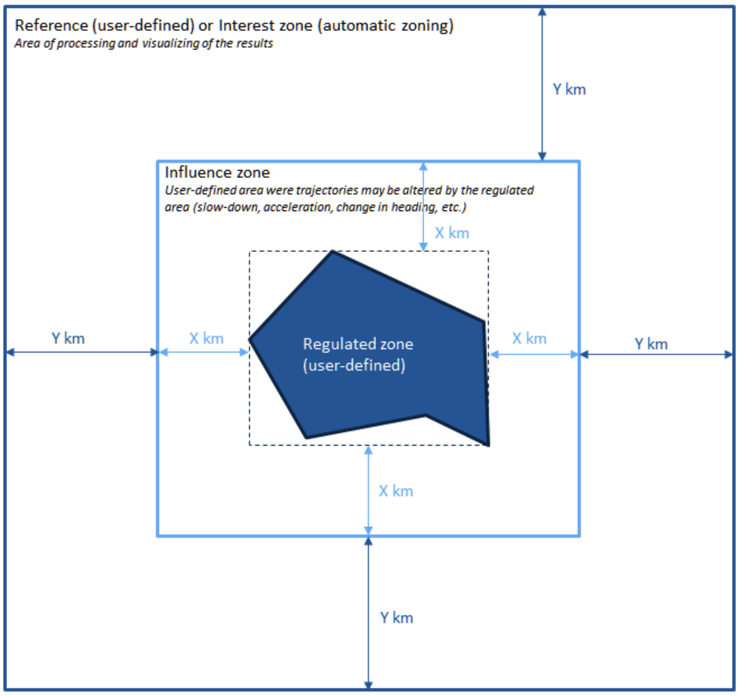

Figure 5: Definition of the areas in OceanPlanner.

3.1.4 Application of the regulations

A scenario may be made of a series of regulations, in different areas and of different nature (speed limit, exclusion zone, limited access, trend). OceanPlanner, after having cleaned and filtered the raw AIS data from errors and inconsistencies, each trajectory of each single vessel is identified and cut into segments (see Fig. 6). A segment starts when either no position if known in a 4h-period or when the vessels stay more than 30 minutes at speed less than 0.5knots (in this later case, it is considered that the vessel might be at a mooring or harbour). Each segment is then tested to assess whether it overlaps with a user-defined regulation polygon of the scenario. The test and application of the mitigation rules then apply in the following order: exclusion area, speed limit, trend and limited access.

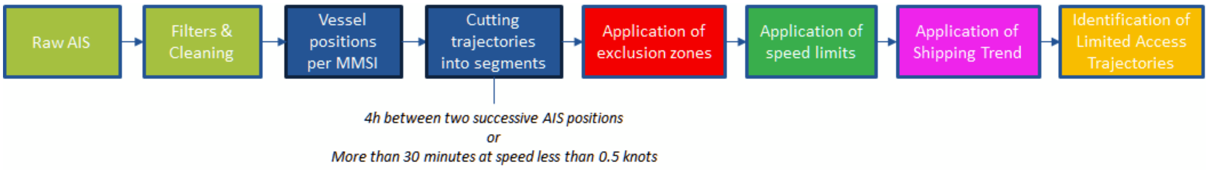

Figure 6: Overview of the application of the regulations along the trajectory of a single vessel.

3.1.5 Description of the management measures supported by the platform

The management measures are defined through areas in which a given regulation is applied. The area has the form of a polygon. To help the definition of the measure, the graphical interface displays the raw Automated Identification System (AIS) data, either comprehensively, or for a specific group of activities among Passenger, Roll-on Roll-off, Container ship, Cargo, Tanker, Cruise, Pleasure, Working Vessel, Fishing, and other vessels.

Speed limit

The speed limit management area is defined for a category or a combination of categories of vessels to which the limitation applies. The speed limitation is expressed in knots. Every vessel trajectory found in the actual AIS data that cross this geographical area and falls into the relevant category, is recalculated by the algorithm in such way that speeds above the limit are reduced to the speed limit, and lower speeds remains unchanged. When a user defines a speed-limited area, the algorithm first determines entry and exit points for each vessel intersecting the speed limited polygon. It then checks if a buffer is applied, which determines the transition between normal and reduced speeds. Once inside the speed-regulated zone, the vessel's speed is adjusted dynamically based on its position and proximity to the zone boundaries. If the vessel's original speed exceeds the maximum limit, the algorithm recalculates the speed profile, ensuring a gradual deceleration upon entry and a controlled acceleration upon exit. This prevents abrupt changes that might be unrealistic in real-world navigation.

The speed adjustment process involves recalculating speed over time by evaluating distances between consecutive trajectory points and correcting for vessel type-specific parameters. If a vessel remains within the regulation zone, its speed is consistently maintained at or below the maximum allowed threshold. When it exits, the algorithm determines whether a progressive acceleration is required to return to normal operational speed. The final trajectory (latitude, longitude and time) integrates these adjustments while preserving the natural flow of the vessel's movement (see Fig.7)

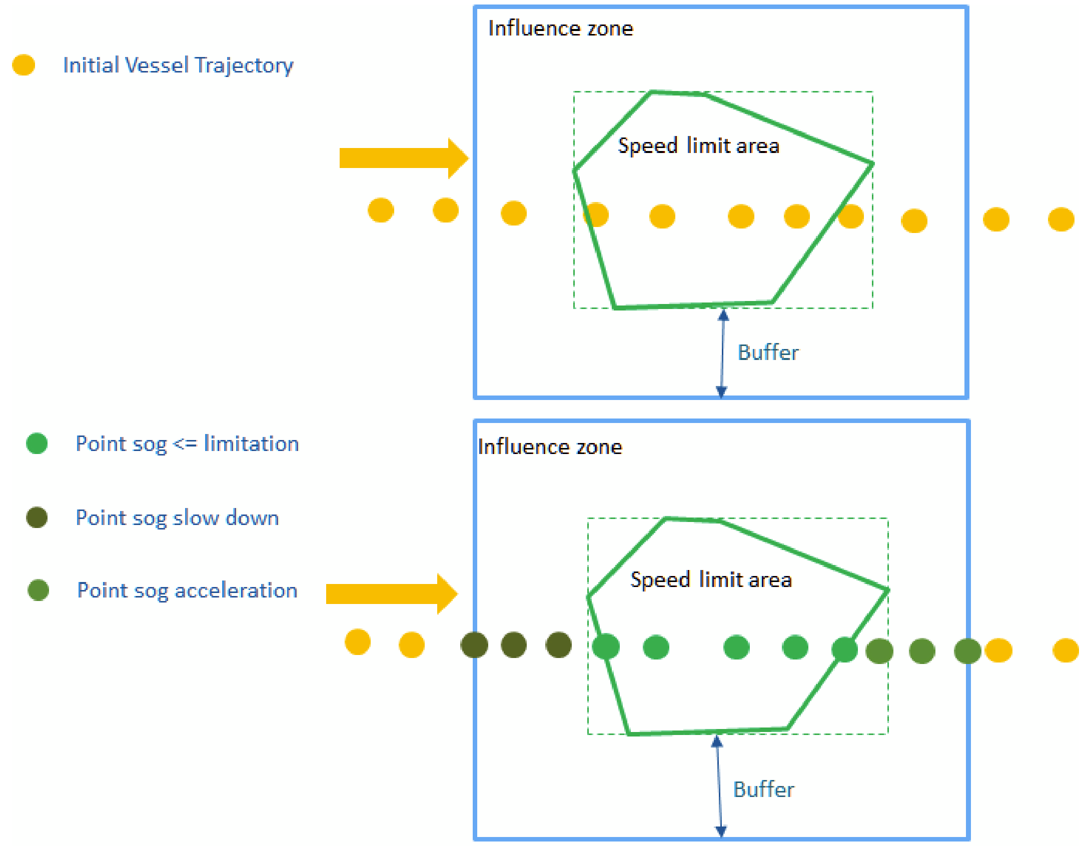

Figure 7: Overview of the application of the Speed Limit regulation along the trajectory of a single vessel.

Exclusion zone: the exclusion management area is defined for a category or a combination of categories of vessels for which it is forbidden to enter the area. Every vessel trajectory found in the actual AIS data that cross this geographical area are modified to circumvent the area. Vessel speeds are unchanged. The average speed is unchanged. The trajectories of the other vessels crossing the area are unchanged. The trajectory is only altered between the entrance and exit points of the influence area around the polygon, which are automatically calculated. When a user defines an exclusion zone, the algorithm first applies a buffer around it to define the area of influence. The system identifies affected vessels and determines if their recorded trajectories intersect with the exclusion zone. If a trajectory crosses the exclusion area, the algorithm assesses whether rerouting is required. If so, it generates waypoints that allow the vessel to bypass the restricted region using the shortest detour possible while maintaining a realistic path. These waypoints are placed strategically at the edges of the exclusion zone or within the buffer if applicable.

The rerouting process involves reconstructing trajectories by interpolating new path points, ensuring that the rerouted vessel follows a natural movement pattern. The system corrects vessel speed inconsistencies and removes anomalies to maintain realistic navigation behaviour. If a vessel starts or ends within the exclusion zone, it is either relocated to the closest permitted position or removed from the dataset if no viable alternative exists. The final trajectory (longitudes, latitudes and time) is built by integrating original path segments with newly generated waypoints, using an optimized shortest-route approach. The result is a reconstructed vessel path that respects exclusion regulations while preserving the integrity of the overall maritime traffic model (see Fig 8).

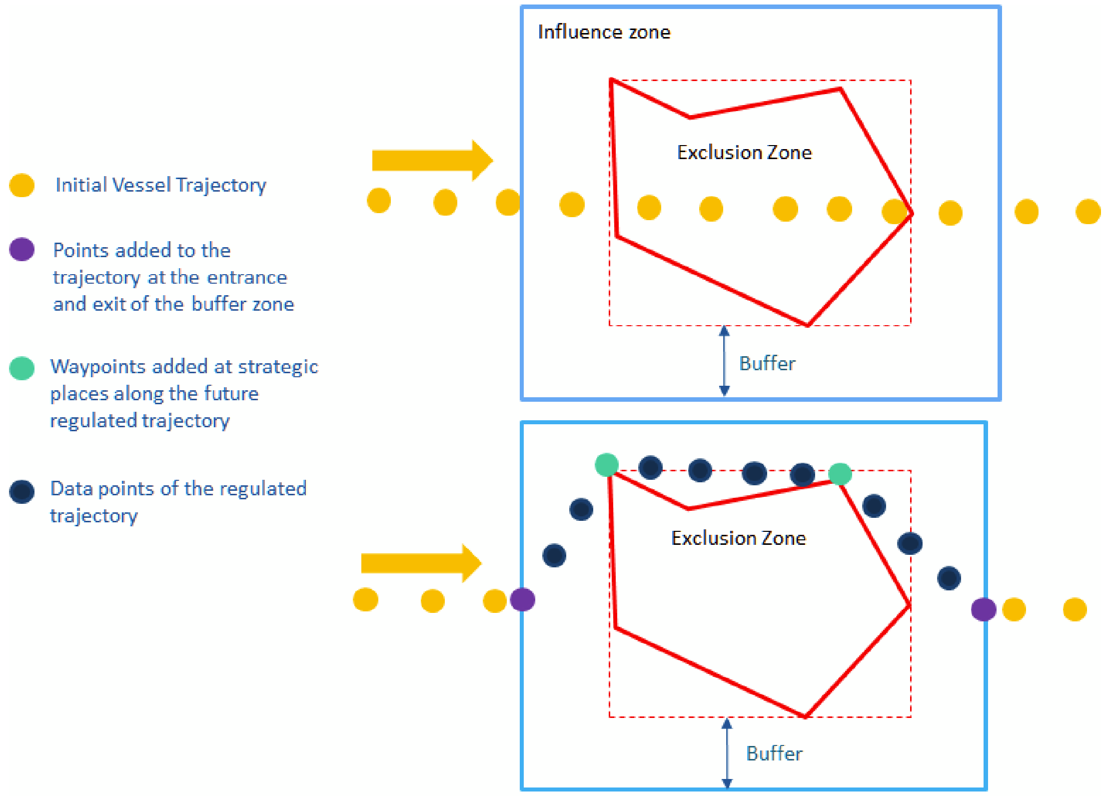

Figure 8: Overview of the application of the exclusion zone regulation along the trajectory of a single vessel.

One way: the one-way management area is a branch of a Traffic Separation Scheme that applies to a category or a combination of categories of vessels. It consists of a one-way shipping lane surrounded by two exclusion zones. The trajectories of ships originally passing through this area are channelled into the shipping lane, in the direction of travel. If the direction of navigation is incompatible with the direction of navigation, the zone is seen as an exclusion area. Vessel speeds are unchanged.

Limited Access: the limited access management area is defined for a category or a combination of categories of vessels for which it is forbidden to enter the area if they don't comply with a URN standard as edited by Class Societies. To date, the access condition consists of limiting access to ships that comply with the noise limits defined by Bureau Veritas Marine & Offshore in its class society note rule on Underwater Radiated Noise NR614 (Bureau Veritas Marine & Offhore, 2018). Entire trajectories (even beyond the managed area) are affected since compliance with such standards are likely to be associated with ship design.

The algorithm begins by analysing AIS-based vessel trajectories to identify all ships whose movements intersect with the designated Limited Access Zone during a specified period (Fig.9). Each identified vessel is then tagged with a Class Society Rule Identifier, which categorizes ships based on their noise emission profiles. Once the vessels are classified, the Quonops modeling system applies URN thresholds according to the assigned class. This ensures that only vessels meeting specific noise emission standards are allowed access to the restricted area, while others are flagged as non-compliant.

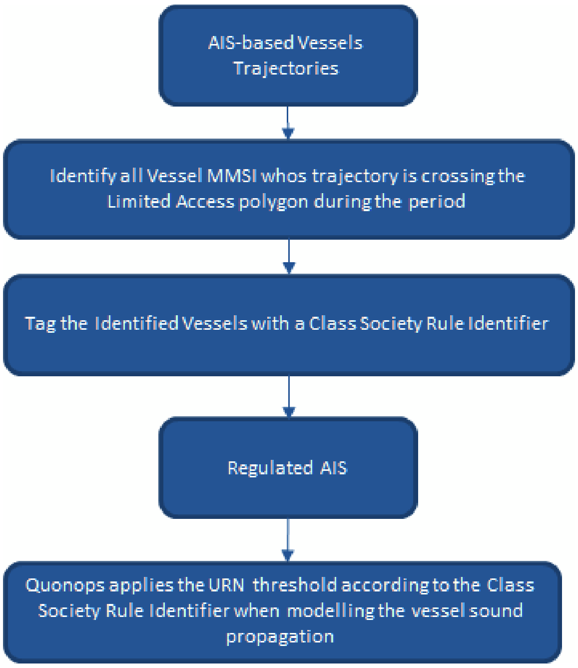

Figure 9: Overview of the application of the Limited Access regulation.

Shipping trend: the shipping trend enables to assess the environmental effects of the evolution of the shipping business for one or a combination of vessels categories (Fig. 10). The evolution is defined as a rate expressed in percentage of growth (>0) or decrease (<0). A rate of +100% doubles the maritime traffic of the relevant category which passes through the defined geographical zone. A rate of -50% divides the maritime traffic of the relevant category which passes through the geographical area by 2. When a user defines a Shipping Trend Zone, the algorithm applies a specified percentage of traffic increase (densification) or decrease (decimation) within a defined effect polygon.

In the case of traffic decimation, the algorithm starts with a dataset containing all recorded vessel trajectories. It then randomly selects a proportion of these trajectories, based on the specified percentage, and removes them from the dataset. The result is a reduced traffic density in the targeted zone while preserving the overall structure of vessel movements.

For traffic densification, the algorithm identifies a set of existing trajectories and generates time-shifted duplicates within a period of 16 days. These new trajectories are offset within valid time intervals to avoid unrealistic overlaps. The modified dataset integrates these additional movements, increasing vessel density in a controlled manner. The algorithm ensures that the generated traffic variations remain within realistic time frames, maintaining navigational coherence while simulating potential regulatory scenarios or future traffic trends.

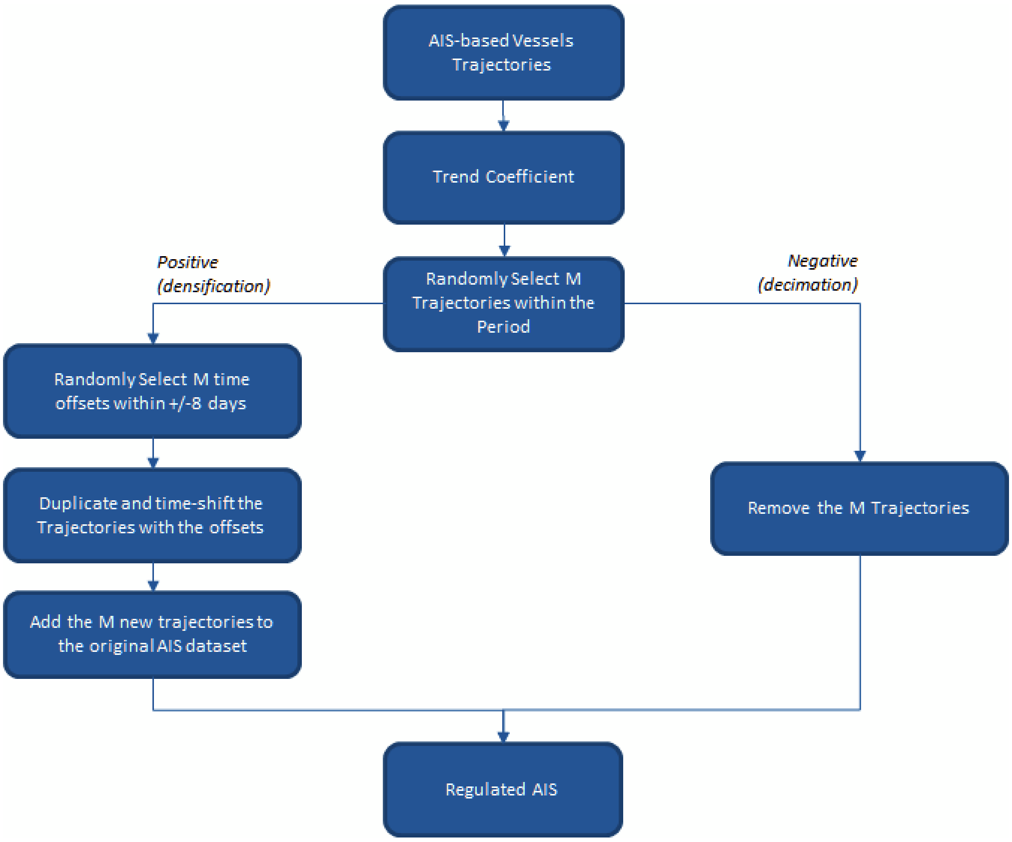

Figure 10: Overview of the application of the shipping trend algorithm.

3.1.6 Assessment of underwater noise in OceanPlanner

OceanPlanner© is supported by the existing operational sound mapping platform *Quonops Online Services©* to produce regional sound maps, either based on the AIS data describing the actual situation or based on the regulated trajectories according to the management areas defined in each scenario.

3.1.6.1 Sound mapping

Quonops Online Services© is an underwater noise prediction platform that fits within a management planning approach to prioritize the most appropriate scenarios to implement (Folegot, 2009). It is built following a similar approach as oceanographic or meteorological prediction systems. Like oceanographic or meteorological forecasting systems, this platform produces sound maps of the spatio-temporal distribution of noise levels generated by known shipping and a large variety of offshore construction and survey activities (Fig. 11). Because *Quonops online Services©* supports gaussian beam ray modelling and parabolic modelling (Collins, 1994), the delivered sound maps reflect the effects of the marine met-ocean environment, the bathymetric conditions, and the nature of the seafloor, which all together significantly affect the sound propagation. *Quonops Online Services©* is handling effective vessel positions provided by a continuous stream of Automated Identification System (AIS) data.

Figure 11: Overview of the principle of the noise mapping platform Quonops© Online Services.

3.1.6.2 Regulation efficiency calculation on underwater noise

The OceanPlanner algorithm estimates changes in underwater noise distribution by comparing sound maps generated from the original AIS dataset and those produced after applying the maritime regulations of the scenario. This process involves modelling vessel noise emissions under both scenarios and analysing the difference between them to assess the impact of regulations such as speed limits, traffic reductions, and restricted access zones.

The methodology starts with the creation of percentile Sound Maps (Folegot et al., 2016) based on the original/reference AIS dataset, which represents the baseline maritime traffic conditions. This dataset includes all vessel categories such as passenger ships, roll-on roll-off ferries, cargo vessels, container ships, cruise liners, tankers, working vessels, and fishing boats. Using these data, OceanPlanner, in conjunction with the Quonops noise modelling system, computes the baseline distribution of underwater sound levels across the study area.

After regulatory measures are applied, a second set of regulated percentile Sound Maps is generated based on the regulated AIS dataset, reflecting the new traffic conditions. These maps incorporate speed restrictions, rerouted vessel trajectories, and areas where vessel access is restricted due to underwater radiated noise (URN) limits, etc. The comparison between the original and regulated maps results lead to a percentile Sound Map of the difference, which quantifies the variations in underwater noise levels across the region.

The final noise reduction map highlights areas where the noise levels have decreased due to the applied regulations. The Figure 12 illustrates for example the change in the 10th percentile of the distribution of underwater noise in the 125Hz decidecade when a 10-knot speed limit scenario is applied to only the passenger, roll-on roll-off, cargo, container, cruise, and tanker vessels when they are navigating in the Pelagos Sanctuary which result in lower underwater noise emissions.

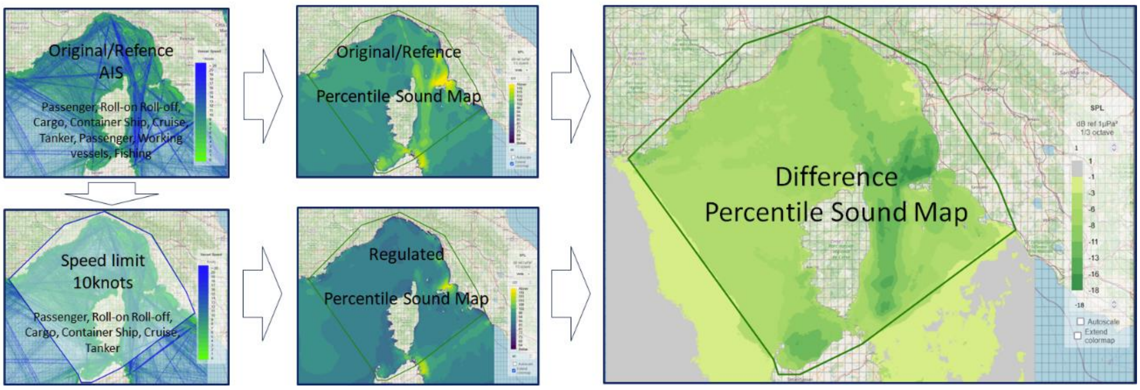

Figure 12: Overview of the principle of the assessment of the effects of the regulation scenario on the distribution of underwater noise. Illustration for a 10-knots speed limit scenario applicable in the Pelagos Sanctuary for passenger, roll-on roll-off, cargo, container, cruise, and tanker vessels. Sound maps are here represented for the 10th percentile and the 125Hz decidecade in August.

3.2 Tools4MSP upgrades

3.2.1 Tools4MSP Overview

The Tools4MSP Geoplatform (Tools4MSP Development Team, 2024) is a community-based, open-source web application designed to support the implementation of Maritime Spatial Planning (MSP) through an MSP-oriented information and data co-production (Menegon et al., 2023). It is built upon GeoNode (GeoNode Development Team, 2024; Corti et al., 2019), a web-based Content Management System (CMS) for developing geospatial information systems (GIS) and for deploying spatial data infrastructures (SDI). It offers a range of features that streamline the handling and sharing of geospatial data:

- Geospatial Data Curation: Users can easily organize and manage various types of geospatial data, including maps and location-based files. The system supports multiple data formats, such as shapefiles and GeoTIFFs making it versatile for different data needs.
- Data Discovery and Metadata Management: The platform allows users to find relevant geospatial data efficiently using keywords, categories, or spatial information. It also supports adding detailed metadata to datasets, including descriptions, tags, licensing information, and data quality indicators.
- Visualization and Mapping: Tools4MSP includes tools for creating interactive maps. Users can overlay multiple layers, customize map aesthetics, apply symbols, and display feature information. It supports various coordinate systems, ensuring flexibility in data presentation.
- Collaborative Data Sharing: The system facilitates the sharing of geospatial data. Data owners and administrators can control access permissions, allowing data to be shared publicly or with specific individuals or groups, thus fostering collaboration and data dissemination.
- Interoperability: The Geoplatform enables the publication of geospatial data as web services, making it accessible to other applications and users. It can generate Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS) endpoints, ensuring that the data can be seamlessly integrated and used by different software systems.
- Data Visualization Widgets: GeoNode's built-in tools, such as charts and sliders, enhance the exploration and analysis of geospatial data. These widgets help users to visualize data trends, tell stories, and communicate insights effectively.

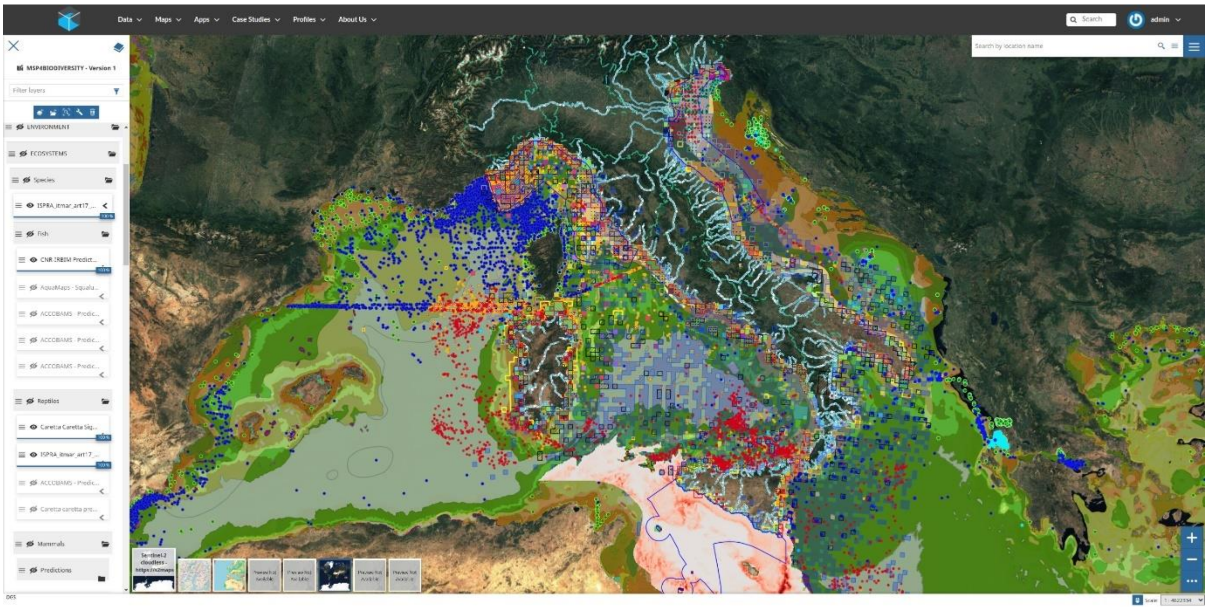

Figure 13: Tools4MSP Geoplatform. Example of an interactive map displaying information on the presence and status of environmental receptors in the Italian seas and the central Mediterranean.

Figure 13 illustrates an example of an interactive map created and shared using the Tools4MSP Geoplatform. This map overlays multiple layers showing the state and distribution of environmental receptors in the Italian seas and the central Mediterranean. The example also demonstrates how the map tool allows users to combine locally uploaded information with data made available through interoperable standards by European sources (such as EMODnet and EUNIS See habitat) or local data infrastructures.

Users can enhance their projects by integrating layers they've loaded on the Geoplatform with layers from:

- European infrastructures like EMODnet, which provides a wide range of marine data across Europe.
- National and local infrastructures, allowing for a comprehensive view that includes local nuances and details.

Now, the Geoplatform serves as a comprehensive repository for over 600 geospatial datasets, which are crucial for various maritime sectors including fisheries, maritime transport, tourism, aquaculture, coastal defence, energy, and environmental protection. These datasets are organized into categories that facilitate easy access and management. The Tools4MSP Geoplatform is transitioning to support a dataset and resource characterization system based on the MSP Data Framework (MSPdF). The Maritime Spatial Planning Data Framework (MSPdF) (Abramic et al, 2023) is designed to support the process of Maritime Spatial Planning (MSP) by structuring and organizing the necessary data. This framework helps in collecting, managing, and analysing spatial data related to various aspects of the marine environment and human activities. Here are the key components (Data clusters):

- **Marine & Coastal Environment:** Data on marine biodiversity, habitats, and ecosystems.

- **Marine & Coastal Conservation:** Information on protected areas and conservation efforts.
- **Oceanographic Characteristics:** Data on ocean conditions, such as currents, temperature, and salinity.
- **Coastal Land Use & Planning:** Information on land-sea interactions and coastal development.
- **Maritime Activities:** Data on shipping, fishing, tourism, and other maritime industries.
- **Socio-Economic Information:** Economic data and social factors affecting maritime regions.
- **Governance Information:** Details on policies, regulations, and governance structures12.

In the Tools4MSP Geoplatform, a modified version of the MSPdF has been adopted. This version includes an additional Data Cluster focused on Ecosystem Services and introduces a hierarchical classification system (see Data Clusters and Themes in Fig. 14) for each cluster. This allows each resource to be tagged with multiple classes, providing higher versatility.

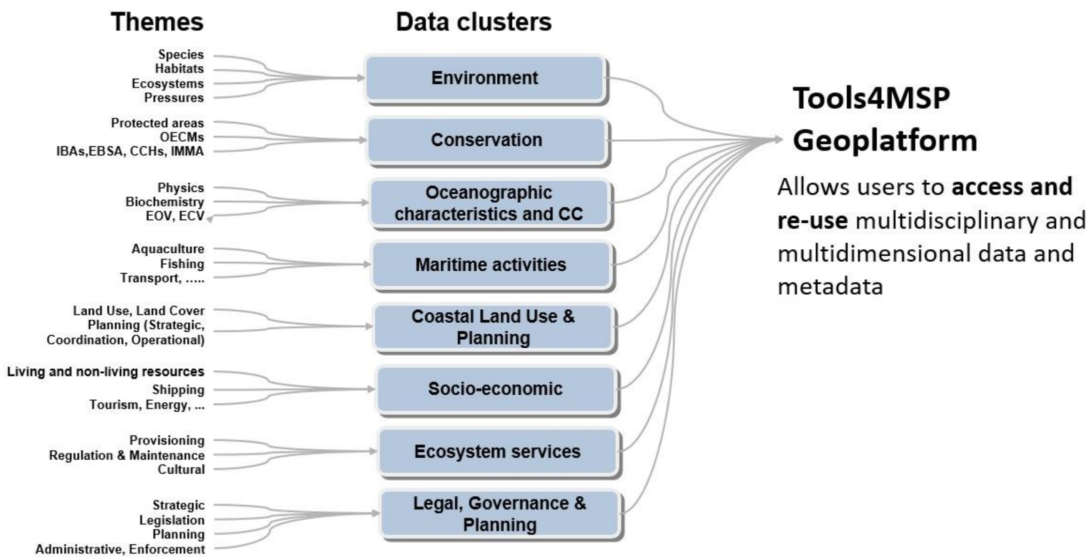

Figure 14: Modified version of the MSPdF adopted within the Tools4MSP Geoplatform.

The relevant clusters for the URN include the Environment cluster, which supports three classification systems derived from the MSFD. In particular, the descriptor/criteria system provides a framework for directly classifying pressure layers based on MSFD Descriptor 11 (D11: Introduction of Energy, including Underwater Noise). This descriptor is further divided into Criterion D11.1 (Low-Frequency Continuous Sound), which assesses the levels of continuous anthropogenic noise from sources such as shipping, and Criterion D11.2 (Intermittent Sound and Impulsive Noise), which focuses on short-duration noise events from activities like seismic surveys and pile driving (European Commission, 2008; MSFD GES Technical Subgroup on Underwater Noise, 2011). Additionally, an "environmental receptor" classification system is available within this cluster to further describe relevant ecological and physical features.

Moreover, Cluster 6, which integrates a classification system based on the extended HILUCS[4] (Hierarchical Land Use Classification System) (e.g., European Environment Agency, 2021), can be used to categorize pressure sources. This classification facilitates the identification of marine and coastal activities contributing to underwater noise, such as marine transportation, recreational boating, small-scale and professional fishing, trawling, and other anthropogenic sources. By combining these classification systems, the approach enables a comprehensive assessment of both pressure sources and their impacts on the marine environment.

3.2.2 Decision Support Tools

A specific feature of the Tools4MSP Geoplatform is its integration of Decision Support Tools, which are specifically developed to aid various stages of the Marine Spatial Planning (MSP) process. Users can still adopt a collaborative approach using these tools. They can create their own case studies from scratch by utilizing the existing data on the platform or by uploading their own data.

Below is a list of the main tools currently available on the platform:

- Cumulative Effects Assessment (CEA):
- Purpose: The CEA tool supports the MSP process under an Ecosystem-Based Approach (EBA) by assessing the potential cumulative impacts of maritime activities on the marine environment.
- Methodology: It is based on the methodology proposed by Menegon et al. (2018), providing a structured framework for assessing cumulative effects.
- Functionality: The tool can localize types of pressures and the most impacting maritime uses, even in transboundary domains, aiding in the management of target ecosystem components.
- Maritime Use Conflict Analysis (MUC):
- Objective: The MUC tool aims to support the MSP process through the reallocation of maritime uses and the creation of collaborative conflict scores analysis.
- Features: It allows for the iteration of analysis over different time periods through the integration of new conflict scores and geospatial datasets on sea uses. It also supports sea use scenario analysis and overlay analysis.
- Pressure Assessment for Marine Activities (PMAR):
- Objective: The PMAR module simulates the propagation of anthropogenic pressures which act as tracers in seawater, by calculating their Lagrangian trajectories from given sources (human uses) and then aggregating them into maps of average concentration.
- Methodology: the tool requires oceanographic and atmospheric data to force the dispersal of virtual particles and georeferenced layers representing the presence or intensity of human activities to be used as sources of pressures.

[4] Extended HILUCS (eHILUCS): https://maritime-spatial-planning.ec.europa.eu/media/document/15245

- Functionality: the PMAR module can be used as a stand-alone tool for the assessment of one or more specific pressures in an area of interest, but it can also enrich the pool of pressure layers to be included in a Cumulative Effects Assessment (CEA).

As part of the SATURN project, the primary focus was on the cumulative impact analysis (CEA) tool. This tool is a key component in supporting the step-by-step approach described in Chapter 4. The project involved extensive conceptual and software development to enhance this tool, particularly in incorporating aspects of Underwater Radiated Noise into cumulative impact analyses.

Below, we will provide insights into the methodology for a risk-based approach in analysing cumulative impacts and details on how to use the tool.

3.2.3 Risk-based Cumulative Effects Assessment

3.2.3.1 Cumulative Effects Assessment: introduction and definitions

Cumulative effects assessment (CEA) evaluates the combined impact of human activities and natural processes on the environment, a concept originating from the US National Environmental Policy Act of 1969. Adopting Judd et al.'s (2015) definition, CEA systematically identifies and evaluates the significance of effects from multiple pressures on receptors, offering management options by quantifying overall effects and pinpointing critical pressures and vulnerable receptors.

CEA supports various processes like Environmental Impact Assessments (EIA), Coastal Zone Management (CZM), Fisheries Management, Offshore Energy Development, marine conservation, Maritime Spatial Planning (MSP), Strategic Environmental Assessment (SEA), and Adaptive management. Its application varies by context, with EIAs focusing on detailed, localized project impacts and MSP/SEA addressing broader, strategic-level impacts with higher uncertainties.

Approaches to CEA include analytical methods (e.g., spatial models, ecological modelling) and planning strategies (e.g., risk-based frameworks). Stelzenmuller et al. (2018) classified CEA applications by input data types (expert knowledge, qualitative and quantitative data) and methods/tools (spatial analysis, statistical models, food-web models).

Recent interest in geospatial CEA indexes has led to methodologies integrating data layers (habitat maps, pollution sources, fishing activities) and assigning scores based on scientific knowledge (Halpern et al., 2008). Its application has been demonstrated across various geographic scales, spanning from global (Halpern et al., 2015) and sea basin (HELCOM, 2023, Micheli et al., 2013, Korpinen et al., 2012) levels to regional assessments (Hammar et al., 2020, Menegon et al., 2018, Clarke Murray et al., 2015). These CEA indexes are valuable for MSP due to their transparency, holistic scope, spatial specificity, and capacity for comparative analysis, though they have limitations like simplification of complex systems and potential subjectivity in scoring.

3.2.3.2 Tools4MSP CEA

At CNR in Venice, we have developed a conceptual model, and a tool called Tools4MSP CEA (Menegon et al., 2018; Menegon et al., 2018b). This tool facilitates the analysis of cumulative impacts and supports the ecosystem-based approach within Marine Spatial Planning (MSP) processes. It offers a structured framework and a suite of tools for decision-makers, planners, and stakeholders managing marine environments. Developed by CNR-ISMAR since 2013, with contributions from a consortium of research institutions, it integrates data, spatial analysis, modelling techniques, and human-computer interaction methodologies to facilitate informed decision-making and the sustainable development of coastal and marine areas.

The Tools4MSP framework includes a specific module for geospatial-explicit Cumulative Effects Assessment (CEA). Initially based on the methodology by Halpern et al. (2008) and later modified by Andersen et al. (2013), this module aims to spatially assess the effects of single or multiple human activities on environmental receptors. It identifies the relationships between the sources of pressure, the pathways of exposure, and the environmental receptors that might be affected (source-pressure-pathway-receptor linkages, impact chain), a key aspect of environmental risk assessment (Judd et al., 2015; Stelzenmüller et al., 2018).

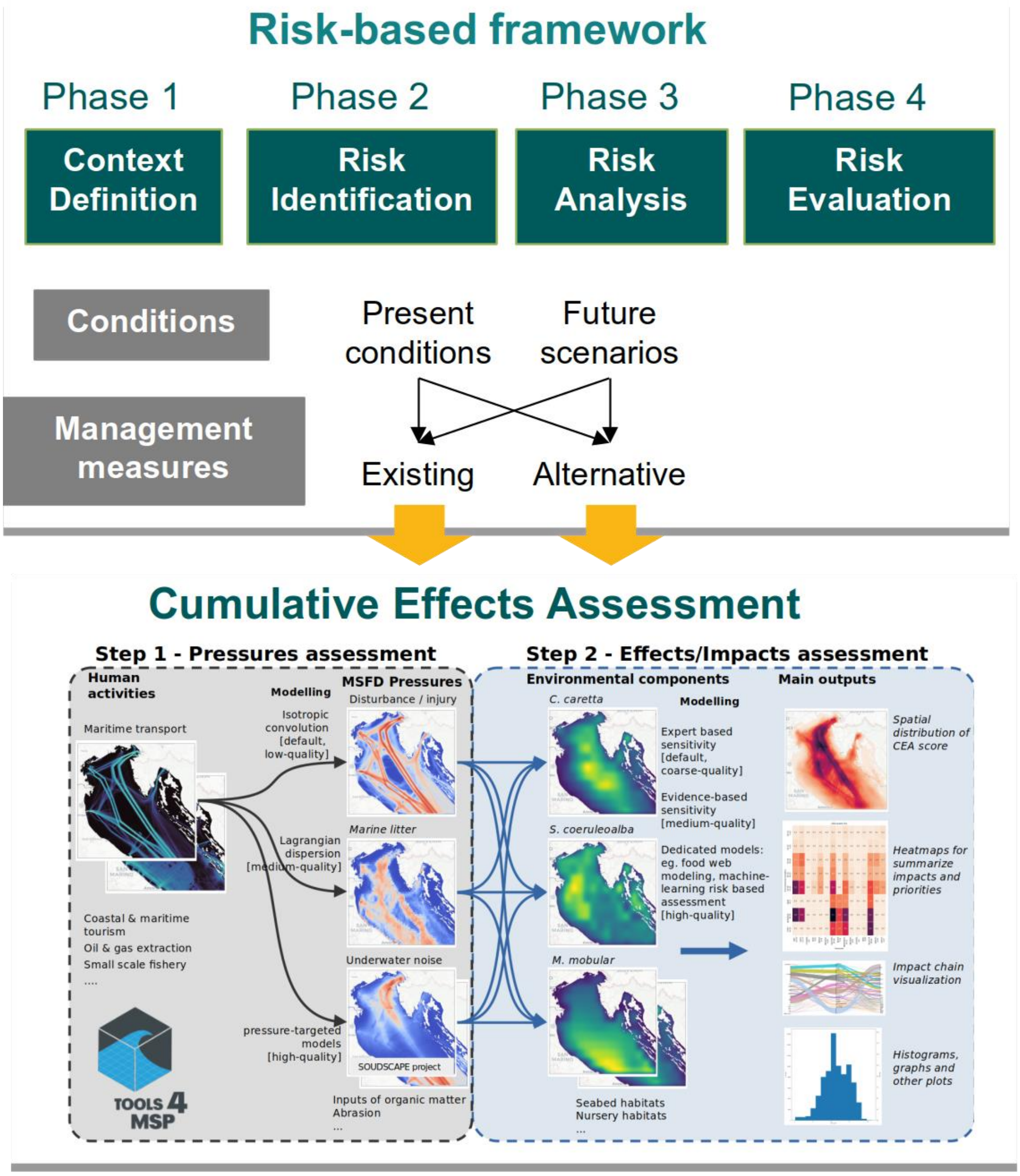

Figure 15: Exemplification of the Tools4MSP CEA module (Menegon et al. 2024).

Primarily a modelling framework, the Tools4MSP CEA module standardizes the CEA process, clarifies relationships between relevant concepts, and provides a structured way to combine and interpret results from multiple models. Impact chains are modelled through two interdependent tasks (see Fig. 15):

- Step 1: Pressures assessment
- Step 2: Effects/impacts assessment

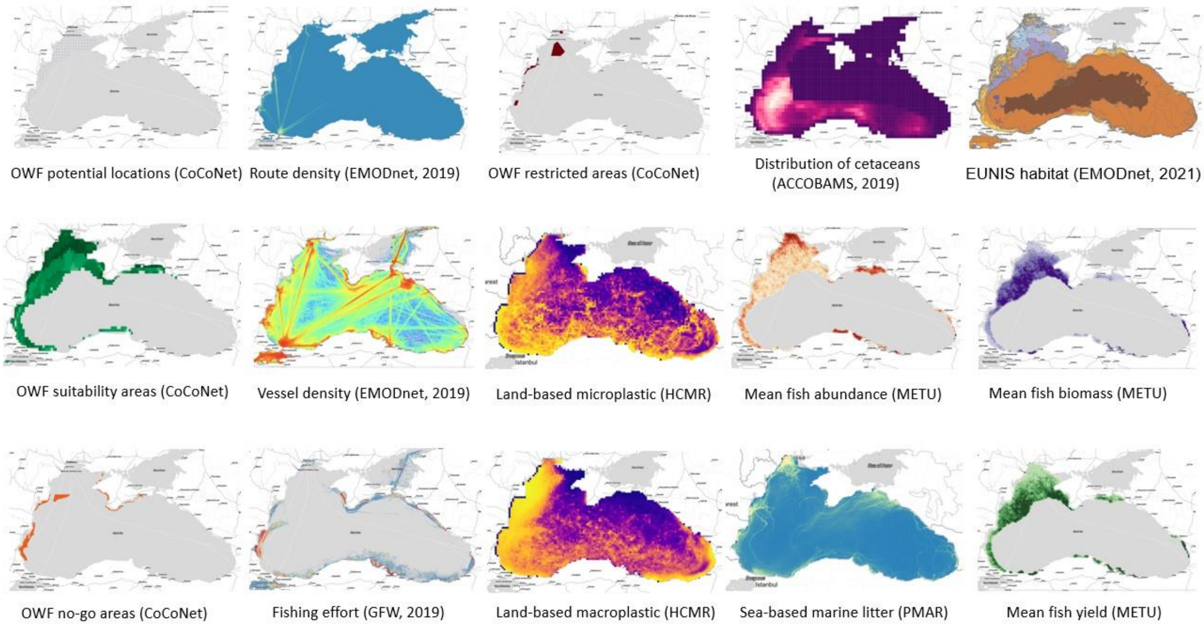

Figure 16: Example of input data for applying CEA in the Black Sea: spatial distribution of human activities and environmental receptors (Menegon et al. 2024).

3.2.3.3 Step 1 Pressure Assessment

Pressure assessment estimates the spatial propagation of pressures generated by one or multiple human activities.

The primary inputs for this step are geospatial layers representing the distribution of human activities at sea. Examples of such layers (Fig. 16) include:

- ACQFIN: Aquaculture – Finfish. Presence of aquaculture farms (points, polygons) with (optional) attributes providing the total annual production statistics (tons/year).
- FPORTS: Fishing ports. Port location (point/polygon features) with an (optional) attribute representing the port utilization (e.g. annual landed fish, characteristics of fishing fleet).
- MIL: Military areas. Polygonal or point data representing the military areas delimitation. or location including (optional) information on area characteristics (e.g. temporary/permanent, firing area, mine hunting exercise).
- OGEXTR: Oil & Gas Extraction. Extraction platform location (point/polygon features) with (optional) attributes reporting the characteristics of the platform (e.g. type, dimensions).
- SHIPDENS: Passage of ships/boats. Gridded data of annual/monthly/seasonal vessel route density (n. of tracks/km2/year) by vessel type (e.g. Cargo, Tanker).
- SSF: Small Scale Fishery. Fishing with nets and smaller vessels. gridded data of fishing effort intensity (hours/km2/year).

A comprehensive description of the geographic layers used to represent human activities is available in the online documentation (Tools4MSP Development Team, 2024b).

To characterize the pressures exerted by the human activities previously described, the Tools4MSP framework typically adopts the pressure classification proposed by the Marine Strategy Framework Directive (MSFD) Annex III (2017/845/EU), which identifies 19 pressures divided into three themes:

- Biological pressures
- Input or spread of non-indigenous species
- Input of microbial pathogens
- Input of genetically modified species and translocation of native species
- Loss or change of natural biological communities due to cultivation of animal or plant species
- Disturbance of species (e.g., breeding, resting, feeding areas) due to human presence
- Extraction or injury/mortality of wild species (by commercial and recreational fishing and other activities)
- Physical pressures
- Physical disturbance to seabed (temporary or reversible)
- Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)
- Changes to hydrological conditions
- Substances, litter, and energy pressures
- Input of nutrients (diffuse sources, point sources, atmospheric deposition)
- Input of organic matter (diffuse sources and point sources)
- Input of other substances (e.g., synthetic, non-synthetic substances, radionuclides) from various sources
- Input of litter (solid waste matter, including micro-sized litter)
- Input of anthropogenic sound (impulsive, continuous)
- Input of other forms of energy (e.g., electromagnetic fields, light, heat)
- Input of saline water (point sources such as brine)

The framework can incorporate various pressure models, prioritizing those that establish spatial relationships between pressures and their sources. In the absence of dedicated models to perform pressure assessments and their corresponding results expressed as geospatial layers, it can use two main models for pressure estimation:

- Isotropic convolution model: This basic model is applied by default when more accurate models are not available. It uses the spatial distribution of anthropogenic activities and pressure weights as input parameters.
- Pressure Assessment of MARine activities (PMAR) model: This model uses Lagrangian particle tracking algorithms to provide mid-quality representations of pressure propagation from human activities.

Additionally, results from external, pressure-specific models can be integrated. This often enhances assessment quality, especially when default models do not meet specific analysis objectives. For example, underwater noise propagation models typically involve dedicated and complex acoustics models that account for sound wave behaviour, attenuation, and environmental factors influencing sound propagation.

Isotropic convolution model

The isotropic convolution model can be expressed as follows:

$$p_{i,j} = G * \left(w_{i,j}\ U_i\right) \qquad \text{eq. 1)}$$

Where:

- $p_{i,j}$ - represents the contribution of the i-th human use to the j-th MSFD pressure
- U_i – is the spatial distribution (intensity or presence/absence) of th i-th human use
- $w_{i,j}$ - is the "release factor" or "weight". It gives insight on the relationship between the U_i and MSFD pressures j-th. It can serve as a dimensional factor (release factor) e.g. when estimating the release of pollutants (oil, ballast water, litter, etc.) from shipping, or it can serve as a a-dimensional / relative factor (weight) expressing, in percentage, the relative contribution of each use in producing a certain pressure. The latter interpretation is employed when utilizing the CEA, in a simplified manner, as a tool for conducting relative risk analysis (refer to the description below for more details).
- G – is the convolution function. For pressures that do not act only locally (e.g. release of pollutants, litter, noise), this function is used to simulate 2D dispersion.
- $d_{i,j}$ – distance (size of the convolution function) represents the radius of influence (in meters) of a pressure from the location of its source (the use).
- $*$ - 2D spatial convolution operator.

The isotropic convolution model provides a quick assessment of pressures when precise and accurate models are unavailable, particularly in data-poor contexts. This model uses a convolution function to distribute a pressure field over a marine space through spatial filtering. This involves combining the pressure values at each location with those of neighboring locations using a predefined kernel, which can vary in size and shape depending on the specific pressure and use (di, j). The convolution transformations employed maintain the invariance of the original pressure distribution, ensuring that the total pressure remains unchanged across the entire space. This process also helps to smooth out abrupt changes or variability in the pressure field, resulting in a more continuous representation of pressure distribution.

Identifying the relationships between uses and pressures and accurately setting the w and d parameters are crucial for reliable results. This information can be collected and synthesized from various scientific literature, international datasets, project findings, meta-analysis or dedicated models (eg. Predictive models). Key sources of information include the Marine Activities and Pressures Evidence database (JNCC, 2022, Version 5.1), the article "An exposure-effect approach for evaluating ecosystem-wide risks from human activities" (Knights et al., 2015), and the report "Human uses, pressures and impacts in the eastern North Sea" (Andersen et al., 2013).

3.2.3.4 Step 2 - Effects / impacts assessment

The effects/impacts assessment allows us to spatially assess the distribution of impact exerted by one or multiple pressures on one or multiple environmental receptors. To accomplish this, the methodology utilizes a response function that incorporates information on ecosystem vulnerability/sensitivity (SENSITIVITIES Matrix) to combine the spatial distributions of anthropogenic pressures (derived from the previous step – Pressure assessment) with the spatial distributions of ecosystem components (see examples in Fig. 16).

Here are some examples of commonly used layers to represent environmental receptors:

- FISH-WHIT: Whiting (Merlangius merlangus). Examples of spatial representations: polygonal data of Whiting hotspots (presence/absence), gridded data of likelihood of presence (probability), gridded data of Whiting abundance (e.g. biomass/km2).
- TURT: Loggerhead turtle (Caretta caretta). Examples of spatial representations: polygonal data of Loggerhead turtle hotspots (presence/absence), gridded data of likelihood of presence (probability), gridded data of Loggerhead turtle abundance (e.g. biomass/km2).
- MB252: Biocenosis of Posidonia Oceanica. Polygons identifying presence.

A comprehensive description of the geographic layers used to represent environmental receptors is available in the online documentation (Tools4MSP Development Team, 2024b).

CEA Score

Below is the equation used to calculate the CEA score for the k-th environmental receptor.

$$CEA_k = rfunc_k(E_k, p_1, \dots, p_J) \qquad \text{eq. 1)}$$

Where:

- CEA_k – represents the spatial distribution of the impact for the k-th environmental receptor
- E_k – is the spatial distribution of the k-th environmental receptor. It can be represented in several ways, for example: presence/absence layer, probability of presence layer or a layer derived from species distribution models (where for each grid cell the estimated abundance in tons/km2 or similar quantities is provided)
- J – is the number of MSFD pressures considered for the assessment
- pj – represents the spatial distribution of the j-th MSFD pressure
- $rfunc_k$ – response function for the k-th environmental receptor

For implementing the methodology in SATURN project, an additive model with linear response functions was employed. The above function therefore becomes:

$$CEA_k = \sum_{j=1}^{J} E_k \; s_{k,j} \, p_j \qquad \text{eq. 2)}$$

Where:

- Sk,j – represents the sensitivity of the k-th environmental receptor over th j-th pressure

Sensitivity refers to the likelihood of change when a pressure is applied to a feature (receptor). It depends on the feature's ability to tolerate or resist change (resistance) and its capacity to recover from impact (resilience) (Tillin et al., 2010). Expert judgment or meta-analysis can be used to determine the sensitivity levels of various ecosystems to individual pressures. This simplified impact modelling is widely used globally to support strategic planning and assessment (HELCOM, 2023; Hammar et al., 2020; Micheli et al., 2013; Korpinen et al., 2012).

The sensitivity scores were calculated as the product of:

- Impact level scores, assigned following the approach used in Carlucci et al. (2021).
- Recovery time scores, assigned according to the Marine Evidence based Sensitivity Assessment (MarESA)[5] methodology within the MARLIN project (Tillin et al, 2010).

Notably, the impact score was never set to zero. In cases where the effect of a pressure on an environmental component was unknown, or when no impact was presumed due to a lack of evidence, a precautionary score of 0.1 was assigned to account for uncertainty.

By using dimensionless modelling to evaluate pressures, the impact assessment also becomes dimensionless. Therefore, the final value of cumulative effects assessment (CEA) should be interpreted as a relative level of risk rather than an absolute measure. The model results cannot be used to quantify absolute reductions in biomass, mortality rates, or similar quantities.

Identical rescaling and weighting approaches were applied to the environmental receptor layers, as described earlier for pressure assessment. These approaches included rescaling layers to a standardized range between 0 and 1 and applying weighting factors such as temporal frequency, magnitude, and relevance. The magnitude weight is crucial for ensuring comparability between individual case studies and global analyses of environmental receptors.

Vulnerability profiles and maps

In addition to the Tools4MSP CEA score indicator presented earlier, two new CEA indicators related to the concept of vulnerability have recently been implemented. These additions aim to better align the CEA framework with standard risk-based assessment practices.

Following standard risk-based assessment practices, vulnerability is based on exposure and effect potential (ICES, 2019; Cormier et al., 2013; De Lange et al., 2010). In this framework:

- Exposure is determined by the spatial and temporal overlap between the pressure and the ecosystem component.

[5] Marine Evidence based Sensitivity Assessment (MarESA): https://www.marlin.ac.uk/sensitivity/sensitivity_rationale

- Effect potential is a function of the pressure load and the inherent resistance and recovery potential of the environmental receptor (i.e. environmental sensitivity).

As a result, the new vulnerability for each impact chain is defined using the previously introduced terms:

$$V_{k,j} = \min\left(1, E_k\, s_{k,j}\, p_j\right) \quad \text{eq. 3)}$$

This formulation ensures that the vulnerability score does not exceed 1, effectively introducing a plateau beyond which additional increases in exposure, sensitivity, or pressure load do not further increase the vulnerability score. A vulnerability value of 1 indicates that the ecosystem component has experienced 100% mortality.

The vulnerability profile for each environmental receptor is then obtained by aggregating the vulnerability values across all impact chains. To prioritize impact chains in each cell and assess the cumulative vulnerability, a ranking process is applied. The cumulative vulnerability is then represented using a cumulative distribution plot, where the x-axis varies from 0 to 100% and represents the fraction of the total environmental receptor present in the case study area where the vulnerability assumes values lower than or equal to the value represented in the y-axis.

In addition, the cumulative vulnerability V_k for each spatial unit is calculated using the following equation:

$$V_k = \min\left(1, \sum_{j=1}^{J} V_{k,j}\right) \quad \text{eq. 4)}$$

The spatial representation of V_k is called the vulnerability map, which visually illustrates the distribution of vulnerability across the study area.

3.2.3.5 Spatial grid of analysis

For the CEA analysis, the study area is partitioned into a grid of regular cells. The resolution of the analysis cells is a crucial aspect in defining the scope and accuracy of a case study. Choosing the appropriate resolution impacts not only the precision of the results but also the relevance and applicability of the findings to real-world scenarios.

Several factors influence the choice of resolution. Primarily, the final purpose of the analysis plays a significant role. If the goal is to support detailed, localized management decisions, a higher resolution is necessary to capture fine-scale spatial variations and interactions. Conversely, if the aim is to inform broader, strategic planning, a coarser resolution may suffice, providing a more generalized overview of spatial patterns and trends.

The extent of the case study area is another critical consideration. Smaller, local case studies benefit from higher resolutions, such as 250 meters, which offer detailed insights into specific zones of interest. On the other hand, larger, cross-border, or basin-level case studies, which cover extensive geographic areas, often employ resolutions of around 1000 meters. This coarser resolution helps manage computational resources effectively while still delivering meaningful results.

In the context of cumulative effects assessment to support MSP, the resolution typically varies from 250 meters for local case studies to 1000 meters for cross-border and basin-level studies. This range balances the need for detail and the practicalities of managing and processing large datasets over extensive areas. However, it is important to consider that using more detailed resolutions requires higher quality datasets to ensure significant results

In terms of the map projection system, the CEA-Tools4MSP automatically aligns the analysis grid with the EEA reference grid, which uses the Lambert Azimuthal Equal Area (LAEA) projection (Peifer, 2011)

When using CEA to incorporate Underwater Noise, it is also essential to consider the characteristics of sound propagation models when choosing the resolution and analysis grid.

3.2.4 Module results

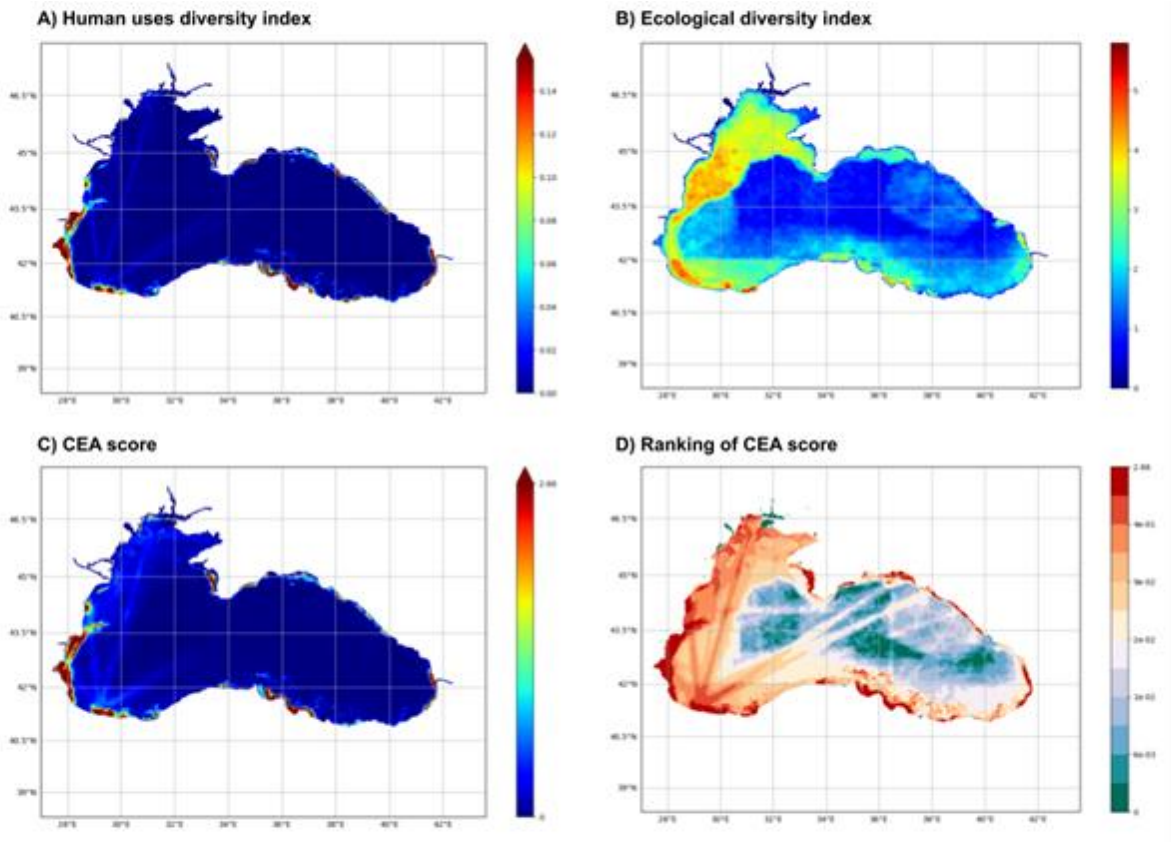

Figure 17: Key geospatial outputs of the Tools4MSP CEA module: Black Sea example (Menegon et al. 2024).

Figure 17 shows the main geospatial outputs of the Tools4MSP CEA module:

- Human Uses Diversity Index (map): an indicator representing the sum of normalized presence or intensity of all anthropogenic activities in each cell.
- Ecological Diversity Index (map): an indicator representing the sum of presence, normalized probability, or normalized abundance of all environmental receptors in each cell;
- CEA score (map): spatial distribution of the overall CEA score, defined as the sum of the CEA scores of individual environmental components (CEA_k).
- CEA score ranking (map): spatial distribution of the overall CEA score using a specialized color bar to highlight the relative rank of impacted areas by percentage of the overall CEA score. The percentages used are: 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 95%.

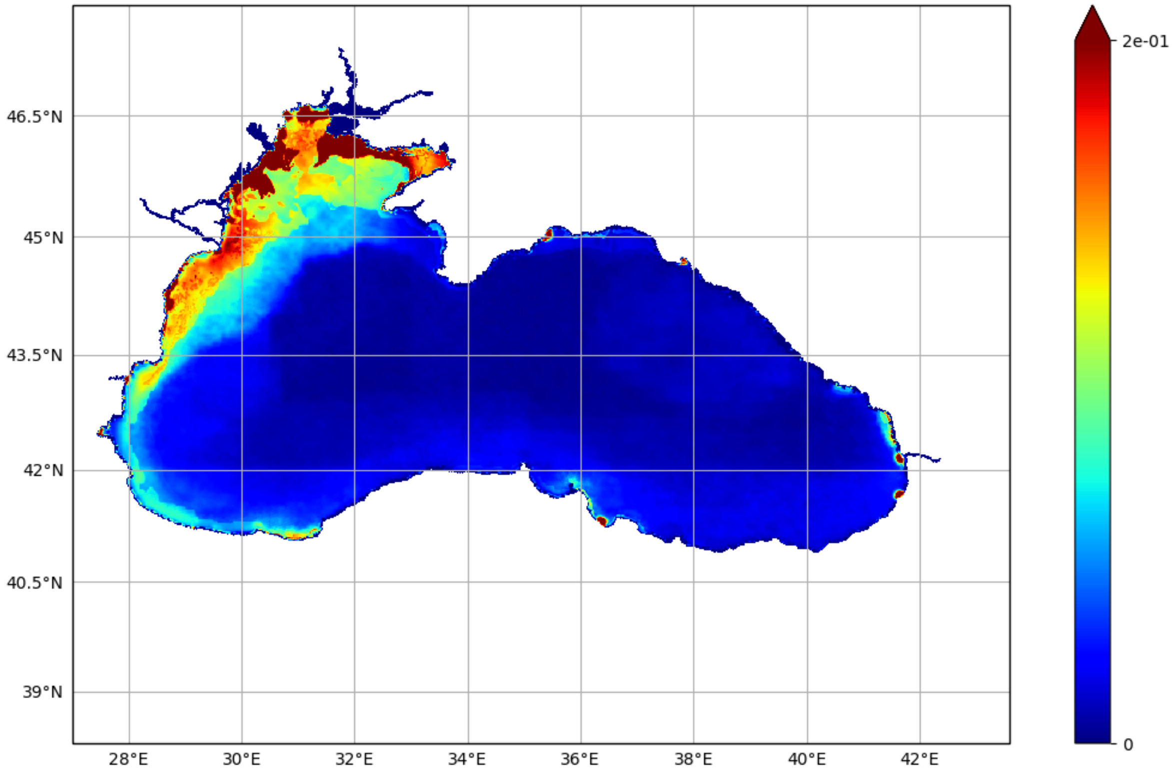

Figure 18: Analysis focused on specific impact chains: example of CEA score evaluating the unique contribution of the MSFD pressure 'Inputs of fertilizers and other nitrogen and phosphorus-rich substances" in the Black Sea.

The Tools4MSP CEA web tool allows users to focus on specific impact chains by selecting a subset of Human Activities, Pressures, and Environmental receptors. For instance, Figure 18 shows the CEA score for the MSFD pressure 'Inputs of fertilizers and other nitrogen and phosphorus-rich substances' resulting from Land-Based Activities, such as contributions from rivers and coastal cities. The image clearly illustrates how the Danube Delta significantly contributes to eutrophication, affecting bottom habitats and some commercially used fish species.

3.2.5 Documentation / User manual

The documentation is available online at http://docs.tools4msp.eu/index.html (see Figure 19).

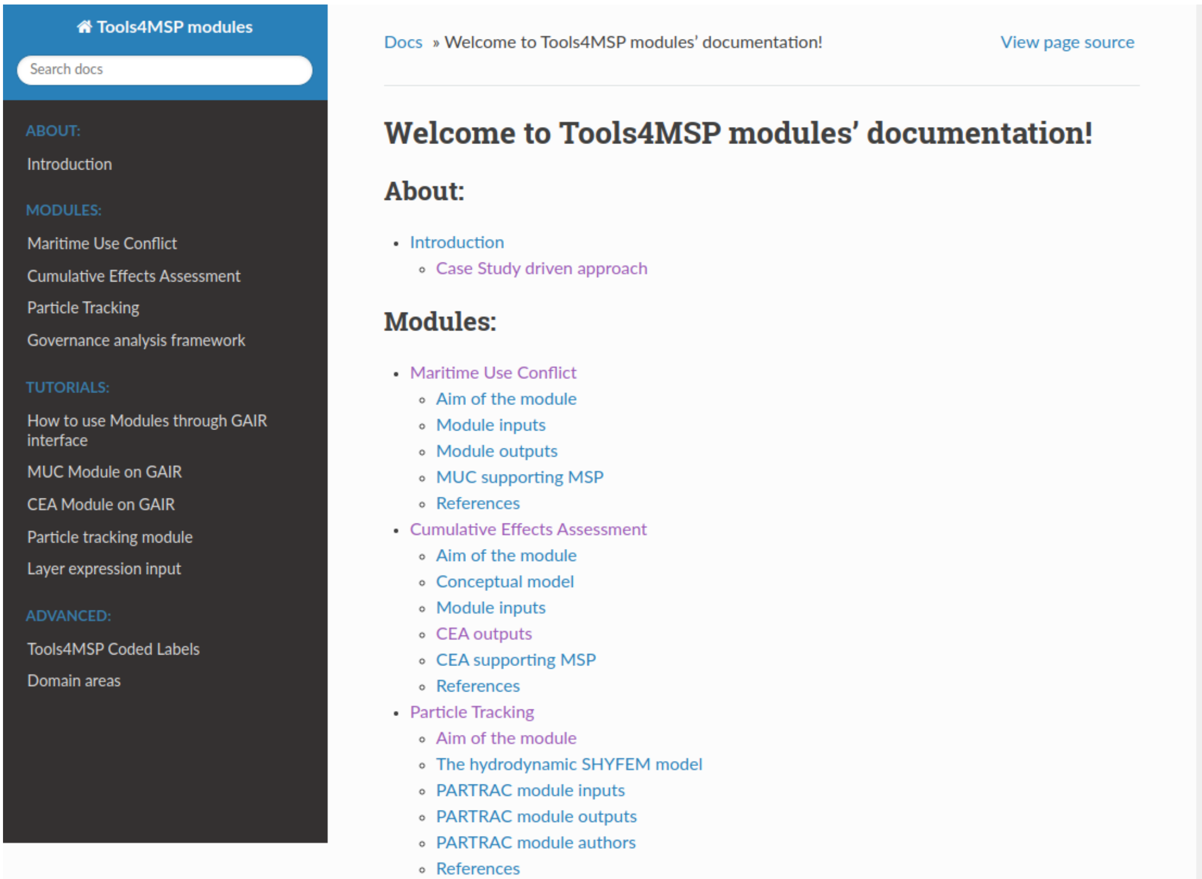

Figure 19: Tools4MSP documentation.

4 A step-by-step approach for incorporating URN in MSP

4.1 Conceptual model

This section outlines the methodology and associated Decision Support Tools developed as part of the D6.5 activity of the SATURN project. These tools are designed to effectively address issues related to underwater radiated noise (URN) in the context of maritime spatial planning (MSP). The methodology, called "A step-by-step Approach for incorporating URN in the MSP" is illustrated in Figure 20.

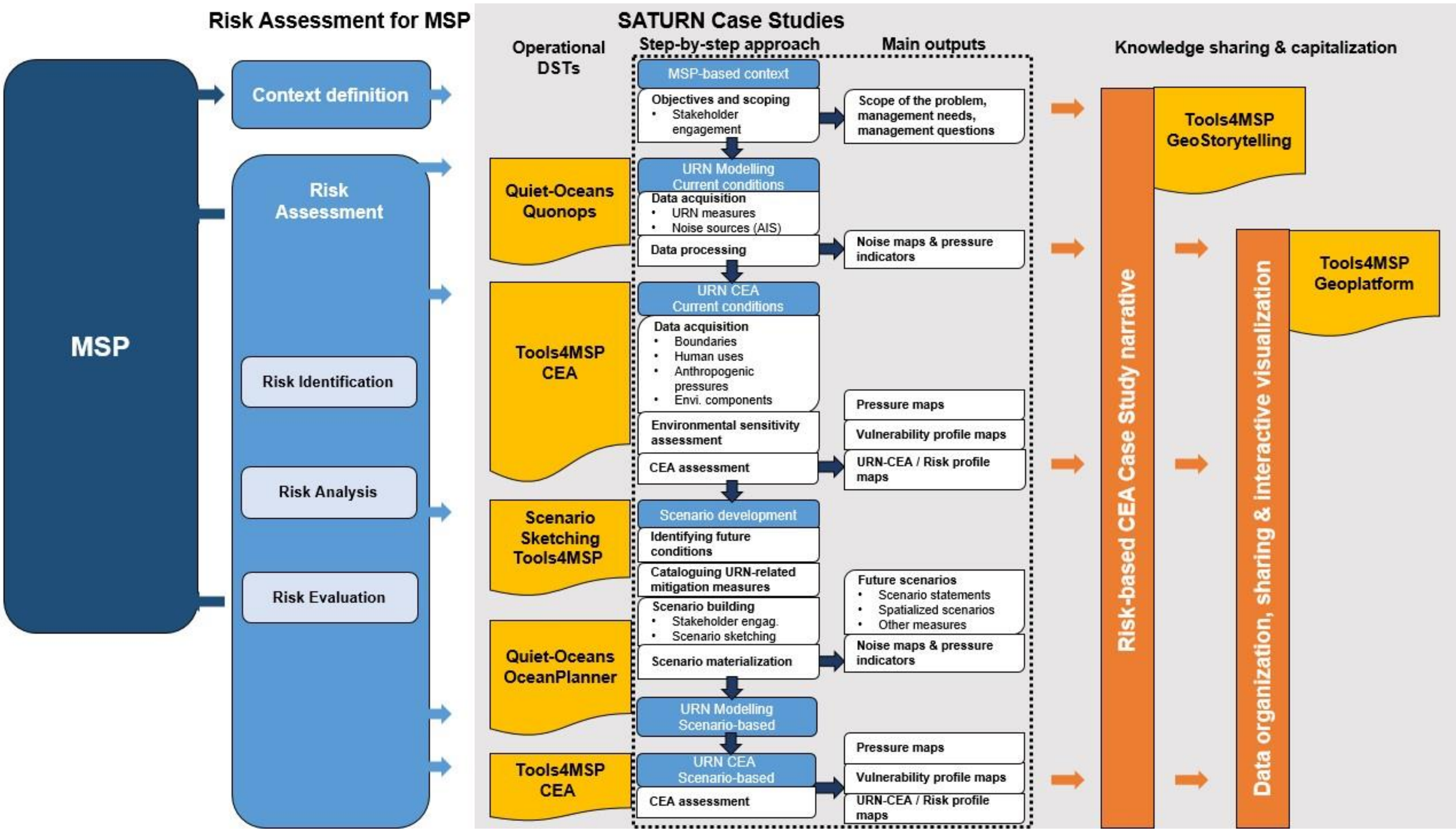

Figure 20: Step-by-step Approach to Support Underwater Noise in the MSP Process. The central part of the diagram illustrates the conceptual model of the step-by-step approach, detailing the main outputs of each step. The yellow sections highlight the integrated system of tools (Operational DSTs) used to support various phases of the process. On the right side of the diagram, the "Knowledge Sharing & Capitalization" functions and the related tools that support the entire process are emphasized. In the left section "Risk Assessment for MSP" it is shown how the step-by-step approach fits into the MSP process.

The central part of the diagram illustrates the conceptual model of the step-by-step approach, detailing the components and the main outputs of each step. The methodology follows a risk-based approach and includes six main steps. It begins with defining the context (MSP-based context), followed by analysing the current conditions, both in terms of underwater radiated noise (URN Modelling) and more generally through cumulative effects assessment (URN CEA). Next, the scenario development phase takes place, which is followed by a risk analysis phase based on the scenarios produced. The yellow sections highlight the integrated system of tools, referred to as Operational DSTs, which support various phases of the process. On the right side of the diagram, the "Knowledge Sharing & Capitalization" functions and the related tools are emphasized. This section is important because it emphasizes the use of core collaborative tools to support the entire process. These Ficetools facilitate the archiving and sharing of outputs produced in various phases, ensuring that information from each tool is easily exchanged and reused within the process. They also enable the persistent sharing of content through features such as Spatial Data Infrastructures, interoperability, and interactive tools. Additionally, to effectively communicate the main phases and results of the process to non-technical experts, Geostorytelling tools are utilized to prepare interactive narratives. Finally, in the left section, "Risk Assessment for MSP", the diagram shows how the step-by-step approach fits into the broader MSP process.

Building upon this conceptual model, the following sections of this report provide detailed descriptions of each step in the approach. These sections also systematically outline the Decision Support Tools (DSTs) that support the various analyses, specify the input and output data involved, and explain how integration occurs among these different tools.

4.2 MSP-based context

4.2.1 Step description

The initial step of the proposed approach involves Context Definition, focusing on the overall framework in which we operate, specifically within Risk Assessment for Marine Spatial Planning (MSP). Context Definition is typically the first step in any risk assessment process and, where it is related to the ecosystem-based management practices, such as Integrated Management, Maritime Spatial Planning, or Environmental Assessments, it is crucial to establish the ecological and management foundations for addressing risks related to potential environmental effects. Within this stage is also important to identify the competent authority responsible for leading the process, ensuring alignment with legislative, policy, and sustainability mandates (ISO 2021, Cormier et al. 2013, ISO 2009).

Below the elements to consider during the MSP-based Context Identification phase are presented in more detail (Cormier et al., 2013).

Legislation

Identify legislative provisions and guidelines, addressing the issue of URN at international, national, and local levels. Here some references:

International Frameworks:

- United Nations Convention on the Law of the Sea (UNCLOS): Provides a legal framework for marine environmental protection, including noise pollution.
- International Maritime Organization (IMO). (2023). Revised Guidelines for the Reduction of Underwater Radiated Noise from Shipping to Address Adverse Impacts on Marine Life (MEPC.1/Circ.906, IMO, 2023)

Regional Agreements:

- European Union Marine Strategy Framework Directive (MSFD): Requires member states to achieve Good Environmental Status (GES) of marine waters, including managing underwater noise (MSFD 2008/56/EC).
- OSPAR Convention: Focuses on the protection of the marine environment of the North-East Atlantic, including noise pollution (OSPAR Commission, 2016). In addition, in 2021, the OSPAR Commission adopted the North-East Atlantic Environment Strategy (NEAES) 2030, which includes Strategic Objective 8: "Reduce anthropogenic underwater noise to levels that do not adversely affect the marine environment".
- ACCOBAMS resolutions: The Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area (ACCOBAMS) has adopted several resolutions to address underwater noise issues. Notably: Resolution 2.16 (2004), acknowledged the potential impacts and emphasized the need for assessment and management); Resolution 7.13 (2019), guidelines to mitigate impacts; Resolution 8.17 (2022).

National Regulations:

- Countries often have specific laws and regulations addressing underwater noise.

Ecosystem sustainability policy – Scoping

Based on a mandate from the competent authority, strategic policy objectives or overarching goals are crucial for properly setting the scope of a risk management exercise. In ecosystem-based management, these overarching goals are often articulated in terms of sustainable development (OECD - Organisation for Economic Co-operation and Development: Sustainable Development), protection, or conservation objectives at the ecosystem level (OECD: Ecological Approach to Sustainable Development). These goals guide the establishment of desired ecosystem management outcomes from the planning process and subsequently frame the issues to be investigated, the criteria for evaluating risk effects, and the management strategies needed to mitigate these effects (OECD: Environmental Protection), as well as considering the portfolio of measures available to support the MSP process (see section 2.2 - Mitigation Scenarios). Often, the sustainability policy is derived at the national level, which then influences the successive competent authorities.

Ecosystem management outcomes

The ecosystem management outcomes specify the expected results of current or future management strategies (OECD: Environmental Quality). Consequently, they should clearly identify the environmental effects to be avoided and the anthropogenic activities, drivers, and pressures that need to be managed. Developing ecosystem management outcomes should involve a consultation process with stakeholders to incorporate their knowledge, including local insights, as well as their priorities, interests, and risk perceptions. The Good Environmental Status (GES) criteria used in the context of the MSFD serve as a comprehensive example of environmental outcomes. Specifically, Descriptor 11 (Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment) addresses the aspects relating to underwater noise.

Geographical boundaries

In the Context Definition stage of an ecosystem-based risk assessment, the identification of geographical boundaries as ecological units, driver/pressure zones of influence, and management areas is crucial.

- Geographical Boundaries: these boundaries delineate the spatial extent of the ecosystem under study. They define the specific area where ecological processes, interactions, and functions occur, which are critical for understanding how different components of the ecosystem interact and influence each other.
- Driver/Pressure Zones of Influence: drivers and pressures refer to human activities or natural processes that exert influence on the ecosystem. These can include industrial activities, urban development, agricultural practices, pollution sources, climate change impacts, etc. Mapping out the zones where these drivers and pressures have their influence helps in understanding the spatial distribution of potential impacts on the ecosystem.
- Management area: it encompasses the management jurisdictions, drivers, and stakeholders involved in addressing drivers and pressures to achieve ecosystem management outcomes within the ecological unit (as defined by the OECD for environmental protection). These areas may align with exclusive economic zones, territorial seas, or international, national, and regional collaborative management zones. The management area should encompass the relevant jurisdictions and drivers that impact environmental effects, potentially necessitating cross-border cooperation between countries. Figure 21 illustrates an instance of these types of areas, depicting the overlap between maritime zones and borders in the transboundary context of the central Mediterranean. This example emphasizes the intersections between areas and borders, which encompass diverse legal, management, and monitoring systems. Notably, it showcases various legal statuses, such as territorial waters and Exclusive Economic Zones (EEZs), as well as multi-scale conservation systems, GFCM (General Fisheries Commission for the Mediterranean) sub-areas, and other sector-related regions.

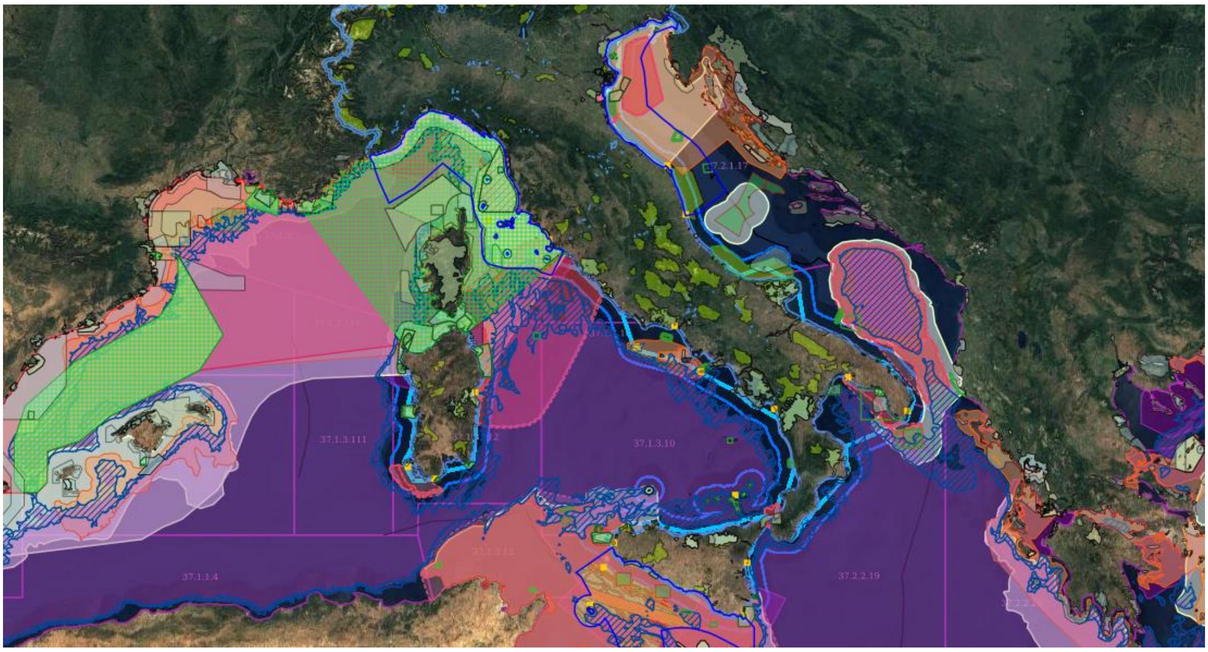

Figure 21: Overlap of maritime zones and borders in the transboundary context of the central Mediterranean: This example highlights the intersections between areas and borders representing various legal, management, and monitoring systems. It showcases different legal statuses (e.g., territorial waters, Exclusive Economic Zones (EEZs)), multi-scale conservation systems, GFCM (General Fisheries Commission for the Mediterranean) sub-areas and other sector-related areas.

Environmental effects risk criteria

To analyze environmental effects and conduct risk assessments, we will use the Cumulative Effects Assessment (CEA) methodology as previously described. Specifically, we will combine the overall spatially explicit CEA results with specific analyses of individual impact chains, which include anthropogenic activities, pressures, and environmental receptors (see Fig. 15). Additionally, we will use vulnerability profiles and heatmaps to highlight the relative percentage contributions of individual uses to overall pressures and total impacts.

For the specific case of underwater noise, a new methodology has been developed (described in Section 4.4). This methodology outlines two versions for incorporating URNs into the risk-based CEA: a Targeted version and a Simplified version. The Simplified version, as we will explain later, can be used in situations with poor data quality, for instance where specific LOBE (e Level of Onset of Biologically adverse Effects) levels or dose-response curves are unavailable. This approach is based on the time-integrated curve of excess sound levels (see Fig. 23) and on the Anthropogenic Noise Pressure Index (ANPIndex) maps (see Fig. 26). While this methodology does not provide a specific and quantitative impact on the studied environmental receptors, it helps identify priority areas of concern.

Finally, a fundamental aspect of the criteria for incorporating URN into the analysis is the selection of frequency bands. These frequency bands should be chosen based on the frequencies relevant to the target environmental components (target species) identified in the previous Context Definition phases.

4.2.2 Expected outputs and results

The output of this stage consists of three main components:

- Context Description Document: This document provides a detailed overview of the context, incorporating all the elements described earlier.
- Information Resources Collection: A compilation of basic reference materials and data that support the analysis. This includes datasets that enable the spatially explicit representation of significant and relevant anthropogenic activities, pressures, and environmental receptors.
- Geodatabase: This database, organized in a structured and accessible manner using interoperable services, contains the collected information. It includes essential geographical elements needed to define the context, such as the study area, management areas (associated with competent and management authorities), relevant maritime boundaries, ecological units, areas influenced by drivers and pressures, and selected target species distributions. Organizing information according to the MSP Data Framework (see Sub-section 3.2.1) is strongly recommended.

4.2.3 Tools to support the process

To support this step of the process, the use of specific decision support tools (DSTs) is not considered. However, it is important to share the results using knowledge-sharing and capitalization tools (see Fig. 20 – right part). Therefore, the geodatabase should be uploaded, documented with metadata, and made available through data organization and sharing tools, such as the Tools4MSP Geoplatform.

Additionally, a summary or the entire context description document should be included in the Case Study narrative. This should be complemented by interactive maps that enable dynamic exploration of the geodatabase layers. Using interactive maps can also facilitate interaction and discussion with stakeholders, which is crucial for consolidating the definition of the context.

4.3 URN Modelling – Current conditions

In this step, the focus is on analysing the current state of URN resulting from human activities in the study area. The primary aim is to generate excess sound maps for the frequencies that were identified as most relevant in the previous phase of context analysis (Step1 MSP-based Context). These frequencies are crucial for evaluating how URN affects the target environmental receptors.

Excess sound is defined as steady state sound pressure level (SSSPL) for all ambient sound minus SSSPL for natural ambient sound at the same position and time, in accord to SATURN D2.3. This metric helps isolate the additional noise contributed by anthropogenic activities. The resulting excess sound maps are then expressed in terms of temporal exceedance levels, which represent excess noise levels above which N % of observations occur in a specified temporal analysis window.

This approach primarily addresses the masking effect of URN, though the methodology could be adapted in the future to assess other effects as well.

The excess sound maps will be integral to calculating the Anthropogenic Noise Pressure Index (ANPIndex), which is detailed in Section 4.4.2. As better explain below the ANPIndex plays a crucial role in incorporating URN into Marine Spatial Planning (MSP) through a risk-based Cumulative Effects Assessment (CEA).

To produce these maps, the Quonops modelling tool is used, as described in Section 3.1. The selection of the study area for this modelling is guided by the results from the earlier context analysis phase. Input data required for this process include detailed environmental conditions such as bathymetry, bottom sediments, habitats, temperature and salinity profiles, and wind-sea state data. These elements help in characterizing how sound propagates through the environment. Additionally, data on anthropogenic contributions, primarily from marine traffic and fishing activities, are essential. This includes Automatic Identification System (AIS) data that provides information on vessel positions, sizes and speeds. The ECHO-JOMOPANS source level model (MacGillivray and de Jong, 2021) is used to estimate sound contributions from these activities. Calibration of the model is performed using in-situ measurements from hydrophones, ensuring that the predictions align closely with real-world observations.

The analysis itself is grid-based, employing regular cells to represent the study area. The resolution of the grid is chosen to balance the need for detail with the requirements of integrating the results into a risk-based CEA procedure. This ensures that the maps generated are both precise enough to be useful and practical for further risk assessments.

In summary, this step produces a set of excess sound maps that depict the current levels of URN due to human activities. These maps are crucial for calculating the ANPIndex and are foundational for incorporating URN considerations into MSP through a risk-based CEA framework.

4.4 URN CEA– Current conditions – Risk Identification

4.4.1 Method

After defining the context, identifying priorities, and specifying the characteristics to be analysed, and after obtaining the spatio-temporal results of the modelling related to the URN in the study area, it is possible to proceed with the Cumulative Effects Assessment.

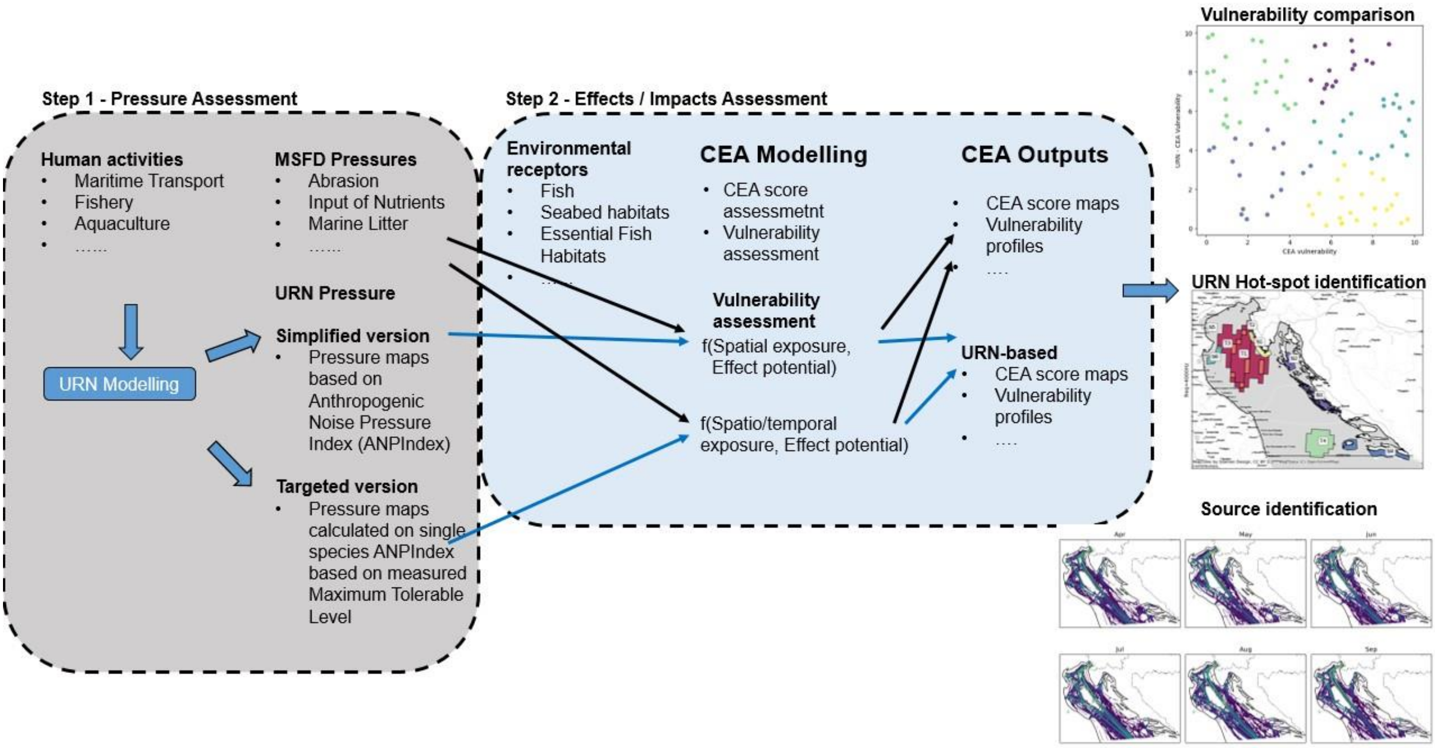

Figure 22. Proposed methodology for incorporating the URN into the Cumulative Effects Assessment.

Fig. 22 illustrates the proposed methodology, which is essentially an adaptation of the general methodology described in Sub-section 3.2.3. The characteristics of this methodology are:

- **Separation of Impact Chains**: Distinguish the impact chains caused by the URN from those generated by other MSFD pressures. This allows for advanced modeling of the pressures and impacts due to the URN.
- **Comparison of Vulnerability Profiles**: Introduce an additional final step that compares the vulnerability profiles of URN and the other MSFD pressures, including spatially explicit terms. The goal is to identify hot-spot areas for targeted URN-related interventions and mitigation measures.
- **Assessment with Limited Knowledge**: Facilitate assessment even when there is poor knowledge of ecological effects or in the absence of dose-response curves for the target species in the study area. For this reason, two different versions for the URN Pressure assessment and for the related Effects/Impacts assessment are provided:
- **Simplified Version** - Pressure maps based on Anthropogenic Noise Pressure Index (ANPIndex).
- **Targeted Version** - Pressure maps calculated on single species ANPIndex based on measured Maximum Tolerable Level.

More in details, the proposed methodology involves setting up a case study for Cumulative Effects Assessment, following the guidelines in Sub-section 3.2.3. Based on the previously defined MSP-Context, the best available data should be used to represent the environmental receptors (e.g., species distribution models, abundance data) and the human activities of interest identified during the context analysis phase.

For the Pressure Assessment (see Fig. 22), we propose isolating the pressure related to URN (Underwater Radiated Noise, indicated by blue arrows) from other Marine Strategy Framework Directive (MSFD) pressures. The other MSFD pressures can be assessed directly using Tools4MSP CEA, which allows for the creation of spatially explicit pressure maps through isotropic or Lagrangian modelling. For assessing URN pressure, an ad-hoc methodology is proposed using a new index called the Anthropogenic Noise Pressure Index (ANPIndex). This index can be mapped and represented spatially, and it comes in two versions: i) Targeted Version: Used when specific ecological knowledge of the Maximum Tolerable Level (MTL) for species is available; ii) Simplified Version: Used when there is no specific ecological knowledge. This version produces a pressure map that provides an approximate and dimensionless indication of the level of attention or vulnerability for URN. The detailed definition and methodology for calculating this new indicator are provided in the following section.

In the second phase of the CEA methodology (see Fig, 22 Effects/Risks Assessment), URN-related assessments are kept separate from those of other pressures, this allows for separate modelling of the impact chains (human activities, pressures, environmental receptors, and vulnerabilities) related to URN from those caused by other activities and pressures.

To enable comparison across different impact chains, two main Tools4MSP CEA outputs can be used: CEA score maps and Vulnerability maps and profiles. Where vulnerability is defined as a function of Spatial Exposure and Effect potential (refer to ICES, 2019 for more details).

As a final output, a vulnerability comparison graphs and maps can be used (see Fig. 22). These will spatially represent areas where URN is more significant compared to other pressures, as well as areas where URN's contribution is minimal in relation to other activities

4.4.2 Anthropogenic Noise Pressure Index (ANPIndex)

This section details the method for calculating an Anthropogenic Noise Pressure Index (ANPIndex) for both the Simplified and Targeted versions.

Human generated underwater noise represents a stressor for the marine environment, which need to be monitored and mitigated. As a result, Marine Strategy Framework Directive 2008/56/EC designed the Criterion D11C2 as a pressure indicator aiming to quantify the amount of noise in EU marine waters and track its changes in time. In 2017 the Commission Decision changed this Criterion from a pressure to an impact indicator (see Borsani et al. 2023), the latter being intended to quantify the impact of noise on populations of aquatic fauna. This new approach implies the choice of (i) a target effect, (i) a target species/ecosystem and (iii) a definition of a noise level at which animals start to have adverse effects for their fitness, the so-called level of onset of biologically adverse effects (hereafter LOBE).

Underwater sound can affect marine organisms in different ways including masking, behavioural disruption and physiological effects (Slabbekorn et al. 2010, Duarte et al. 2021, Rako-Gospić and Picciulin 2019). In the present context, masking is considered the target effect. Masking is the process by which the thresholds for hearing for one sound is raised by the presence of another (masking) sound (ANSI, 2008). At a given ambient sound level, there is a maximum distance over which two animals can reliably communicate without degradation in their signal to noise ratio; an increase in ambient sound levels, as the one caused by vessel traffic, decreases communication distances. Generally speaking, an input of acoustic energy equal to 20 dB above the natural level at sea generates a reduction of 90% of the communication distance in vocalizing biota, assuming a simplified spherical spreading (Hermannsen et al. 2014); such a level is a conservative estimate given that the reduced communication space is likely to be much higher where cylindrical spreading occurs. Further in biological systems masking is a far more complex phenomenon to be predicted in detail: it needs information on the spectral features of both the biological and human-generated signals, on the local underwater environment as well as the characteristics listener's auditory systems (Erbe et al. 2016) and it deserves more research on all these aspects. Still, masking is a universal feature of natural communication systems and therefore it is a good candidate for a holistic investigation approach, which does not target a single species, as the present case of study.

A suitable metric to address the potential for masking is the human-generated elevation of ambient sound. This metric has been termed the excess sound level, which here represents the AIS-based shipping-generated sound contribution exceeding the local natural soundscape (i.e. the "reference condition" according to TG Noise Recommendation, Borsani et al. 2023). It has to be noticed that excess sound is, by its nature, the amount of sound that can be potentially regulated by applying an MSP approach (natural sound is not).

Excess sound maps for a target area can be calculated by using underwater sound simulation, that, in the present context, was performed by Quonops underwater noise prediction system (see Folegot 2009 and SATURN Deliverable 6.5 for details). Natural sound maps are generated by considering natural noise sources only (wind and waves); baseline sound maps are calculated based on the distribution of both natural and AIS-based vessel sources. Excess sound maps are obtained by subtracting the baseline sound pressure levels (SPLs) of each steady-state modelling to the natural SPLs at the same time and presented in the form of seven temporal exceedance levels (EL). Temporal exceedance levels provide an estimate of the distribution of sound levels over time; thus, 10 EL (10% exceedance level) was the SPL value exceeded for the 10% of the year, usually representing rare sounds characterized by the highest noise levels. Monthly excess sound maps are created on a spatial geographical grid with a spatial resolution defined on the base of the specific case study.

According to the TG Noise Recommendation (Borsani et al. 2023), the value of LOBE should result from evidence-based studies; alternatively, the precautionary principle should be indicative. In many practical situations, evidence-based values for LOBE thresholds or dose-response curves are not available. Therefore, a methodology has been developed that can be applied, with minimal adjustments, even in the absence of these values. In both case the procedure includes the following steps:

- Each grid cell of the excess sound map is considered as a unit. No monthly central tendency has been considered. On the contrary, per each cell, on a monthly period, the relationship between the sound Excess Levels (y axis) and the proportion of time (here expressed by the Exceedance levels) these levels are reached (x axis) is represented as a curve (Figure 23). This curve provides a very condensed expression of the temporal dynamic conditions in each grid. Further the area below each curve is measured and the obtained values is converted into a one-dimensional, time-integrated (per month) index, hereafter called 'Integrated Excess Index' (hereafter IExI).
- An Anthropogenic Noise Pressure Index (ANPIndex) is calculated as the ratio between the measured (yellow area in Figure 24) and the maximum tolerable (blue area in Figure 24) IExIs. In Figure 24 the yellow area represents the extreme case of a cell grid where the excess levels are always (100% of the monthly time) equals to the maximum tolerable excess level for a given species/ecosystem; both in this case as well as in case of excess levels higher than the maximum tolerable level, the ANPIndex will be equal to 1. Conversely if for 100% of the monthly time the excess level is lower than the maximum tolerable excess level the ANPIndex is getting close to 0. These two extreme cases illustrate that the ANPIndex ranges from 0 to 1 value. In Figure 25 a linear relationship between IExI and ANPIndex is assumed: human generated pressure is considered "low" if the ANPIndex is close to 0 or "high" close to 1. Here the Maximum Tolerable Excess Level (i.e. conceptually corresponding to a LOBE according to the TG Noise Recommendation, Borsani et al. 2023) is not numerically defined based on a specific target species (but it will be discussed in the Deliverable 6.5 where this methodology will be applied to the Northern Adriatic Sea). This ensures adaptability of the presented framework to future improvements to follow potential innovations in this field.
- By including each cell of the target area, a new map of ANPIndex, ranging from low to high values, is calculated per each target frequency. The obtained map is used as input for CEA. Figure 26 represents an example of such a map for the Northern Adriatic Sea.

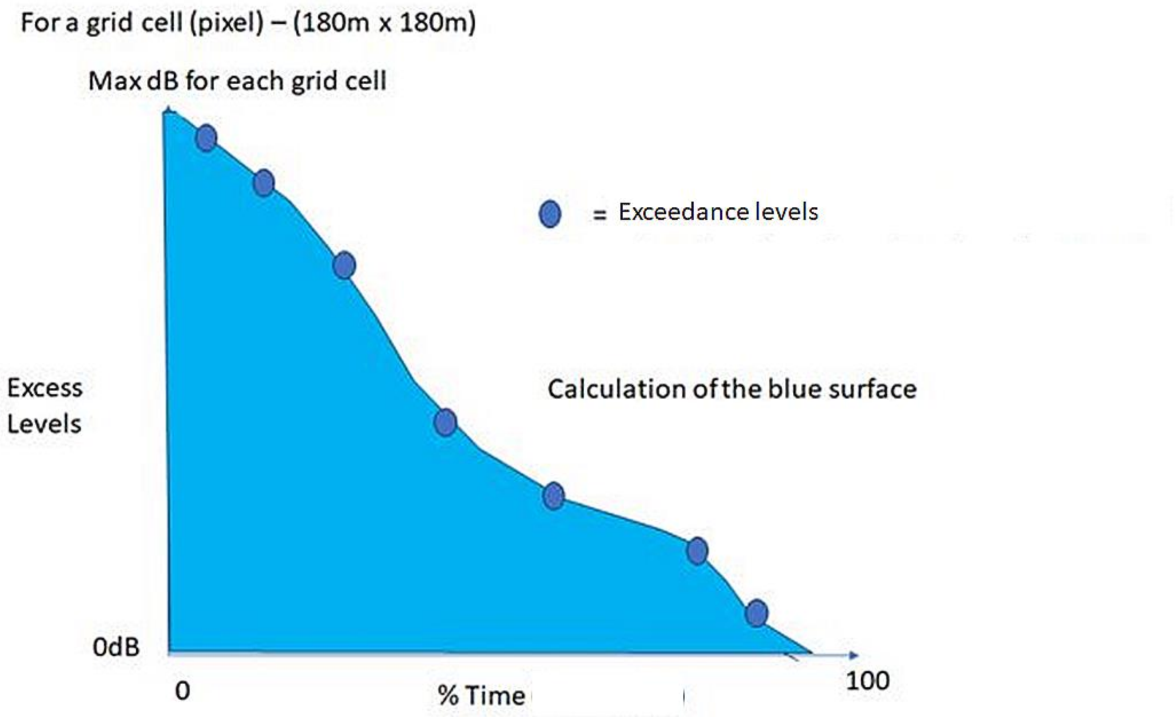

Figure 23. Example of a curve of time-Integrated Excess Index (IExI) obtained per a grid cell of a sound maps (from excess sound map in the example here discussed).

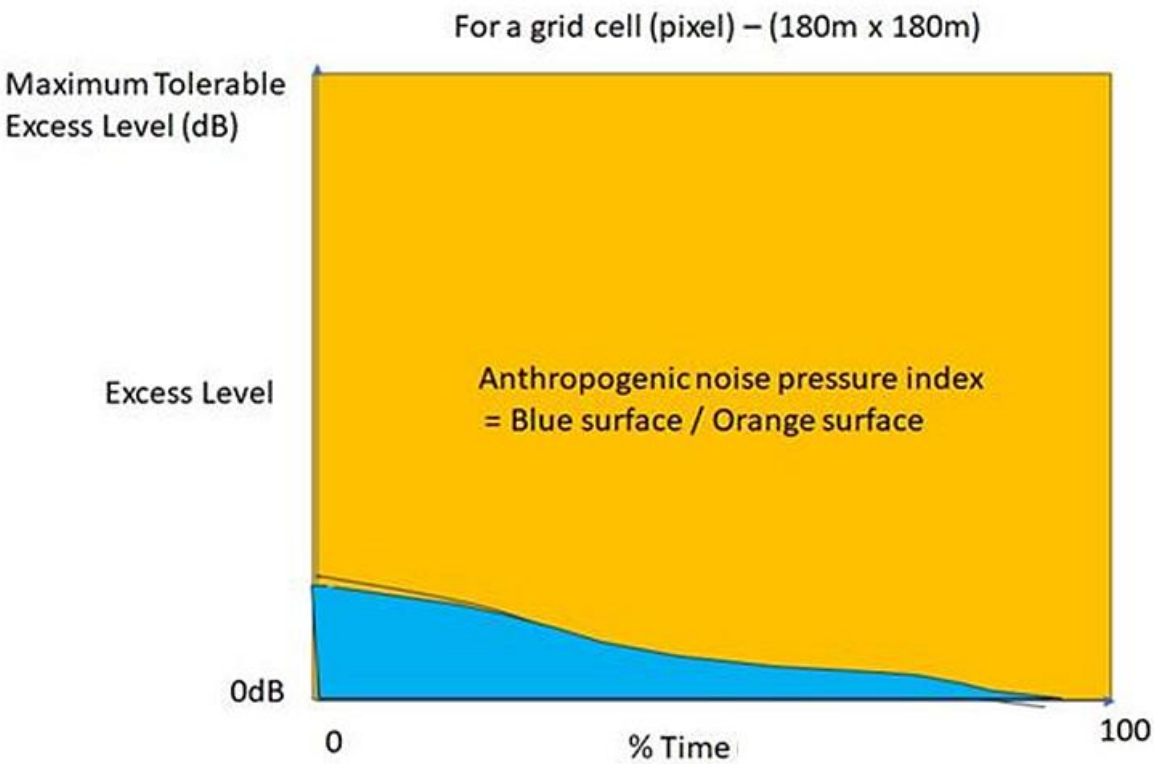

Figure 24. Anthropogenic Noise Pressure Index (ANPIndex) is calculated as the ratio between the maximum tolerable (yellow area) and the measured (blue area) Integrated Excess Index (IExI).

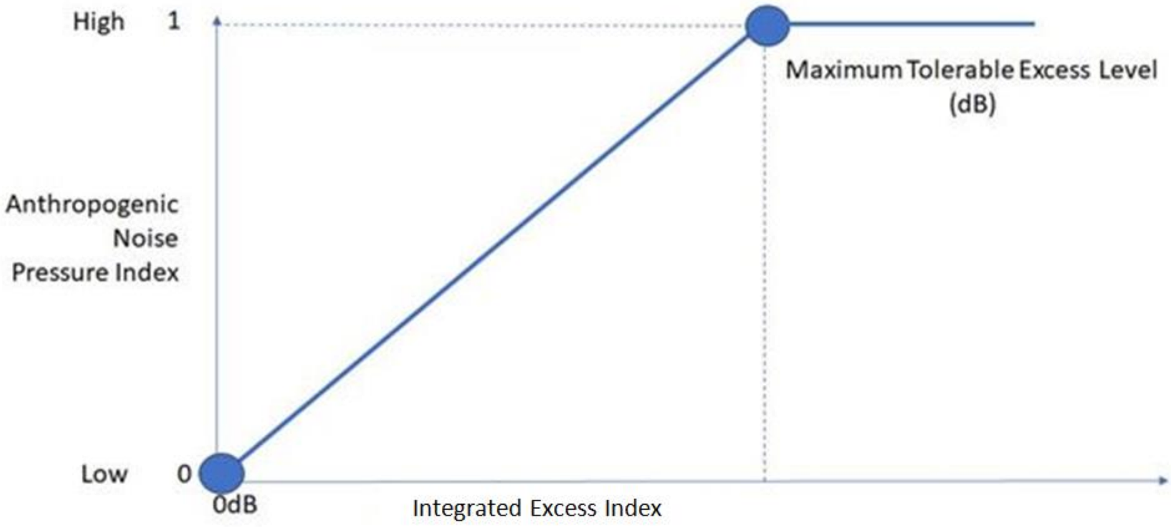

Figure 25. A linear relationship is assumed between the Integrated Excess Index (IExI) and the Anthropogenic Noise Pressure Index (ANPIndex).

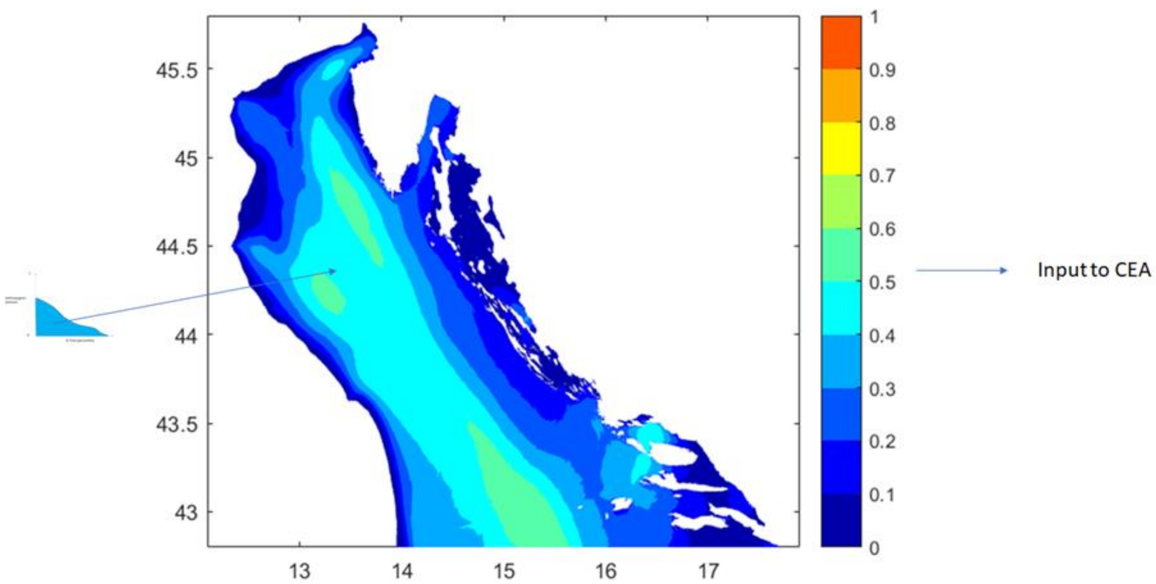

Figure 26. Example of North Adriatic Sea map related to masking based to Anthropogenic Noise Pressure Index (ANPIndex) based on the arbitrarily defined maximum tolerable excess level equal to 20 dB. Low pressure is expected at level around 0 and high pressure is foreseen at level equal to 1.

The present methodology is developed by considering (i) the masking as target effect of human-generated underwater noise on marine fauna, (ii) the CEA dimensionless evaluation of the impact/risk. Once the impact predictions will be further developed and evidence-based, the proposed framework could be improved and potentially adapted to include also behavioural or physiological effects calculated on the base of modelled sound pressure levels.

4.4.3 Expected outputs and results

The outputs from this analysis step primarily support the development of future scenarios that incorporate underwater noise mitigation measures (next Step). These outputs include geographical indicators, such as the overall CEA score, which provides a comprehensive view of the risk map. They also include CEA scores specific to environmental receptors (e.g., target species) considered relevant for URN assessment. These scores are calculated separately for URN-specific pressures and for all other pressures, allowing for a detailed evaluation. Furthermore, overlay analyses can be performed to combine the results, identifying areas where hotspots converge or diverge in a spatially explicit manner. Additional expected outputs include aggregated statistics of the various CEA scores, calculated for the entire study area or specific sub-areas of interest (e.g., Marine Protected Areas). These analyses help determine which human activities and pressures contribute most significantly to risk and which environmental components are subject to higher risk levels. This type of analysis also supports risk communication and stakeholder engagement, facilitating informed decision-making

Moreover, the results from this Step need to be compared with the results from the URN-CEA Scenario-based analysis. This comparison will help evaluate any spatial and semi-quantitative differences resulting from the introduction of mitigation measures.

4.4.4 Tools to support the process

The primary tool for supporting the analysis of cumulative impacts is Tools4MSP CEA (see Sub-section 3.2.3). To perform the analysis, you need to configure a new case study by defining the following input parameters:

- Analysis Area: A polygon that defines the area for the analysis.
- Analysis Resolution: The desired spatial resolution for the analysis.
- Anthropogenic Activities: Geospatial layers that characterize the distribution or presence-absence of human activities in marine and coastal areas.
- Anthropogenic Pressures: Geospatial layers that characterize the distribution of human pressures. If you want to use specific systems for the dispersion of pressures (e.g., Pressure map related to masking based to Anthropogenic Noise Pressure Index (ANPIndex)), include these layers. Otherwise, for the other considered pressures the tool will default to applying the isotropic convolution model previously described.
- Environmental Receptors: Geospatial layers that characterize the spatial (and possibly spatiotemporal) distribution of the environmental receptors (i.e. target species) being analyzed.

- Pressure Weights Matrix: A matrix of pressure weights needed for applying the isotropic convolution method for pressure dispersion (see $w_{i,j}$ in Eq. 1).
- Environmental Sensitivities Matrix: A matrix that combines "impact level" and "recovery time" to determine, for each combination of environmental pressures, a linear response function of environmental receptors to the presence of human pressures.

The tool's graphical interface assists the user with a series of guided procedures to set up the Case Study. Figure 27 illustrates an example of a pre-configured Case Study for the Bulgarian coastal area of the Black Sea. The image shows the configuration and import of 41 geographic layers into the Case Study, including:

- 1 layer to define the analysis grid
- 27 layers of environmental receptors
- 10 layers of anthropogenic activities
- 3 layers of pre-calculated pressures from land-based activities

Using the functions provided by the graphical interface, the user can select various combinations of human activities, pressures, and environmental receptors. This allows for the generation of Cumulative Effects Assessment (CEA) maps and specific vulnerability maps and profiles, facilitating detailed investigation of individual aspects.

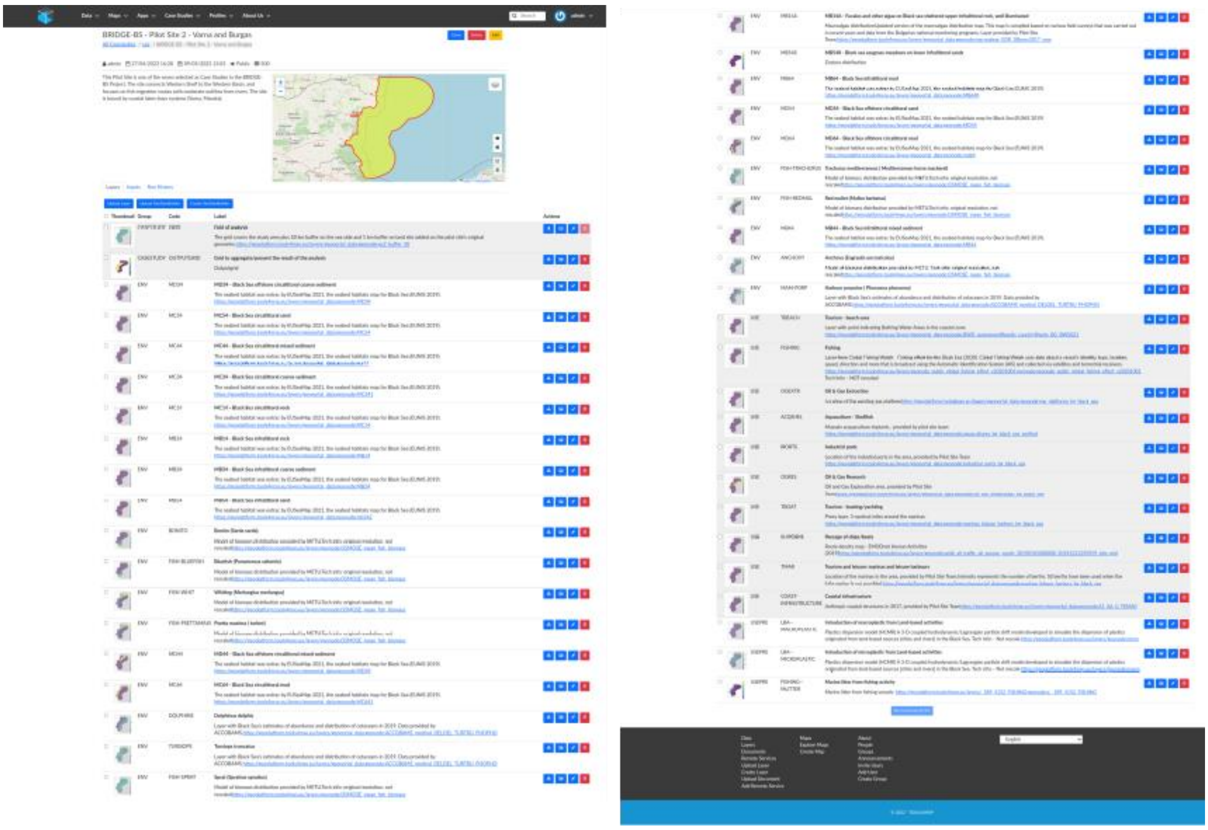

Figure 27. Tools4MSP Geoplatform: interactive interface to CEA Case Study setup.

4.5 Scenario development

4.5.1 A Scenario-Based Approach for URN in Maritime Spatial Planning

Scenarios can be defined as different possible futures or desirable trajectories of a given system or geographic area (Oteros-Roza et al., 2015; Neef et al., 2020). They can be considered coherent and plausible stories about possible co-evolutionary pathways of combined human and environmental systems (Swart et al., 2004). They do not provide predictions of the future, but a range of potential future alternatives based on pre-identified assumptions, therefore encouraging stakeholders and decision-makers to act despite uncertainty (Neef et al., 2020; Swart et al., 2004). Scenarios can be used to co-design the potential alternative evolutions of human activities at sea, including maritime uses (e.g. maritime transport, fishing, aquaculture, tourism, offshore energy production, mining, etc.) and environmental protection. Once defined, scenarios can be then used to analyse related effects, as in the case of underwater radiated noise.

The approach for the scenario formulation summarised in this report capitalizes on the more extended methodology developed under the project MSP4BIODIVERISTY and is described in more detail in Barbanti and Gusatu (2023). The implementation of the methodology is based on the combination of extended knowledge and literature review with experts/stakeholders' consultation. Consultation is essential to come to co-created scenarios, considering the different perspectives.

The first phase is represented by the definition of the baseline, which includes two major steps. The first step deals with the identification and description of the **key drivers** to be take in into consideration the scenario formulation. Drivers can be defined as factors influencing the development of marine and coastal activities and the evolution of marine ecosystems in a given area. There are several typologies of drivers to be considered, including legislation, policies, plans, regulations, technological innovation elements, demographic trends, trends of economic sectors, changes in the distribution and functioning of ecosystems and habitats, climate change, etc. The analysis of drivers should take into account factors acting at different geographical scales, from global to regional and to national/sub-national.

The baseline analysis includes a second, parallel step dealing with the definition of the current state of the study system or area, through the detailed description of its ecological, social, economic, policy and governance elements, as well as of their mutual interactions. This provides an in-depth knowledge of the biophysical and social factors that regularly interact in the considered areas, defining what in literature is referred to as the **Social-Ecological System (SES)**. The SES can be defined as a coherent, perpetually dynamic and complex system of biophysical and social factors that regularly interact in a resilient, sustained and continuously adaptive manner (Redman, Grove, & Kuby, 2004). The system is defined at several spatial, temporal and organizational scales, which may be hierarchically linked, and consists of critical resources (natural, Social-economic and cultural). Several conceptual frameworks have been proposed in previous research as referred in Barbanti and Gusatu (2023).

The description of the drivers and the definition of the SES consider both the input coming from the analysis of the available knowledge and the input provided by experts (the engagement of the stakeholders is considered in the successive phase dealing with the proper scenarios formulation) The engagement in the studied area can consider various means, including structured questionnaires, interviews, the compilation of pre-defined templates in Excel, revision of drafted documents, workshops, etc. A combination of different instruments is generally used.

The following phase consists of the **formulation of the scenarios**. The methodological approach firstly foresees the identification of the overarching goals the scenarios aim to reach. In the case of the MSP4BIODIVERISTY project, this scope is the improved mainstreaming of biodiversity conservation in MSP, i.e. reinforcing the way MSP plans can operationally improve the protection, conservation and restoration of biodiversity under different conditions (those defined by the scenarios). Such overarching goal (or goals) is translated into strategic objectives which drive all the considered scenarios. The scenarios differ in the way, the intensity and the velocity they implement these objectives.

Within MSP4BIODIVERSITY and SATURN projects, the scenarios are used for a "***what-if*" analysis**, aiming to understand the ecological, environmental and socio-economic effects of the scenario occurrence. In the case of SATURN, the analysis focuses on the way the different scenario assumptions (intensity, distribution and regulation of human activities, with a particular focus on shipping) affect the intensity and distribution of the underwater radiated noise. In consideration of the what-if approach, the scenarios to be considered in both projects are as much as possible quantitative, measurable and spatially based. It is also essential that the considered scenarios an enough diverse to represent alternative possible futures. In the case of the MSP4BSIOVERISTY and consequently of SATURN, three scenarios have been considered:

- Slow Pace; the development of the marine area follows the current trends, with a low emphasis on nature protection;
- Nature@Work; focusing on the expansion of nature-protected areas and including several measures and regulations to improve the protection, conservation and restoration of marine habitats;
- Blue Development: focusing on the fast development of the sustainable blue economy, still considering nature protection highly important also to support some of the sectors of the blue economy.

The baseline for the scenario building is the SES previously identified. Each scenario is illustrated through (1) a consolidated scenario narrative illustrating when the strategic objectives are achieved; (2) maps representing the spatial distribution of the different marine uses (including protected areas); (3) the description of the set of measures/actions required to implement the scenario-specific conditions; (4) the timeline for the scenario to unfold.

According to the methodology, the formulation of the scenarios includes the following major steps:

- Collection of input from the team of experts on the relevance of each considered strategic objective and on narrative elements (i.e. description of the expected evolution of human activities and uses at sea, possibly including quantitative information) for the formulation of the scenarios. For this activity, a structured Excel template has been developed and distributed to the experts as part of the work conducted within MSP4BIODIVERSITY
- Collection of input on the spatial distribution of human activities and uses under the different scenarios. These inputs are provided by the experts through the Scenario Sketching Tool4MSP (see following sections)
- Combination of the different inputs to produce draft scenarios, including narratives, maps and timelines

- Discussion of the draft scenarios with the team of experts and consolidation of the co-created scenarios
- Finalization of the scenarios through the engagement of selected stakeholders. The proper planning of this step includes a clarification of the scope of the scenario exercise, reflecting the what-if approach.

The textual, quantitative and mapping elements forming the scenarios can be summarised and made easily accessible through Tool4MSP GeoStorytelling, as described in the following section

4.5.2 Tools to support the process

Two tools have been developed with the MSP4BIODIVERISTY project to support the scenarios formulation and dissemination.

The first is the Scenario Sketching Tool4MSP, enabling experts and stakeholders to interactively design spatial elements characterizing a scenario in a given area. This tool provides the users with a wide set of spatial data, easily browsable and accessible from the left column of its main interface (Figure 28). The same tool includes the *annotation function* (Figure 29) enabling a user to design a polygon, line or point to represent the spatial distribution and/or location of human activities or measures in a given scenario. A textual annotation can be associated with each designed element to provide additional information.

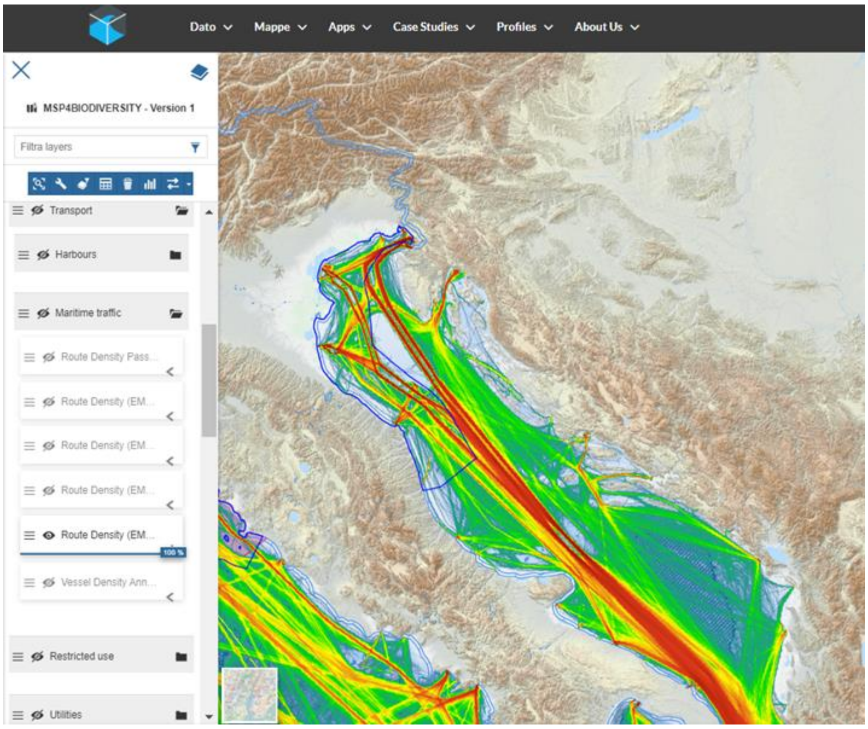

Figure 28. The opening interface of the Scenario Sketching Tool4MSP. The example shows the annual route density of cargo (data source: Emodnet Human Activities).

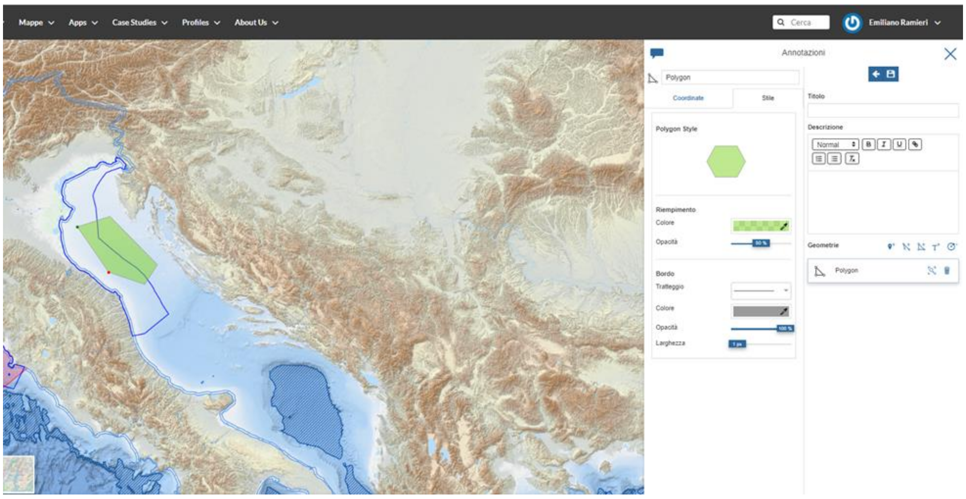

Figure 29. Annotation function of the Scenario Sketching Tool4MSP. The function can be for example used to indicate the location of an area of attention for the presence of species or habitats of conservation relevance.

The second tool is the Tool4MSP GeoStorytelling (see Fig. 30). This web-based application enables the creation and dissemination of scenarios, through the combination of texts, interactive maps (those depicting the distribution of uses and activities under the different scenarios), and multimedia content like images and videos. Geo-stories are powerful tools for the communication of complex issues and can be used to engage fewer expert stakeholders in the formulation of the scenarios.

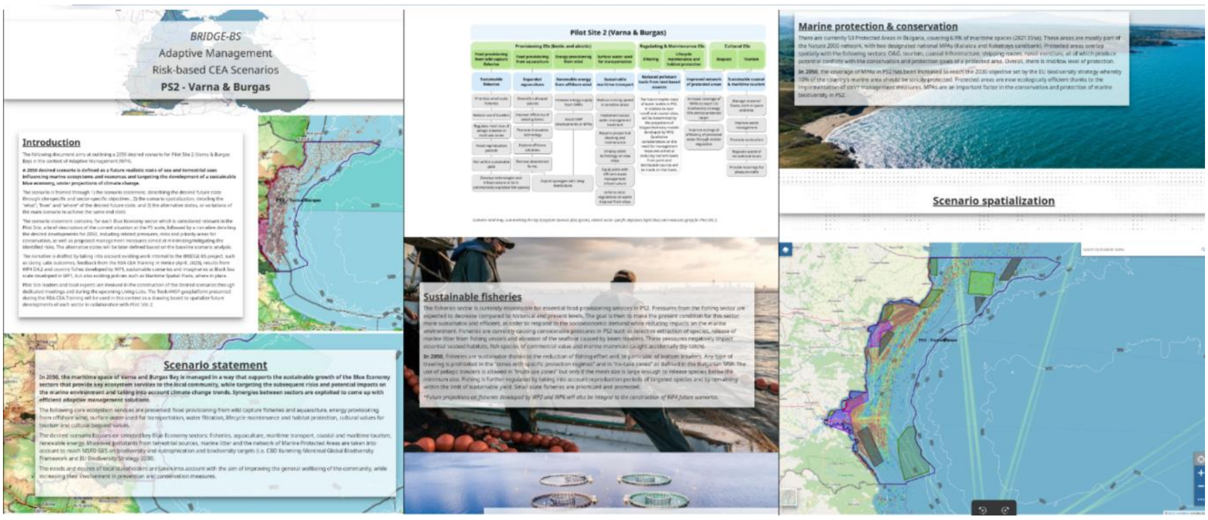

Figure 30. An illustrative Geostory that integrates narrative segments, images, interactive maps, and dashboards. This excerpt is taken from the Geostories created to facilitate the Scenario

Building and stakeholder engagement phases for the Varna & Burgas Case Study within the BRIDGE-BS project[6].

4.6 URN Modelling – Scenario-based

The main goal of this step is to understand how the underwater sound soundscape might change in the future, considering different scenarios and the application of specific mitigation measures. These measures have been previously defined in spatial-explicit terms in the Scenario development stage.

To achieve this, we can use the OceanPlanner tool, which is described in Section 3.1. This tool is capable of modelling various management measures such as speed limits, exclusion areas, one-way management areas, limited access zones, and shipping trends.

First, OceanPlanner estimates how vessels will redistribute due to the introduction of these management measures. This involves calculating a new distribution pattern for the vessels. Based on this new distribution, the tool reconstructs new AIS (Automatic Identification System) tracks that simulate future scenarios. These tracks represent the paths that vessels are likely to follow under the new conditions. With these simulated AIS tracks, OceanPlanner then generates new excess sound maps. These maps illustrate the changes in underwater sound levels resulting from the reallocated vessel distribution and the new management measures. These maps are crucial as they provide a visual representation of the future conditions.

In addition to the sound maps, OceanPlanner also produces detailed reports. These reports describe the variations in the underwater sound soundscape and analyze the economic effects of the new scenarios and management measures. The reports offer insights into how the changes will impact both the environment and the economy.

The new excess sound maps and the accompanying reports will be used as inputs for the next step (URN CEA – Scenario-based), providing a comprehensive analysis of the future underwater noise conditions and the implications of the mitigation measures.

4.7 URN CEA – Scenario-based

4.7.1 Description

This stage in the step-by-step approach is very similar to the Step "URN CEA – Current Conditions" step (Section 5.4). However, the key difference is that now the CEA analysis must consider the new

[6] BRIDGE-BS Project (Advancing knowledge, delivering research, empowering citizens for sustainable and climate-neutral Black Sea): https://bridgeblacksea.org/

configurations of human activities and pressures which result from the previous steps (i.e., 5.4 Scenario Development and 5.5 URN Modeling – Scenario-based).

In addition to the specific underwater radiated noise (URN) measures that have already been described and incorporated directly into the URN models seen previously, it is also necessary to incorporate other scenarios to complete the CEA analysis. In Table 3, there is a list of some scenarios related to the Maritime Spatial Planning (MSP) process, organized by sector, along with a brief description and the implications of how these can be incorporated into a CEA case study.

Table 3: Examples of scenarios, measures, or actions that can be developed within an MSP context and guidance on how to integrate them into a CEA Case Study setup.

Sector	Scenario Type / Measure / Action	CEA setup	
		direct	indirect
Aquaculture	Aquaculture development	Includes new aquaculture sites / polygons specifying the type of aquaculture (e.g., finfish, shellfish) and the type of management practices	Remove or reduce incompatible uses in new aquaculture areas. Consider the increased traffic from ports used for maintenance and harvesting operations.
Fisheries Regulations	Bottom Trawl ban	Mask the layers describing the current bottom trawl effort using polygons that outline trawling ban areas, such as those within a minimum distance from the coast or within marine protected areas	Adjust the fishing activities to focus on the areas where fishing is still allowed. Take into account the potential benefits, such as increased fish populations spilling over from the newly protected areas into the surrounding regions.
Renewable Energy	Offshore Wind Farms development	Include new offshore energy sites / polygons specifying the type and other main characteristic (e.g., foundation type, floating, monopiles, etc.)	Remove or reduce incompatible uses in new OFW areas.
Oil and Gas	Exploration	Include new Oil and Gas exploration areas	

	Trend in extraction activities	Include new Oil and Gas extraction areas. Remove sites that have been decommissioned or converted for other uses.	Remove or reduce activities that are not compatible with the new oil and gas areas. Consider the coastal transport pipelines and the necessary buffer zones around the plants and pipelines. Adjust the use of areas that have been decommissioned to accommodate new, suitable activities
Shipping and Marine Traffic Management	Industrial port planning	Update shipping routes and intensity for Cargo and Tanker	
Conservation Initiatives	Marine Protected Areas	Add new protected zones	Remove or reduce incompatible uses in new MPAs
Coastal and maritime Tourism	Beach development	Add new beach locations including related facilities	
	Marina Development	Include new marina locations, including information about number of berths	
	Recreational Fisheries	Update recreational fishing areas and intensity	Reduce other activities in the new recreational fishing areas. Also, consider converting some traditional fishing activities into fishing tourism
Land Sea Interactions	Urban Development / Population growth	Update land use and zoning maps; increase population density parameters.	
	Industrial Growth	Add new sources of emissions; update industrial land use maps	
	Agricultural Intensification	Adjust land cover data; increase usage of fertilizers and pesticides	

	Waste Management Improvements	Add new waste treatment facilities; assess reduction in environmental load	
Climate Change	Modify climate models; update temperature and precipitation projections	-	Update future maps showing the presence or abundance of environmental receptors to reflect changes in climatic conditions.
Policy Implementation (e.g., emission limits)	Integrate new regulations	Changes due to new emission limits, fishing net regulations, and technological improvements (e.g., changes in gear as the Bycatch Reduction Devices BRD, optimization of propellers) are incorporated into the CEA by adjusting the pressure sources of various human activities (e.g., reducing pressure weights) and modifying the input parameters of the pressure propagation models.	
Technological Advancements	Integrate new technologies		

As shown in the table, different MSP scenarios, measures, and actions can be incorporated into a CEA analysis in various ways, such as:

- Modifying and adjusting the geographical layers that describe the presence and intensity of various human activities in marine and coastal areas (e.g., new aquaculture areas, oil and gas extraction sites, offshore wind farms, changes in the intensity of marine traffic for certain types of vessels).
- Modifying the sources of pressure introduced by these activities, mainly due to new regulations and restrictions on emission limits or the use of certain equipment, or due to technological advances.
- Modifying the future distribution of environmental receptors and habitats due to external factors (exogenous drivers) that cannot generally be controlled by a planning process, such as changes caused by climate change.

Additionally, as highlighted in the last column of the table (CEA setup - indirect), many measures and scenarios, although designed for a specific use, can have indirect effects on other uses. For example, introducing a new activity at sea (e.g., offshore wind farms, aquaculture, oil and gas extraction) can alter the distribution of other maritime activities that are incompatible or partially incompatible. Moreover, the introduction of some activities also requires logistical infrastructure, either at sea (e.g., cables for energy transport from offshore wind farms) or on land (e.g., logistics systems for aquaculture or for the assembly and maintenance of offshore wind farms).

All these considerations, along with the new geospatial information about the expected future distributions of human activities, will form the foundation for setting up a new CEA Case Study (CEA - Scenario Based). This will also guide the related CEA analyses, like what was described in section 5.4 (CEA - Current Conditions).

4.7.2 Expected outputs and results – Case studies and scenarios comparison

One of the main results of this step is the comparison thorough analysis of the "CEA - Current Conditions" versus the "CEA - Scenario Based" projections. This comparison aims to identify geospatial differences in CEA scores and assess the qualitative and semi-quantitative impacts of each scenario and on impact chains. This also provides an opportunity to gather initial feedback on how effective the decisions and measures in the MSP proposals might be.

To begin, geospatial data for both the current conditions and the scenario-based projections are collected. This data is then used to create maps that display the CEA scores for each scenario, highlighting areas with significant differences. The spatial distribution of human activities and environmental receptors is analysed to identify regions where changes are most pronounced.

The differences between the case studies and the scenarios can be analysed in detail for specific sub-areas, such as particular environmental receptors, specific pressures, or certain human activities. This includes quantifying expected reductions or increases in pressure weights and evaluating the effects of technological advancements and new regulations on the CEA scores. Additionally, evaluating individual vulnerability profiles will be a crucial tool in this assessment.

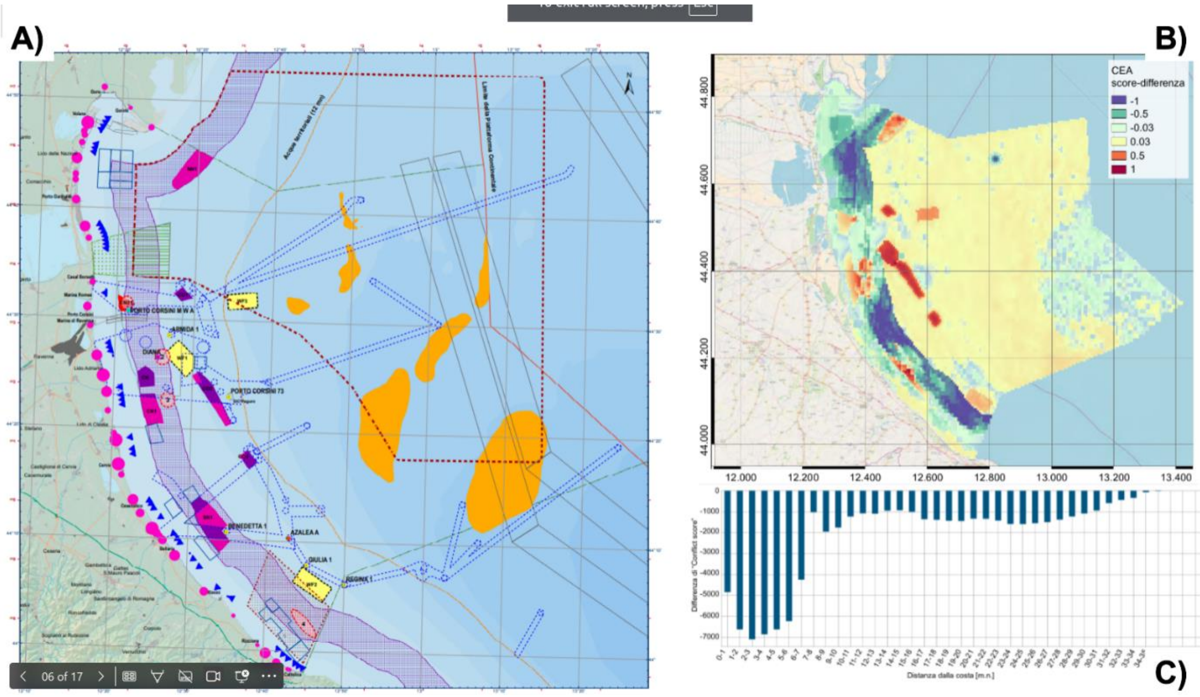

Figure 31: Example of comparison between CEA scenarios in a planning process for the Emilia-Romagna region in the Adriatic Sea (Barbanti et al. 2018). It illustrates: (A) the detailed spatial distribution of various planning measures which identify in the "managed development" scenario; (B) the geospatial representation of the differences in CEA scores between the "CEA managed development" scenario and the "CEA current situation"; (C) the same differences shown in classes based on their distance from the coast.

Figure 31 shows a scenario comparison between two CEA (Cumulative Effects Assessment) analyses within an MSP (Maritime Spatial Planning) context. This planning process was applied to the Italian maritime waters off the Emilia-Romagna Region in the Northern Adriatic Sea. The example compares the CEA analysis of a hypothetical future MSP scenario called 'managed development' with the CEA analysis of the current situation.

Finally, the comparison informs decision-makers about the potential outcomes of each scenario, considering trade-offs and synergies. Based on this analysis, final recommendations for future actions are developed, ensuring alignment with the overall goals and objectives of the decision-making process.

4.7.3 Tools to support the process

For the 'CEA scenario-based' analysis, you can use the Tools4MSP CEA tool as described in section 5.4.4. Currently, there is no specific tool available for comparing different scenarios. However, you can use desktop GIS tools to easily produce differences between raster by directly using the GeoTIFFs generated by Tools4MSP.

The results of the 'CEA scenario-based' analysis, as well as the results of any comparative analysis, can be included in the narrative using Tools4MSP Geostorytelling. This approach facilitates better communication and interaction with stakeholders, helping to gather their feedback effectively.

4.8 Co-design of the Decision Support Tools

4.8.1 Stakeholder workshop

The SATURN workshop titled "Maritime Spatial Planning (MSP) as a tool to mitigate the impacts of underwater noise" was organised with the aim of involving relevant stakeholders and competent authorities in co-designing the SATURN Decision Support Tool for incorporating underwater noise into the MSP process. The objective of the workshop was to test the demand for such tools to support planning activities carried out by MSP or MSFD experts and to gain an understanding of their needs and expectations for the outputs of the DST. In particular, the workshop intended to investigate which geospatial and statistical indicators would be most efficient for incorporating URN in an MSP context in different study areas. Special attention was also given to assessing the applicability of URN mitigation measures in different contexts.

Deliverable D6.3 (Folegot et al., 2024) provides a comprehensive description of the event organization, the methodology used, and the results obtained.

The event was held in hybrid form on September 14th, 2023, at CNR-ISMAR in Venice (Arsenale, Tesa 104, Castello 2737/F, 30122 Venice, Italy) and was organised by CNR-ISMAR, Quiet-Oceans, and Bureau Veritas. The workshop included 15 experts in Maritime Spatial Planning and Marine Strategy Framework Directive from 10 different countries.

The agenda alternated presentations on key topics to Q&A sessions with the participants, in full interactive mode. The event was split into the three following sessions:

- "Setting the frame", which provided some context on how member states are currently including URN in their MSP plans and introduced results of the working group TG Noise;
- "SATURN project", which presented the progress made within the SATURN project in integrating underwater noise into MSP, with examples of applications;
- "Group work and plenary discussion", where stakeholders were invited to take part in a structured conversation and share their vision on the functionalities and knowledge outputs of the SATURN DST.

The Q&A sessions and plenary discussion were carried out with the support of interactive online tool Slido (www.slido.com). Based on the outcome of this discussion, a stakeholder survey was produced and distributed following the workshop with the aim of gaining a more comprehensive understanding of the needs and expectations of various stakeholders.

4.8.2 Main outcomes

The following section aims at reporting the questions presented to the stakeholders during the final session of the workshop and the main outcomes resulting from the discussion. The questions were posed through the Slido.io online platform and participants were given a few minutes to answer anonymously from their personal devices by choosing their preferred answer or ranking a series of options. A brief group discussion followed each question. The key topics of the discussion were 1) knowledge needs, 2) underwater noise criteria, 3) DST functionalities, and 4) mitigation measures.

Q1 – Knowledge needs: As a marine planner, which aspects would you prioritize when addressing underwater noise in the MSP process?

This question highlighted the variety of sectors involved in producing noise-related activities, but also the range of impacts and targeted species, which were ranked as the top 3 aspects. These were followed by the need to address harmonisation with other existing policy and research, in terms of common metrics and thresholds for the management of noise, the input from stakeholders, the transboundary nature of underwater sound and, finally, the use of geospatial data describing sound propagation in the planning area.

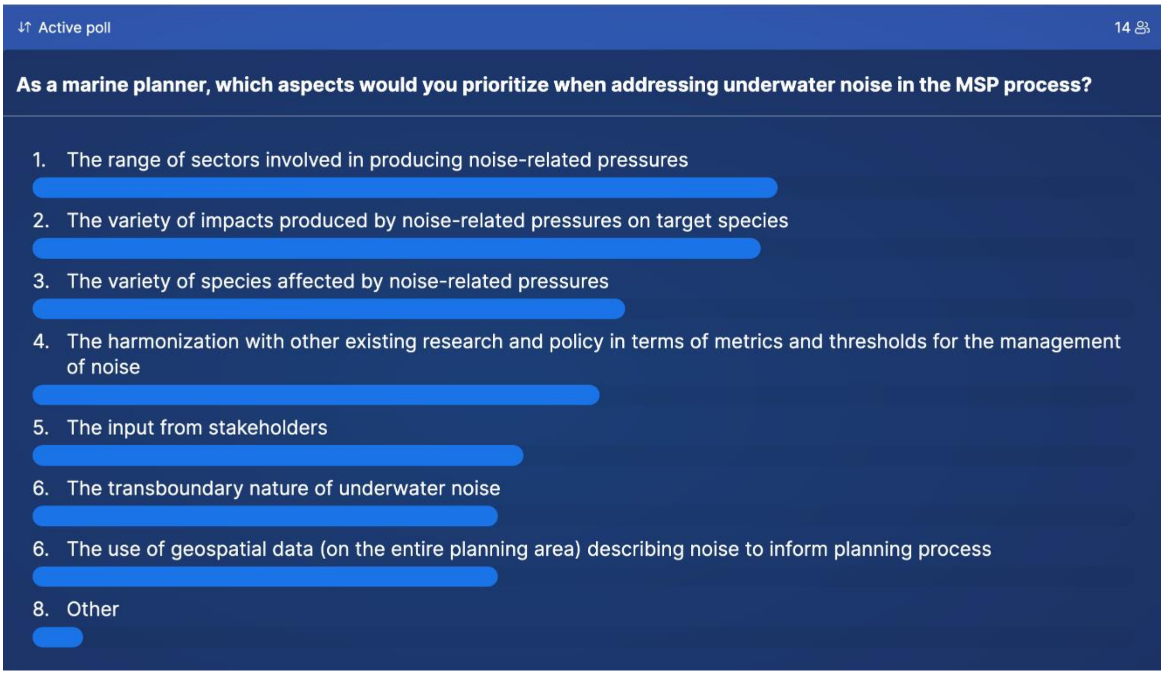

Figure 32: Slido results for Q1.

Q2 – Underwater noise criteria: What is your level of knowledge of the Marine Reporting Unit (MRU) used in the framework of the MSFD?

The majority of participants (62%) stated they had an approximate knowledge of MRU in the MSFD framework, while 31% voted for “precise knowledge” and only 8% admitted to having no knowledge at all. None of the participants deemed the topic as “not relevant”.

Q3 – Underwater noise criteria: Do you know what indicator species sensitive to noise you need to address in the MSP?

Answers to this question were split equally, with a third of respondents stating they were “confidently aware” of indicator species, one third “approximately” and one third “not really”. No votes for “not relevant”.

Q4 – Underwater noise criteria: Do you know the spatial distribution or the habitat of the indicator species?

Just over half of respondents (56%) called attention to the lack of available data, while a third (33%) stated that data are mostly available but difficult for them to access. Only 11% declared that the data are available and easily accessible to them, and no votes were given to “the data do not exist” or “not relevant”.

Q5 – Underwater noise criteria: Do you have access to shipping distribution data?

Exactly half of the participants (50%) claimed they have access to detailed data on ship position, while 30% was only able to obtain data on shipping routes. The remaining 20% has no access to shipping data.

Q6 – DST functionalities: What new features would you find most useful to be included in a Decision Support Tool (DST) supporting the risk assessment of underwater noise in MSP? Please rank.

The option which obtained the highest ranking for this questions was “to calculate noise statistics or indicators on a user-defined geographical region (e.g. MSP planning unit, target species hotspot, Natura2000 areas, etc.)”, somehow contradicting Q1 where “the use of geospatial data describing sound propagation in the planning area” obtained the lowest score as an aspect to prioritize in the MSP process. This was closely followed by “the possibility of exploring the seasonal or monthly changes of noise-related pressures and impacts” and “the ability to trace back to the main sources of noise-related pressures and impacts in a specific region”. Other options which did not make the top 3 included, in this order: “to develop a base-level assessment of noise impact on ecosystem services”, “the ability to compare statistics and indicators from different user-defined case studies (e.g. scenario comparison)”, “to be user-friendly, for example by automatically selecting key frequencies based on a choice of species”, and, finally, “to investigate the changes of noise-related pressures and impacts in the water column”.

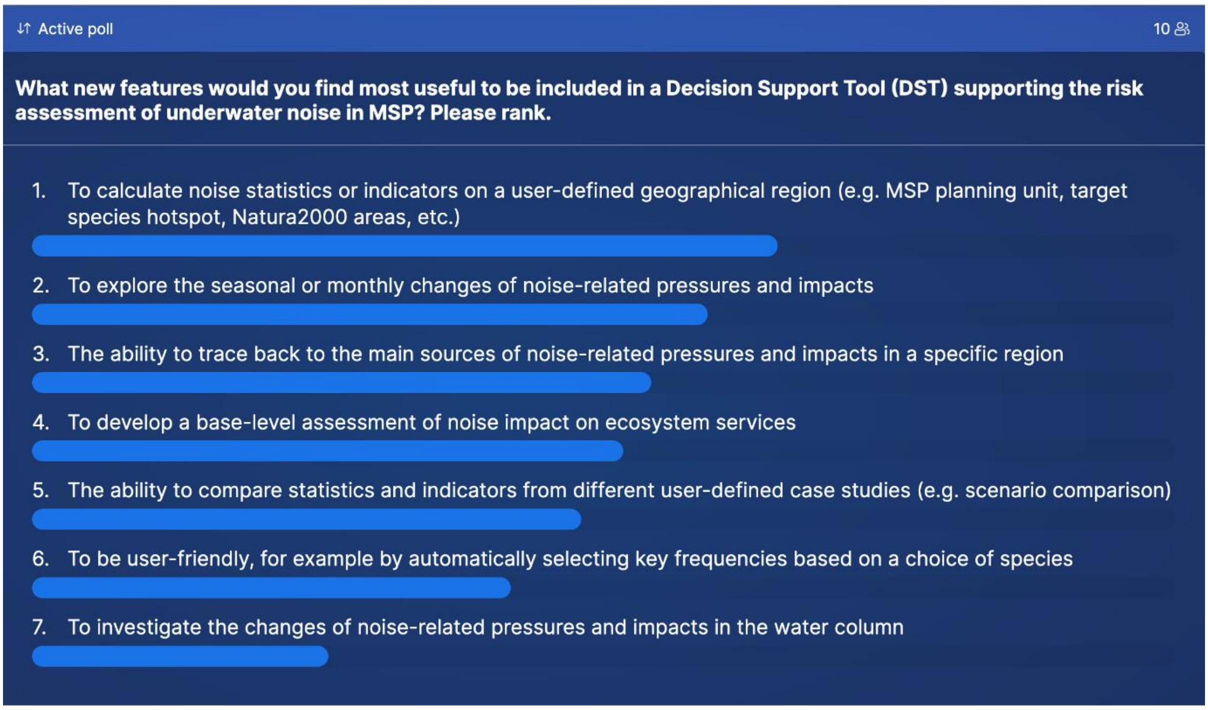

Figure 33. Slido results for Q6.

Q7 – Mitigation measures: Which types of noise-mitigating measures are, in your opinion, most feasible to implement from an MSP perspective? Please select and rank 3.

The three selected measures were, in order: “strategic, such as the inclusion of specific objectives for noise mitigation in plans”, selected by a vast majority of stakeholders, followed by “the establishment of "Particularly Sensitive Areas" (PSSAs) or "Areas To Be Avoided" (ATBA)” and “behavioural, e.g. speed reduction, regular hull and propeller maintenance, etc.”, which obtained a similar score.

4.8.3 Conclusions and Implementation of Workshop Outcomes

The stakeholder workshop provided useful insights that influenced the refinement of both our step-by-step approach conceptualization and the tool development. The discussions revealed disparities in the availability and accessibility of essential data, particularly concerning shipping distribution and species habitat mapping (e.g. noise-sensitive species and their habitats). While many stakeholders recognized the importance of such datasets, they also highlighted difficulties in obtaining them. To address this challenge, efforts were made to streamline data integration within OceanPlanner and the Tools4MSP Geoplatform, facilitating more effective scenario-based planning and ensuring that external datasets could be more easily incorporated into the analysis.

Another key takeaway was the stakeholders' strong preference for functionalities that allow the calculation of noise statistics and indicators on user-defined areas, such as MSP planning units, Natura 2000 sites, and species hotspots. This led to a targeted improvement of the DST, ensuring it could generate customized risk assessments in specific regions. Additionally, the demand for a more refined temporal analysis of noise-related pressures and impacts resulted in the enhancement of seasonal and monthly assessment capabilities, making it easier to evaluate changes over time.

A further critical aspect that emerged was the importance of aligning noise mitigation strategies with policy frameworks. Stakeholders placed strong emphasis on strategic mitigation measures, such as embedding noise reduction objectives into MSP processes and defining Particularly Sensitive Areas (PSSAs) or Areas To Be Avoided (ATBAs). To support these needs, even though it was not possible to develop it within the scope of this project, a policy guidance layer will be incorporated into the DST, providing planners with a clearer reference for integrating mitigation strategies within spatial planning frameworks.

5 Conclusions

The methodology called "A Step-by-Step Approach for Incorporating URN in MSP" systematically outlines the steps required to integrate Underwater Radiated Noise (URN) into Maritime Spatial Planning (MSP) using a risk-based Cumulative Impact Assessment (CEA) approach. This methodology is structured around six key steps, from defining the MSP-based context to scenario development and impact assessment, ensuring a comprehensive process that incorporates both present and future conditions.

A crucial element of this methodology is the development of a dedicated toolkit, composed of specific software components and web-based tools, such as Quonops, Tools4MSP-CEA, and OceanPlanner. These tools enable the collection, visualization, and analysis of geospatial data, as well as the modelling of URN sources and impacts. The integration of these components within a structured workflow ensures that decision-makers can effectively explore management scenarios and mitigation measures, improving transparency and scientific robustness in MSP decision-making.

A key advancement of this approach is the introduction of the Anthropogenic Noise Pressure Index (ANPIndex), which provides a structured means to assess URN-related pressures and effects. The methodology includes two versions of this index: i) a simplified version, which utilizes general pressure maps based on the ANPIndex; ii) a targeted version, which applies species-specific assessments using the Maximum Tolerable Level (MTL). This flexibility ensures that the methodology remains applicable in both data-rich and data-poor conditions, allowing for assessments even in cases where dose-response relationships for target species are incomplete or unknown.

The scalability and adaptability of this methodology and its toolkit make it a versatile solution for integrating URN into MSP and CEA processes at both national and international levels. It is currently being applied in the Northern Adriatic case study within the SATURN project, where its real-world implementation will provide valuable insights for further refinement. The results of this application will be detailed in Deliverable D6.5, supporting the ongoing evolution of this methodology for broader use in MSP and URN management.

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Annex 1: Access to Tools and Usage Conditions

This annex provides info to the tools referenced in this methodology, detailing where they can be accessed, their mail functionalities, and any conditions or restrictions for use.

Tool Name, acces link	Description	Usage Conditions & Restrictions	Support Contact
Quonops Online Services	Sound modeling for marine traffic and fishing activities under current conditions.	Access requires a commercial agreement with the provider.	support@quiet-oceans.com
Tools4MSP CEA	Cumulative Effects Assessment of URN and other anthropogenic pressures.	User registration is required, with approval for account monitoring purposes. For extensive use in projects requiring large datasets and analyses, a Memorandum of Understanding (MoU) is generally preferred.	tools4msp@ismar.cnr.it
Tools4MSP Geoplatform	Geospatial platform for scenario development and stakeholder engagement.	User registration is required, with approval for account monitoring purposes. For formal use in data-intensive projects, a Memorandum of Understanding (MoU) is generally recommended.	tools4msp@ismar.cnr.it
OceanPlanner	Scenario-based URN modeling, noise map updates, and impact assessments.	Access requires a commercial agreement with the provider.	support@quiet-oceans.com

For further inquiries or to request credentials for restricted tools, please reach out to the respective support contacts provided above.

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