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Norsaic REPORT

PARAMETERS FOR THE USE OF CUMULATIVE IMPACT ASSESSMENTS IN MSP AT LOCAL AND TRANSNATIONAL SCALES

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Report D1.8 on the Parameters for the use of Cumulative Impacts Assessments in MSP at local and transnational scales

Highlights

- Cumulative Impacts Assessments are a useful tool for Maritime Spatial Planning, allowing planners to identify areas with high risks of impacts on the environment and plan activities accordingly.
- Most commonly used CIA models are derived from the formula proposed by Halpern et al., 2008, and compute the sum of all pressures on all ecosystem components, weighted by the sensitivity of the ecosystem components to each pressure.
- The standard models present a number of limits and biases caused by the initial assumptions of the model (e.g. that the relationships between pressures, or impacts, are cumulative and not synergistic or antagonistic).
- The implementation of CIA in transnational MSP still faces many challenges, such as data collection and harmonization or integration of the consequences of MSP into the calculations (e.g. an activity shifting to a different area, thus moving the pressures to this area).
- A synthesis of frameworks proposed in the literature for the implementation of CIA in MSP is provided.
- Several elements of the assessment are essential for planners, including reliability and uncertainty, as well as the assumptions included in the model

Keywords

Maritime Spatial Planning; Cumulative Impacts Assessment; North Sea; framework for international policy implementation

Abstract

The implementation of maritime spatial planning, the process by which human activities at sea are coherently managed at an international scale, is mandatory for all Member States of the European Union. In the North Sea, a sea basin with a dense population, heavy industrialization and busy harbours and lanes, organizing human activities at the transboundary level to maintain a healthy and sustainable marine environment is a challenging task. To further this goal, the Norsaic project will bring together actors and planners from countries bordering the North Sea to design common strategies to tackle essential issues related to Maritime Spatial Planning. In order to achieve a sustainable use of maritime space, planners can use tools such as Cumulative Impacts Assessments, which provides them with important information regarding the state of pressures on the environment. In the framework of the Norsaic project, the present study focuses on the use of Cumulative Impacts Assessments in Maritime Spatial Planning, both at a local and transnational scales. More specifically, this report aims to study the “parameters” (i.e. any relevant data, method or information) for the implementation of Cumulative Impacts Assessments in Maritime Spatial Planning. In the first part of this report, general information is provided on Cumulative Impacts Assessments. Definitions of Cumulative Impacts Assessments, as well as the concepts involved in this type of analysis, are provided: a Cumulative Impacts Assessment is a procedure aiming to evaluate the significance, or sometimes risk, of an impact on ecosystem components caused by pressures derived from human activities. The most commonly used models of Cumulative Impacts Assessments are derived from a formula proposed by Halpern et al., 2008. These models represent Cumulative Impacts as the sum of each pressure on each ecosystem component, weighted by the sensitivity of the ecosystem component to the pressure. The human activity-pressures relationship, as well as the sensitivity of ecosystem components to various pressures, are integrated into the model as matrices, which are often made based on expert knowledge and contain some biases and assumptions. The sensitivity matrix in particular is very often site-specific. Cumulative Impacts Assessments face multiple challenges, such as the lack of harmonized data; and biases, including the lack of integration of population dynamics and of the repercussions of impacts on species on the trophic network; but also the need for additional scientific literature on the relationship between ecosystem components and pressures to determine whether the impact is a linear function of the pressure intensity.

In the second part of the report, the implementation of Cumulative Impacts Assessments into local and transnational Maritime Spatial Plannings is studied. Examples of use of Cumulative Impacts Assessments in Maritime Spatial Planning are provided. A synthesis of the frameworks proposed by various authors in the literature for the implementation of Cumulative Impacts Assessments in Maritime Spatial Planning is proposed. The proposed steps go from defining the scope of the assessment as well as any elements required by the planners, to choosing the planning scenario, or scenarios, explored by the assessment accordingly, to listing the activities, pressures and ecosystem components considered, describing the relationships between these elements through matrices, selecting the most relevant ecosystem components and pressures if necessary, evaluating the Cumulative Impacts of the considered scenarios, and finally interpreting the results. The assessment of uncertainty in the calculation, an information of high importance for planners, is also described. Finally, the challenges and important points to keep in mind for the use of Cumulative Impacts Assessments into local and transnational Maritime Spatial Planning are detailed, such as cross-border data format variation (e.g. habitat classification) or the integration of the consequences of planning itself in a scenario.

Contents

Introduction

Context: Maritime Spatial Planning

In the span of the last decades, an increase of maritime uses and activities has been observed across the globe. Traditional maritime activities such as fishing, transport of goods and people, tourism, and more recent activities, like production of offshore renewable energy, have developed to meet the growing demand. With them, the pressures they cause on the environment have increased as well, leading to an increased need of marine protected areas, which can also be considered a specific use of maritime space.

To better coordinate activities at sea, the Directive 2014/89/EU establishing a framework for maritime spatial planning was created. Maritime Spatial Planning (MSP), defined as a "cross-cutting policy tool enabling public authorities and stakeholders to apply a coordinated, integrated and trans-boundary approach" in the Directive, was made mandatory for Member States to establish and implement.

Area of interest: the North Sea

Located in the northwest of Europe, between the coasts of the United Kingdom, Scandinavia and western continental Europe, the North Sea is a shallow epicontinental sea connected to the Atlantic ocean through the Norwegian Sea and the Channel, and to the Baltic Sea through the Skagerrak, the Kattegat and the Danish Straits. The Greater North Sea area can be defined as a sea region covering the entire North Sea proper, the Kattegat and Skagerrak, and the English Channel.

The Greater North Sea area is a densely populated, widely used, heavily industrialized sea region shared by many countries in and outside of the European Union. Various busy ports are located on these shores, e.g. Rotterdam, the busiest port in Europe, as well as Antwerp or Hamburg, and thus its shipping lanes are among the busiest in the world. Beyond transportation of goods, this sea region is heavily used for diverse activities such as fisheries, oil and gas exploration, sand extraction, offshore wind energy production, and tourism.

However, due to climate change and increasing human activities and needs, Maritime Spatial Planning in the Greater North Sea is currently facing the challenge of maintaining a healthy, sustainable, future-proof sea basin while accounting for the disturbances to human uses and ecosystems caused by climate change both today and in the future. To tackle this challenge, an adapted MSP approach needs to be jointly developed by decision-makers, researchers and maritime actors, for an improved cooperation governance on every level.

The Norsaic project

The Norsaic project aims to improve cooperation in Maritime Spatial Planning between countries bordering the Greater North Sea by bringing together actors from the entire sea basin to develop a joint vision for a healthy, sustainable North Sea, and advancing together on crucial MSP-related issues in order to achieve this objective.

Norsaic will develop adaptation strategies in MSP to address the challenges created by a rapidly changing climate by tackling issues related to land-sea-interaction, cumulative impacts and multi-use of space in the context of climate change, in order to develop future-proof maritime spatial plans in the Greater North Sea.

Norsaic aspires to bring MSP in the North Sea to the next level by facilitating a transition towards sustainable activities: the project will also build joint cooperation capacity for a better cooperation in MSP, and create innovative MSP tools and techniques.

Overall Norsaic will increase transnational cooperation in ocean governance and in MSP through the creation of innovative MSP tools, the development of adaptations, strategies and action plans according to the joint vision, which will be adopted and implemented by national and local authorities in the Greater North Sea region.

Objectives of this report

This report will identify the parameters for the implementation of a relevant Cumulative Impact Assessment (CIA) in the MSP process in the North Sea. Such parameters may be defined as “any data, method or information relevant for the implementation of a relevant CIA in MSP in the North Sea”. As such, the parameters include:

- A model or formula to calculate a CI score, and a detailed overview of its specificities, including simplification, input data, and potential biases
- A list of necessary or potentially important data to consider. Such list can be derived from previous works on CIA, including in their application to MSP in Europe (Halpern et al., 2008; Kelly et al., 2014; Menegon et al., 2018; Hammar et al., 2020)
- A framework to tailor the assessment to the intended application, which can be derived from previous works in this field (Judd et al., 2015; Lonsdale et al., 2020; Piet et al., 2021)
- Recommendations on how to include, or consider, spatial and temporal scales as well as the differences between local scale and transnational scale: (Halpern et al., 2008) applied their method to the whole world, but there are examples for a sea basin (Hammar et al., 2020) and for local scales and applications to multiple scales (Quemmerais-Amice et al., 2020)

In the first part of this report, general information on Cumulative Impacts Assessments are detailed, including the most commonly used models, general data needs, the usual steps of a CI assessment, but also general limits and biases of CI assessments, regardless of the purpose of the assessment (i.e. information that applies to any and all CIAs, including but not limited to MSP-related Cumulative Impacts Assessments). The second part of the report provides more information on the use of CIA in MSP. Firstly, use cases of CIA in MSP in the European Union are described. The works of several authors who proposed a framework for the application of CIA in MSP are then synthesized, and each step of the resulting synthetic framework is detailed. Finally, the remaining challenges for the use of CIA in MSP are described.

Additionally, this report will document the gaps in knowledge mentioned in the literature, provide recommendations on how to bridge such gaps whenever possible.

Abbreviations

CI: Cumulative Impacts
CIA: Cumulative Impacts Assessment
MSP: Maritime Spatial Planning
EU: European Union
EC: Ecosystem Component

Cumulative Impacts Assessment

Questions this chapter answers

- What is the definition of Cumulative Impacts assessments? What are the basic concepts related to this?
- What models are used to quantify Cumulative Impacts?
- How are the impacts of activities on species or habitats calculated?
- What are the steps of the analysis?
- What are the biases and limits of this type of study?
- Are temporal aspects taken into account?

Definition of Cumulative Impacts Assessments

The expressions “cumulative impacts” and “cumulative impacts assessments” need to be defined before each analysis, as there is some variability in how these terms are used by planners, academics and managers alike (Judd et al., 2015). Recently, Cumulative Impacts Assessments have been defined as “a systematic procedure for identifying and evaluating the significance of impacts from individual or multiple sources and/or activities” (Judd et al., 2015; Piet et al., 2017; Lonsdale et al., 2020), and Cumulative Impacts as “the incremental impact of an action when added to another past, present and reasonable foreseeable action” (Piet et al., 2017). These definitions are used in this report and are further explained below.

Human activities are known to create pressures on the environment. For instance, sand or gravel extraction increases water turbidity and destroys benthic habitats; maritime traffic can cause underwater noise; etc. Each of these pressures is assumed to have an impact on specific parts of the ecosystem, or “ecosystem components” (EC), a concept covering both habitats and species. For instance, common porpoises are sensitive to noise, whereas seagrass species are sensitive to the destruction of benthic substrate and to increased turbidity. The goal of a “Cumulative Impacts Assessment” is to calculate the combined impacts of pressures caused by various human activities on the entire ecosystem. Such an assessment has a spatial component by definition, as the interactions between activities and EC are dependent on their spatial distributions.

However, a need to move to a “risk” approach was mentioned in the literature (Quemmerais-Amice et al., 2020): instead of readily assuming a pressure will have an impact, the risk of that pressure having an impact is calculated instead. This is done by using a matrix of “risk of impact” rather than a matrix of “impact”. The main difference is found in the accuracy of the statement: in practice, the calculation remains the same, though the sensitivity of ecosystem components to pressures may be more accurate.

Finally, some concepts and notions in Cumulative Impacts Assessments have been found under different names in the scientific literature, whereas some names were used to describe unrelated concepts; therefore, it is a good practice to establish a list of terms at the beginning of the study (La Rivière et al., 2015). In this report:

- The “impact” is the (most often negative) consequence of the pressures caused by human activities on an ecosystem component. In the literature, “impact” and “effect” are used somewhat interchangeably, or to cover similar concepts, or multiple concepts found in the link between a pressure and an ecosystem component.
- “Effect” is used as a synonym of “Impact”. In a slightly different, more detailed approach, the work from (Judd et al., 2015) differentiates pressure, impact and effect as: “Human activities exert pressures which have effects which may lead to impacts on [ecosystem components]”, but this level of detail is still difficult to achieve in data and was thus not considered.
- “Pressure”: a transformation of the initial state of the environment caused by human activities, that may lead to negative consequences for considered ecosystem components. Pressures can be physical (e.g. noise), chemical (e.g. introduction of contaminants), biological (e.g. introduction of invasive species)…

- “Risk of impact, risk of effect”: As it is difficult to accurately predict the exact impact of a set of pressures on an ecosystem component, recent literature (Quemmerais-Amice et al., 2020) has used the term “risk of impact” instead of “impact” in the framework of CIA.

These definitions are mostly based on the DAPSIR model (Drivers, Activities, Pressures, State changes, Impact, Response) which is commonly used to represent the causes and consequences of human activities on marine environments (e.g. OSPAR, 2022; derived from Elliott et al., 2017).

Most commonly used models

The most commonly used models and formulas are derived from the works of Halpern et al. (2008). They use four main elements: the spatial distribution of activities included in the survey, the spatial distribution of ecosystem components included in the survey, a matrix of pressures generated by activities (e.g. the intensity of noise generated by maritime traffic, by the creation of new offshore wind farms, by sail navigation, etc.), and a matrix of impacts caused by pressures, which is usually described as the sensitivity of ecosystem components to each pressure (e.g. sensitivity of harbor seals to underwater noise, to turbidity, to the introduction of chemicals, etc.), both matrices being usually dimensionless (e.g. Quemmerais-Amice et al., 2020 where the relationship between activity and pressure is identified as a binary True/false, or 0/1, and the intensity of the pressure is assumed to be linearly related to activity intensity). Initially, the 2008 model (Halpern et al., 2008) went directly from human activities to impacts. Ban et al., 2010 later assigned a single pressure (and a distance of effect) to each assessed activity, an approach then improved by other studies (e.g. Heinänen et al., 2013; Korpinen et al., 2012).

The initial model (Halpern et al., 2008) was based on several assumptions which were better explored later (Halpern and Fujita, 2013). For instance, activities included in the calculation have roughly equal weight in the final score. In other words, lumping together artisanal fishing and industrial fishing, or high-frequency and low-frequency noise, assumes that both elements of the group will affect ecosystem components in the same way. There is not enough literature to support this claim for every group or subgroup of activities.

Furthermore, calculations are done on grids, with rather wide cells: 1 NM × 1 NM cells may be used for assessment on an EEZ section, due to exponentially increasing computing times with smaller resolutions. Habitat distribution can be obtained at a much finer resolution, but it is often more difficult to obtain pressure or activity data at finer resolutions. However, pressure or activity distribution (e.g. anchoring) may not be homogeneous within the 3.4 km^2 (1 NM^2) area.

Various applications of the original model, including the original paper, use a presence/absence factor to describe habitats: in the model created by Halpern et al., (2008), the presence of an ecosystem component in a cell is limited to the values 0 meaning the ecosystem component is absent from the cell, or 1 meaning the ecosystem component can be found in the cell. The actual surface covered by the habitat is not always used, which may lead to an overrepresentation of an impact on a marginal habitat. Similarly, calculating the CI score as a sum of all ecosystem components may assign higher scores to cells where there are multiple EC, compared to cells where there are fewer EC. This could be considered a bias in itself, as the calculation in the original article only considered the presence or absence of ecosystem components and not the area covered by an EC, thus emphasizing the impact of pressures on fragments of EC in some cells.

There is not enough scientific literature on the relationship between ecosystem components and pressures: it is difficult to define whether the risk of impact is defined by a linear, logarithmic, exponential relationship, or any other curve. Other possible specificities of such relationships, e.g. thresholds of pressure levels above which risks of impact start occurring, have not been sufficiently explored for enough species to establish a fully accurate method of calculating Cumulative Impacts.

The need to investigate the inclusion of pressure thresholds into CI assessments has been discussed during the Norsaic webinar organized in June 2024.

Finally, the common models represent the cumulative impacts in an additive way: the assessment usually does not take into account the actual complexity of the interactions between activities, pressures and ecosystem components. It has been reported that pressures can have synergistic (the impact of combined pressures is superior to the sum of each single impact) or antagonistic (the impact of combined pressures is inferior to the sum of each single impact) interactions (Crain et al., 2008; Teichert et al., 2016; Judd et al., 2015; Halpern and Fujita, 2013). Such interactions were shown to vary depending on various factors such as response level (community vs. population) or even the selected pressures. For this reason, they are difficult to model. Nevertheless, removing such effects from the model reduces its scientific accuracy.

Use and limits of matrices in the models

Matrices of sensitivity, which describe the sensitivity of ecosystem components to pressures generated by human activities, are usually built from experts' knowledge and available data in the scientific literature (La Rivière et al., 2015; Tillin et al., 2010; Quemmerais-Amice et al., 2020)

Various approaches (La Rivière et al., 2015; Quemmerais-Amice et al., 2020; Tillin et al., 2010) consider "sensitivity" as a combination of resistance and resilience. Resistance (also called "tolerance" in the literature) is the ability of an ecosystem component to stand a given amount of pressure, in a way that its functions and characteristics are not significantly altered. Conversely, resilience is the amount of time an ecosystem component needs after being confronted to a pressure to restore its functions to their original state. In such approaches, the sensitivity score of an ecosystem component to a pressure is given based on the combination of the scores of resistance and resilience of the ecosystem component to this pressure.

To complete matrices of sensitivity, these approaches first filled the sensitivity matrix with the best available data from the scientific literature, then relied on expert knowledge to complete the remaining gaps through the organization of workshops where experts debated the proper attribution of scores (e.g. Hammar et al., 2020; La Rivière et al., 2015). For instance, expert knowledge was required for a significant number of benthic habitats (La Rivière et al., 2015). In some methods, a confidence index can be attributed to each score (e.g. Quemmerais-Amice et al., 2020) to identify the values for which experts are less certain. A study (Jones et al., 2018) has mitigated uncertainties linked to expert knowledge by asking experts to propose a range of impact based on their own knowledge, instead of an unique score, for the sensitivity of each Ecosystem Component.

Reusing a matrix constructed for a specific project area "as is" in another area should not be done: there may be variations in the sensitivity of ecosystem components to the same pressure from one site to another (Halpern and Fujita, 2013). In other words, communities of a given species in the North Sea may have a different sensitivity to a given pressure compared to communities of the same species in the Irish Sea. Those have to be mitigated by validating the sensitivity matrix with a panel of experts prior to the analysis.

Several complex effects linked to human activities at sea, the pressures they cause, and their impact on species, have been observed. For instance, disturbing harbor porpoises leads to lower reproduction beyond simple relocation of individuals (Rijkswaterstaat, 2019), which is a more complex impact than, for instance, the destruction of a habitat. It can be difficult to take into account the complexity of such effects when building a sensitivity matrix, which can contribute to a lowered accuracy of the CIA predictive capabilities.

As such, the point listed can be discussed for all the relationships described in a matrix of sensitivity. But there are other complexities linked to each one, for example:

- The artificial reef effect is caused by the introduction of hard substrates (e.g. wind turbines) in an environment with predominantly soft natural substrate. This effect is said to increase biodiversity by offering a hard surface for hard substrate fauna to colonize. While an increase in hard substrate species is observed, articles in the literature nuance the "benefits" of this effect (e.g. Degraer et al., 2020; Lindeboom et al., 2015), which 1) is still caused by an artificial change in the nature of the substrate, 2) may not be sufficient to compensate the negative impacts of the construction and 3) still lacks full scientific understanding.

- The barrier effect, cited in various cumulative impact studies (e.g. Brignon et al., 2022) is the creation of an obstacle on the pathways used by a species, which then has to spend more energy to circumvent the obstacle. While the obstacle itself is not a direct cause of mortality in the species, it is the cause for an increased energy expenditure, an indirect disadvantage. However, the impact of the barrier effect is not understood well enough to be included in a CI assessment yet.

- Species mobility was mentioned as a parameter of CIA during the June 2024 Norsaic webinar. On this topic, the Rijkswaterstaat (2019) mentions that due to the high mobility of certain species (including various marine mammals and birds), conservation of these species must consider the biogeographical population level, i.e. the pressures encountered in the entire areas where a species is likely to be found. This is hardly compatible with the grids of relatively small cells used in most CI assessments.

In a similar approach to sensitivity, in more recent models, human activities are translated into pressures through the use of activity-pressure matrices. Unlike matrices of sensitivity, an activity-pressure matrix serves as a guide to determine what pressures are caused by various human activities, and can be used to prepare the data for the calculation.

For instance, in their report on the use of Cumulative Impacts in MSP in the Baltic Sea, Bergström et al. (2019) present a table of potential relationships between human activities and generated pressures in the Baltic Sea. Pressures listed in this table are then derived from human activity data, and then completed with monitoring and measurements at sea for certain pressures. Similarly, Quemmerais-Amice et al. (2020) use relationships between human activities and pressures to derive pressure values from activity data.

There are multiple ways to identify pressures generated by human activities, including expert knowledge (e.g. Quemmerais-Amice et al., 2020) which can be supported by technical baseline documents for specific types of activities; but also using a backsourcing model going from the list of pressures affecting an environmental component, to the list of potential sources for these pressures (Menegon et al., 2018).

The relationships between human activities and pressures appear to be better understood than the sensitivity of ecosystem components. The main differences between models in the handling of activities-pressures relationships lie in the representation of pressure intensity from activity data. Quemmerais-Amice et al. (2020) use a binary relationship ("this Activity causes/does not cause this Pressure") weighted by the intensity of the activity, log-normalized for the entire study area. This has an added bias of assuming two activities will cause the same amount of pressure at the same intensity. In other words, trawl fishing and sand extraction, at the same normalized intensities, would cause the same amount of pressure (e.g. physical destruction of benthic habitats). Similarly, Jones et al. (2018) attribute a spatial intensity score between 0 and 1, where 1 is the highest intensity of the activity observed in the study area. Such intensity scores are therefore relative to other spots in the study area.

Data needs in CIA

In fine, Cumulative Impact scores “only” require three inputs: a map of Ecological Components (usually weighted by covered surface area in the cell), a map of Pressures, for example weighted by their intensities, and the sensitivity of each Ecosystem Component to each Pressure (usually in the form of a matrix).

For the Pressures, they are rather difficult to measure locally in the entire sea basin over an extended period of time (e.g. there will most assuredly not be any direct measurement of noise level in every single cell over a year). However, as described earlier, the Pressures, and their intensities, can be derived from a list of activities carried out in the cell, using a matrix of “Pressure per activity”. For instance, the activities “Navigation” and “Wind turbine construction and installation” both cause the pressure “Noise”. While completing this work, as mentioned during the June 2024 Norsaic webinar, it is essential to consider land-sea interactions.

However, the lack of data is probably one of the main obstacles to the realization of a complete CI assessment: in order to perform a complete analysis, one must collect data on the spatial distribution of every ecosystem component and every activity concerned by the objectives of said analysis. It may prove difficult to gather recent data, as systematic studies are costly and infrequent, especially at the scale of a State’s entire Exclusive Economic Zone. This can sometimes be mitigated to some extent: for instance, Heinänen et al., (2013) used what they call “fuzzy measures” (e.g. predicted probability of presence) to make up for the lack of precise data in the North Sea. Otherwise, uncertainty caused by lack of data can be mitigated by the use of confidence indexes (e.g. Quemmerais-Amice et al., 2020), or careful selection of relevant data. However, this causes another issue: as only ecosystem components for which reliable data is available are used in the final assessment, this means that the impact of pressures on important ecosystem components for which little data is available may end up underestimated in the final Cumulative Impact scores.

Beyond the risk of a lack of data, there is a secondary risk of not finding data on ecosystem components categorized using the same criteria as available sensitivity matrices. For instance, if an available matrix is built using national classification, but available data classifies habitats using European Nature Information System EUNIS codes, and the categories in both classifications do not match one-to-one exactly, remapping the habitat data to match the matrix is difficult and time-consuming.

For those reasons, one of the main challenges of CI assessments is the time-consuming step of collecting, then processing of data to put it into the correct format for the assessment.

Steps of the analysis

The first step of the assessment is to use the matrix of generated pressures per activity to translate the spatial distribution of activities into a spatial distribution of pressures. The simplest way to do this is to assign the corresponding pressures at the location of each activity, and for each pressure to consider the sum of each individual pressure as the total (e.g. total noise = sum of noise generated by maritime traffic and noise generated by fishing). During this step, it is important to consider the pressures generated by each phase of the activity (e.g. prospection, construction, exploitation and decommission of an offshore wind farm).

Prior to the calculation, a step of logarithm-based normalization of pressure data into a [0;1] scale has been used by various studies (e.g. Quemmerais-Amice et al., 2020) including the original study (Halpern et al., 2008). This was done to allow the comparison of pressures on a unitless, harmonized scale and prevents a pressure with a higher upper limit to be overrepresented in the calculation.

Cumulative Impacts are usually represented in the form of a score attributed to each cell of a grid. Essentially, such scores are calculated as the sum of the impacts of all pressures in the cell, applied to all the ecosystem components found in the cell, considering the sensitivity of the ecosystem components to the pressures. In other words, in most models, the next step is the sum, for a given location (a cell of the grid), of a pressure intensity at this location, multiplied by an ecosystem component, multiplied by the sensitivity of this ecosystem component to this pressure, all of which applied for all pressures and all ecosystem components at this location.

For instance, in the case of a cell in a 1 minute grid, where seagrass and harbor seals can be found (ecosystem components), and underwater noise and turbidity are caused by human activities (pressures), the Cumulative Impact score of the cell is as follows:

Seagrass presence × Noise intensity × Seagrass noise sensitivity
+ Seagrass presence × Turbidity intensity × Seagrass turbidity sensitivity
+ Harbor seal presence × Noise intensity × Harbor seal noise sensitivity
+ Harbor seal presence × Turbidity intensity × Harbor seal turbidity sensitivity

In Halpern et al. (2008), a final step was added to compare the model's predictions with ground truth, i.e. local empirical data on ecosystems. A relatively weak match has been found; although the initial model used very large scale data and focused on drivers rather than pressures, which probably resulted in less accurate results.

Limits and biases of CIA

It has been noted that Cumulative Impacts assessments as a whole face several challenges (e.g. Judd et al., 2015; Lonsdale et al., 2020), including variations of definition, model, mapping, process and choice of inputs. Beyond those, several other effects and limits have been observed.

Multiple data and information on the environment need to be considered in a CIA, such as areas used for various ecological functionalities (migration, resting, feeding, reproduction) by species. The destruction of a species' functional areas will definitely have an indirect impact on that species' population. This impact needs to be taken into account, alongside the direct impacts of pressures on species and habitats. In other words, while the pressure "Physical loss and disturbance of the seabed" seems to primarily concern benthic, fixed species, the destruction of a seagrass meadow, for instance, will reduce the feeding areas of multiple grazing species such as sea urchins, sea turtles, etc. Similarly, for computational, modeling, mathematical and data-driven reasons, CIA usually does not consider the repercussions on the trophic network of the impacts on a species. For the same reasons, taking into account the population dynamics of species into the model is difficult (Piet et al., 2021)

Furthermore, a number of ecosystem components are vulnerable, endangered, or critically endangered, at a global, national, regional or local level (IUCN, 2012). While a CI assessment can be tweaked to focus on a selection of ecosystem components, the most common methods give the same weight to each ecosystem component regardless of their conservation status. Even worse, an already critically endangered ecosystem component may have a reduced spatial distribution (due to its rarity and critical conservation status), which in the calculation leads to an underrepresentation of all the impacts it may suffer. Similarly, as briefly mentioned above, missing data is an important obstacle to the realization of a complete CI assessment. Data availability is an important bias in itself: only elements for which reliable data is available will have significant weight in the analysis. Therefore, species and ecosystem components for which little scientific data is available (as can be the case for rarer ecosystem components) will be underestimated in the assessment. However, this issue can be prevented simply by attributing different weights to ecosystem components based on conservation status, or alternatively by attributing weights to impact scores based on the conservation status of ecosystem components concerned by the impact score.

Even so, as described by Lonsdale et al. (2020), "the process should be able to incorporate exogenic unmanaged pressures such as climate change". In other words, while climate change is not technically speaking an activity that can be regulated, its effects on the marine environment, such as seawater temperature rise, salinity shifts, ocean acidification, etc., are akin to pressures. With the predicted increase of climate change effects in the next decades, it seems important to consider such pressures on the environment: climate change hotspots that seemingly suffer few impacts from direct human activities are not as resilient or “safe” as a “climate-blind” CI assessment would make it appear, especially if the assessment is used to determine the best location for further development of human activities. Furthermore, the transformations of the environmental conditions caused by climate change are predicted to cause shifts in species distributions, which raises the question of determining the distribution of ecosystem components. However, due to the longer time scale at which climate change functions, it seems unlikely that species distribution shifts would be much relevant in a Cumulative Impacts Assessment, at least for a Maritime Spatial Planning that is to be renewed at least every ten years.

Finally, as there are differences in the behavior and distribution of pelagic and benthic species and habitats, especially between mobile and fixed organisms, it is essential to consider the specificities of each group in a CI assessment.

Time series

In the original CI assessment paper (Halpern et al., 2008), pressures are not directly assessed. Rather, pressure drivers are evaluated: in the DPSIR model, on which the later DAPSIR model was based, Drivers cause Pressures on the environment, which transform its State, causing the Impact (which then prompts a Response from the ecosystem). Because of this, this study does not consider the difference between an occasional, intense pressure and a somewhat less intense pressure extended over time. However, in the Carpediem tool from Quemmerais et al. (2020), the user can choose to attribute continuous and occasional pressures to different variables, which allows for their separate consideration, provided the user possesses a matrix of sensitivities where the sensitivity of ecosystem components is also distinguished between occasional and continuous or extended pressures.

Furthermore, as mentioned during the Norsaic webinar in June 2024, additional biases can be caused by seasonality effects and the timing of activities: sudden pressures at a critical point of the life cycle of species are more likely to have an impact. The seasonality of constant, continuous pressures also needs to be studied, as the intensity of the pressure may change over time, and thus may affect ecological compartments differently.

Use of Cumulative Impact Assessment in MSP

Questions this chapter answers

- What is the interest for the integration of CI assessment in national or international MSP? What are the possible uses of CI assessments in the MSP process?
- Are there challenges specific to the use of Cumulative Impacts Assessments in MSP?
- Are there examples of use of CI assessments in MSP in Europe?
- What feedback is given on the inclusion of CI into MSP plans?
- Can CI be related to observed environmental events? (e.g. loss of biodiversity)
- What are the differences between applications of CIA at different spatial scales? What are the specificities of each scale?
- Is there a framework for the use of CI assessments in MSP?
- Are there MSP tools to calculate Cumulative Impacts?

EU examples of inclusion of CIA in MSP or management of the marine environment

Cumulative Impact Assessment is a powerful tool for MSP, as it provides the planners with an overview of the impacts of all human activities in an area. Its use is essential for implementing an Ecosystem-Based Approach to the management of the marine environment, as required by the MSPD (*Directive 2014/89/EU*, 2014).

Several models based on the initial formula (Halpern et al., 2008) have been developed, which have extended the functions of the model or improved the base formula. The inputs vary between tools in the data formats and preparation, but in essence, most of the tools require the spatial distribution of activities and a correspondence between activities and pressures (or the spatial distribution of pressures in the case of SPIA), the spatial distribution of ecosystem components, and a matrix of EC sensitivities to pressures. Examples of tools include:

- The Baltic Marine Environment Protection Commission (HELCOM) uses the SPIA tool to calculate the Baltic Sea Impact Index (Bergström et al., 2019) and notably used it for study cases, on OWF in the Baltic sea and on the impacts of green infrastructures (i.e. combinations of species and habitats with high ecological value or providing important ecosystem services).
- In Sweden, the tool Symphony is used specifically for MSP. It was in particular used to compare two MSP scenarios, one with the actual proposed MSP plans, and one where data was modified to reflect a slightly more ecosystem-based approach.
- The Carpediem tool is developed by the French Biodiversity Office (Quemmerais-Amice et al., 2020). It represents various effects (nonlinear pressure-impact relationship, multiple pressures non-additive effects) by random modifiers and Monte-Carlo analyses, and contains a simple pressure diffusion model.
- A study in the United Kingdom (Lonsdale et al., 2020) proposed a framework and a tool for the implementation of CI assessments into the British MSP process.
- Tools4MSP (Menegon et al., 2018) contains a CIA module. This module also includes non-linear responses to pressures, pressure interactions, pressure diffusion, etc.

Various MSP processes and MSP-related efforts in Europe already include some form of Cumulative Impact Assessment, such as the Swedish national MSP process (Hammar et al., 2020), or the Baltic Marine Environment Protection Commission which monitors the Baltic Sea at the international level (Bergström et al., 2019; Andersen et al., 2015).

- Sweden, an example of CIA use in MSP

In Sweden, the Symphony tool (Hammar et al., 2020) is used for the inclusion of CIA in the MSP process, as the environment-based approach to MSP is considered a crucial component of the process. Symphony is based on the principles first described in a 2008 study on CIA (Halpern et al., 2008) with the cumulative impact score of a cell being the sum of the (weighted) impacts of all pressures on every ecosystem component present in the cell.

For the Symphony tool, tables of the regional human pressures (in the Swedish EEZ) and ecosystem components were compiled. Then, a general list of impacts on ecosystem components from was collected previous scientific works in the North and Baltic Seas, and adapted to local conditions (i.e. only ecosystem components relevant to Swedish waters were selected, and the pressures were adjusted according to Swedish political commitments). Components for which there is a lack of available data or difficulties in spatial representation were removed. For this reason, there are differences in the ecosystem components in Swedish North Sea and Swedish Baltic Sea, due to differences in species distributions.

Symphony also contains a layer on data availability and a layer of average confidence in data quality, both collated from the metadata of the various sources used in the analysis. These layers were provided to the planner to inform them on data confidence.

Symphony contains a scenario component to assess how the implementation of an activity will modify the impacts on the environment. Each plan is included in the GIS as a polygon layer in which each feature being an area where specific uses have priority. Additional pressures are added wherever the prioritized uses would cause them, and existing pressures are removed wherever the uses causing these pressures are declared incompatible in the plan. Precaution areas (in which measures must be taken to avoid causing pressures) were simulated by adapting the pressure matrix accordingly.

To compare two scenarios with this tool, two datasets were used: data representing the MSP plans currently considered in Sweden, and the same data with modifiers representing a slightly different plan with a reinforced consideration of environmental issues in MSP.

- HELCOM and the SPIA tool

The Baltic Marine Environment Protection Commission (HELCOM) is the international organization tasked with (inter alia) monitoring the environmental status of the Baltic Sea. HELCOM participates to a joint MSP working group with the Baltic Sea specific MSP-planning forum Vision And Strategies Around the Baltic Sea (VASAB) to facilitate cooperation in MSP at the scale of the sea basin, in order to establish national maritime spatial plans following the ecosystem-approach with cross-border coherence. To achieve these goals, HELCOM gathers data through mandatory surveys in every signatory country and carries out periodic Holistic Assessments of the Baltic Sea (HOLAS) using various indicators: thematic assessments, social and economic analyses, but also Cumulative Impact Assessment, since the Baltic Sea is affected by multiple pressures caused by a wide range of human activities, both directly at sea and onshore in the Baltic Sea catchment area.

The Cumulative Impact Assessment included in the HOLAS is performed using the Baltic Sea Impact Index (BSII), using the SPIA tool developed by HELCOM for this purpose. The SPIA tool uses grids of pressure intensity and ecosystem component density as its inputs (a grid for each pressure or ecosystem component), as well as a sensitivity matrix.

Through the application of this BSII indicator and further analysis on the results, HELCOM managed to:

- Identify to which types of pressures a majority of the identified impacts could be attributed
- Identify the most widely impacted ecosystem components, and the most impacted areas at sea basin and regional scales
- Demonstrate that pressures caused by human activities are found in the entire Baltic Sea

In their MSP work, HELCOM estimates that the application of a Cumulative Impacts Assessment that integrates the ecosystem components is a better way to approach an ecosystem-based approach than to just focus on generated pressures (HELCOM Secretariat, 2018).

As illustrated by the examples shown above, Cumulative Impacts Assessments can be used at different scales for different purposes in the framework of Maritime Spatial Planning.
At the sea basin level, Cumulative Impacts Assessments can be used for coordinating conservation efforts and the management of activities between multiple countries by identifying areas of the sea basin under heavy pressure or under heavy risk of impact. Additionally, applying a sea basin-wide CI assessment forces the collection and harmonization of necessary environmental data, which in turn also facilitates coordination. However, the example of HELCOM suggests it requires strong political commitment to coordinated MSP in the entire basin.

At the national level, CIA can be used to explore planning scenarios, identify sources of pressures and prioritize actions in the framework of national MSP. It allows for a finer and more accurate approach than sea basin-wide CIA: for instance, data on ecosystem components and their sensitivity to pressures can be refined to better suit local specificities, as was done in the case of Symphony in Sweden. Additionally, CI assessment is one of the tools available for the implementation of an ecosystem-based approach to Maritime Spatial Planning, as it focuses on the interactions between pressures generated by activities and ecosystem components. It can face particular challenges at the boundaries of national EEZ if potential pressures generated outside of the national EEZ can diffuse into the study area. Similarly, at a very local level CIA can identify the most impacted areas in a given space. However, at such a small scale it is even more important to take into consideration the possible diffusion of pressures which sources are located from outside of the study area.

Using CIAs in MSP: Framework and Parameters

As illustrated by the examples above, as well as many other studies and use cases, Cumulative Impacts Assessments can have multiple uses in the framework of the MSP process:

- Evaluate the impact of multiple pressures caused by multiple human activities (Gissi et al., 2017; Heinänen et al., 2013)
- Identify the contributions of multiple pressures to the Cumulative Impacts in an area (e.g. Hammar et al., 2020)
- Provide strategic information to planners (Depellegrin et al., 2017) and allow decision-makers to draft scientifically supported, data-driven plans and avoid opinion-based decisions (Bergström et al., 2019)
- Compare scenarios (Hammar et al., 2020; Vaher et al., 2022)
- Assess the Good Environmental Status of marine habitats (Korpinen et al., 2013) in the framework of the Marine Strategy Framework Directive (MSFD) of the EU (*Directive 2008/56/EC*, 2008), and planning accordingly
- CIA are also one of the tools integrated into the conceptual framework proposed by Borja et al. (2024) to address and reduce the impacts of human pressures on marine environments.

Besides, while CIAs consider the entirety of the pressures exerted on the environment, CIAs must be applied in the framework of the environmental assessment of a single project (*Directive 2014/52/EU*, 2014), in which they serve to determine whether the added pressure of the project will significantly transform the impact, or risk of impact, on the environment. However, some authors suggest including them at a higher strategic level rather than project level (e.g. Gunn and Noble, 2011). However, it is worth mentioning that in recent works, authors have challenged the use of the term “Cumulative Impacts Assessments” (and other synonyms) when describing the impacts of a single project or a single type of developments, and compared it to an Environmental Impact Assessment instead, while bringing concerns about legal matters tied to the mandatory aspects of both assessments in project managements (Lonsdale et al., 2020). The present report is not discussing the differences between the two, and merely underlines that confusion may exist and that definitions are not always clear-cut, as was already observed earlier by Judd et al. (2015).

It is important to note that scientific research on the topic of Cumulative Impacts is quite recent and its significance is still ongoing. A study by Stockbridge et al. (2021) failed to significantly correlate the status of seagrass habitats with cumulative impacts scores in Australia: the authors interpreted this result as caused by incorrect assumptions in the CIA model they applied (such as the distribution of pressures in the grid, the representation of pressures as presence/absence, linearity of response, etc.). On the other hand, Andersen et al. (2015) found statistically significant correlations between biodiversity status and cumulative pressures and impacts calculated with SPIA.

• *Framework for use in MSP*

In 2015, a framework was proposed to organize the application of CI assessments (Judd et al., 2015), which starts by defining the purpose of the assessment (e.g. holistic assessment for maritime spatial planning, or assessing the cumulative impacts of a series of projects, etc.) and builds on this information to provide a series of steps to follow in order to implement a CIA adapted to the needs of the user.

The framework proposed by Judd et al. (2015) goes as such:

1. Defining the “problem”, the scope of the study
2. Listing the pressures and their interactions, the sources of the pressures, and the effects of the pressures on the environment (in which “Effects” is described as the factual transformation of the environment/EC, and “Impact” as a “measurable, detrimental, change to a species or habitat”)
3. Describing the relationships between sources of pressure, pressures, and ecosystem components.
4. Evaluating spatial and temporal scales of pressure effects, evaluating the likelihood of exposure, and assessing the uncertainties and assumptions included in the process.
5. Assessing the importance of cumulative impacts, their causes, and envisioning possible mitigations
6. Providing conclusions based on the original scope of the study.

Similarly, in their effort to establish a common “umbrella” framework for multiple types of environmental assessments, Tamis et al. (2016) estimate that much like other environmental assessments, a CIA usually starts by defining the scope (determining which information and data should be included), then describing the considered activities as well as the environment in which they are taking place. Only then is the impact, or risk of impact, evaluated. The later stages of the assessment include reporting and suggesting mitigation measures when necessary (Tamis et al., 2016). Brignon et al. (2022), in their study developing this framework, precise that the five steps of the assessment are “Goal and Scope definition, Preliminary Analysis, Scenarios definition (Baseline, Project, Alternatives), Scenarios Impact Assessment, Interpretation.” (Brignon et al., 2022). In this definition, the Preliminary Analysis is the selection and prioritization of activities, pressures and ecosystem components.

After comparing the frameworks proposed by these studies, it appears that they have several elements in common, or at least similar successions of steps. In the end, a generic succession of steps to a CIA can be derived from these works:

1. Defining the scope of the assessment, the information and elements required by the planners, the scale and temporal extent of the assessment, etc.
2. In accordance with the scope, defining the scenario, or scenarios, explored by the assessment (current situation, planned situation, alternatives, etc.)
3. Listing the activities, pressures and ecosystem components considered in each scenario
4. Describing the relationships between ecosystem components and pressures, i.e. building sensitivity matrices.
5. Through a first analysis, and if necessary, selecting the most relevant ecosystem components and pressures.

6. Evaluating the Cumulative Impacts of the considered scenarios
7. Interpreting the results.

Finally, a recent study (Piet et al., 2021) tried to improve the methods involved in the framework proposed by Judd et al. (2015) and address several of the challenges presented by CI assessments by combining the "likelihood of exposure and its consequence" and "exposure and effect" approaches. They notably tried to separate Exposure, Effect, and Impact, which can then be quantified using available scientific knowledge, in order to achieve a quantitative assessment independent from expert knowledge. In this model, Exposure is calculated based on spatial and temporal overlap of pressure and EC, likelihood of encounter, magnitude of the pressure and severity of the exposure. Effect is the direct change in the EC caused by the pressure, and Impact, or Risk of Impact, is the likelihood of change of the state of the EC. However, this study relied on a limited number of species to describe largely defined ecosystem components (Birds, Marine mammals and Benthos, where Birds and Mammals were respectively included through 4 and 2 species) as a proof of concept. While the quality of their results is doubtless, such choices were made due to data availability. As such, data availability is an important defining factor for this improved framework.

• *Defining the scope of the study*

In the framework proposed by Judd et al. (2015), the scope of the study was initially only defined as the specific reason to carry out the assessment. However, as was reviewed by participants to the Norsaic webinar organized in June 2024, the scope of the study is one of the main elements that guide the definition of several parameters of the assessment, such as the prioritization of activities and ecosystem components and the adequate planning scale: large scale for strategic steps and fine scale for the operational ones. Additionally, the requirements of the planners, such as the questions or scenarios to review, make an important guideline for the assessment.

The scale and resolution of the study and the data used must be decided beforehand, depending on data availability, objectives, etc. Smaller scales produce finer, more detailed results as long as small scale, high resolution data is available. For instance, recent study found that the estimations of cumulative impacts on reef and sandbank habitats in the Baltic Sea were stronger at small scale, compared to estimations at larger scale (Vaher et al., 2022).

However, technical limitations render smaller scale assessments difficult, or even inadvisable at sea basin level. Additionally, when working at a very local scale, there is a risk of neglecting an important source of pressure located outside of the study area. The bias caused by the lack of integration of species' migrations is also increased. Finally, on the topic of resolution and scale, Piet et al., (2021) recommend that this choice must take into account the desired resolution of the final assessment, while considering also the precision and resolution of each available dataset. In order to avoid losing the meaning of coarse datasets, the choice to lose some resolution in the most detailed datasets may need to be made.

Multiple studies (Judd et al., 2015; Lonsdale et al., 2020) suggest to use three-dimensional location of the pressure and EC (i.e. add the vertical position: is it benthic, pelagic, above the water, or through the entire ecosystem?), as opposed to simply comparing the positions of pressures and ecosystem components "on a map" (i.e. on 2 dimensions). Other approaches (e.g. Quemmerais et al., 2020) include the effects of verticality in the matrices of sensitivity: pelagic species are described as not sensitive to pressures that only apply to the bottom of the sea, and pressures that affect the entire water column are described separately.

• *Preliminary analyses: prioritization and assessment of data availability*

In the application of Cumulative Impacts Assessments, several orientations must be given to the study due to multiple restrictions. As studies rarely have the means, time, budget, or available data to cover the entirety of the interactions, a prioritization of activities, pressures or ecosystem components is often carried out, to determine which should be included in the assessment.

To identify the most relevant elements for the assessment, Tamis et al. (2016) propose the following steps: in a geographical information system (GIS), to implement first the activities which may be considered, then to map the cumulative pressures they cause and to compare with the presence or absence of ecosystem components negatively affected by the pressures. Brignon et al., (2022) developed this framework, specifically in the context of pressures generated by offshore wind farms, basing their work on the notion of “impact pathway”, i.e. the chain of phenomena through which activities are connected to, and affect, ecosystem components.

Starting from the pressures and ecosystem components listed in the scope of the assessment, they performed a screening of the most relevant activities, pressures and receptors by removing any pressures generated by accidental and coincidental means. They also removed pressures that were generated in negligible amounts compared to other sources of the same pressure in the vicinity of the OWF project. Further classification of EC into groups for easier prioritization was carried out.

Then, all relevant pairs of pressure and ecosystem component (that is, every pair where the ecosystem component is affected by the pressure) were ranked through the use of a scoring index determined by expert knowledge. The final score was composed of the multiplication of three grades (each given out of 10 points): a first grade describing the sensitivity of the EC to the pressure, a second reflecting how detailed is the current scientific knowledge on the interaction between the EC and the pressure, and a third grade describing the conservation status of the EC (based on the IUCN assessment of species in France and Europe).

In the end, after minor reworking of pairs and careful consideration of remarks and suggestions, the biology experts were consulted for a final selection of pressures and ecosystem components (Brignon et al., 2022).

One of the main interests of this framework is its inclusion of conservation status. While it does not actually give species with a more endangered conservation status more visibility, or more importance in the calculation of the final impact score, it helps remove abundant species of low concern from the selection. That being said, deliberately selecting a limited number of ecosystem components can be considered contrary to the “spirit”, so to say, of a Cumulative Impacts Assessment.

A recent study (Lonsdale et al., 2020) proposed a slightly different approach in which a database of projects and related activities is created first. This database will allow the program created in this study to associate each project type with a number of activities and related pressures, which in turn are matched with ecosystem components through a table of likelihood of impact that takes into account the 3-dimensional position of the pressure (i.e. vertical position in or above the water column). Additionally, specific buffers are also applied to each activity to determine an area in which it may have an impact. This approach is similar to the other ones described here: the main difference is that standardized project profiles are premade and reused instead of listing activities and pressures involved in each assessment, which simplifies the selection and prioritization of pressures. However, this method carries the assumption that projects of the same type will necessarily cause the same types of pressure. As with any preliminary assumption, this needs to be communicated to the decision-makers along with the results of the assessment.

Uncertainty assessment

In a 2016 study, the authors use Monte-Carlo random simulations (i.e. repetitions of random transformations) representing potentially incorrect model assumptions. In this study, common model assumptions such as the linear response of the ecosystem component to the pressure, or the additive nature of pressures, are randomly replaced with other possible situations (e.g. non-linear response with a threshold, non-additive pressure with only dominant pressure, antagonistic pressures…) in simulations. The authors find a greater variability than expected in the results of Cumulative Impacts Assessments, showing that model assumptions do have an effect on the final results (Stock and Micheli, 2016). Similarly, Quemmerais-Amice et al. (2020) introduce Monte-Carlo simulations in their model to represent potentially incorrect model assumptions.

For this reason, in order to best exploit the results of a CIA in the MSP process, planners need to have an estimation of the reliability of the methodology employed for the assessment. This can be achieved by a clear description of the biases and limits of CI assessments, as was done in the first part of this report, but also by providing a detailed recount of the specific choices and assumptions made during the analysis, such as, for instance, which activities were grouped together or split, and why. It is especially important to provide a clear assessment of results uncertainty caused by the uncertainties in the sensitivity matrix. For this purpose, some CI studies include Confidence Indexes in matrices (e.g. La Rivière et al., 2015; Quemmerais-Amice et al., 2020). For the same reasons, planners require a clear description of the assessment, which assumptions were made, which data was included, etc.

Gissi et al., (2017) identify "locations of uncertainty" in which uncertainty can occur during the application of CI assessments in the context of MSP, including in the stakeholders' interests and priorities. Other decisions that can create uncertainty include, for instance, the choice of model, the choice of tool and the input data. Some of these sources of uncertainty were described in Part 1. Gissi et al., (2017) then propose a framework to carry out an uncertainty assessment jointly with the CI assessment.

On the topic of uncertainties, Vaher et al. (2022) give several recommendations: attributing greater weight to results with smaller margin of error, and reducing large uncertainties with complementary specific studies (preferably in the area of the CIA) whenever the margins of error are too large.

Carrying out an uncertainty assessment, with a matrix of all sources of uncertainty, with the help of the community of experts and stakeholders involved in MSP, benefits the entire MSP process by ensuring the inclusion of diverse sources of knowledge and data. It also provides direct insight into the CI assessment to MSP planners. Additionally, the method proposed in this study identifies the most important sources of uncertainty at every MSP cycle, which allows planners to tackle these before the next cycle. This method also allows the application of the precautionary principle whenever the criteria (based on risk of impact and scientific uncertainty) are met (Gissi et al., 2017).

Challenges and opportunities for use in MSP in the North Sea

Beyond the challenges fundamentally associated with Cumulative Impacts Assessments, described in Part 1, there are challenges specific to the inclusion of CI assessments into MSP in Europe, due to the requirements of international coordination of MSP in Articles 11 and 10[1] (reiterated in articles 6.2. sub e and f) of the MSP Framework Directive (2014/89/EU, 2014), and due to the importance of international coordination in order to achieve MSP goals in general.

However, unlike the Helsinki Commission in the Baltic Sea, there is no formal international, sea-basin scale agreement to sustainably manage the North Sea yet, beyond European Union agreements and obligations and the OSPAR Convention which covers almost the entire North Atlantic. Similarly, there is no international institution tasked with monitoring the environmental status of the (Greater) North Sea beyond EU and OSPAR obligations. Cumulative Impacts in particular are not calculated on a sea basin wide scale, and the question is if there is enough international effort to harmonize policies in this direction. As such, while initiatives, task-specific organisations and projects exist,

[1] 1. Member States shall organise the use of the best available data, and decide how to organise the sharing of information, necessary for maritime spatial plans.

there has been little political movement to establish concrete regulations and objectives at a sea basin scale so far besides the establishment of the OSPAR Convention. Nevertheless, the recent (end 2023) Greater North Sea Basin Initiative adopted by Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden, United Kingdom, and European Commission services, proposes to improve international political and stakeholder cooperation to manage the North Sea maritime space in a sustainable way and restore the environment. The GNSBI will propose a governance framework for its own organisational arrangements respecting the pre-existing legislation of all participating countries, and take into account several "working tracks", one of which is the consideration of Cumulative Impacts. The idea behind this is to assist and support the ongoing work on Cumulative Impact Assessments agreed in the OSPAR 2030 working agenda S07.01[1], with the aim to deliver results for the North Seas (OSPAR regions II and III) faster than 2028.

Also it should be noted that the Joint Programming Initiative (JPI) Oceans has published a handbook on Cumulative Impact Assessments in June 2024 (Melaku Canu et al., 2024) which contains a detailed overview of gaps and challenges in Cumulative Effects Assessment (see Appendix 1), which can help steer and prioritize needed work on CI assessments.

In a more technical standpoint, a CI assessment carried out in the framework of MSP in Europe, and specifically in the North Sea, will need to consider data from multiple countries. Various opportunities will facilitate this effort, such as international (EU) data portals such as EMODNet (the European Marine Observation and Data Network), which can provide aggregated data. Other sources, such as national data, data collected by various specific international groups like the International Council for the Exploration of the Sea (ICES, which mainly focuses on fisheries and the fishing sector), or even data collected in the framework of the Marine Strategy Framework Directive, might also be of use for the completion of Cumulative Impacts Assessments. However, not every country provides all the data relevant for a CIA on such portals. Besides, not all the countries around the North Sea are Member States of the European Union. As cooperation with such countries still needs to be ensured (Article 12, Directive 2014/89/EU, 2014), including relevant data from the United Kingdom and Norway in CI assessments remains essential.

For these reasons, one of the main challenges in carrying out a CI assessment in MSP is the cross-border effects in data, when measurements and formats vary from one country to another (e.g. Bergström et al., 2019). The variations in classification of ecosystem components can exacerbate this effect. For instance, despite the existence of a combined habitat map at a EUNIS level 4 accuracy (EU SeaMap), in a study in 2020, multiple sources of higher precision data on benthic habitats were used to replace EU SeaMap whenever possible for better results. In order to prepare the data, a conversion from one classification type to another was performed on several datasets, a step which took a significant amount of time. It is of note that the relationships between different habitat typologies is not always clear-cut: the output habitat (output classification) definition may *contain* the original habitat in its entirety (e.g. "Dead mattes of *Posidonia oceanica* without epiflora" would be contained into "*P. oceanica* meadows" of the output classification), or the other way around, or else there is incomplete overlap between the two (Quemmerais-Amice et al., 2020).

Besides, modeling the consequences of an MSP plan itself can be difficult. For instance, if a plan forbids an activity (e.g. fishing) in an area, it stands to reason that this activity will shift to a different location, which increases pressures related to this activity in this new area. This redistribution of activities in response to MSP plans can be difficult to predict. Similarly, the indirect effects of pressures (i.e. the long-term consequences on the environment of the impact caused on one specific ecosystem component) are a complex chain of events which are difficult to accurately predict, for

[1] S7.O1 By 2028 OSPAR will further develop methods for the analysis of cumulative effects in the marine ecosystems of the North-East Atlantic, taking into account relevant spatial and temporal information on human activities, pressures, sensitive receptors and habitats, and use the results to inform the establishment of measures and actions to prevent, reduce or otherwise manage impacts.

multiple reasons, such as statistical relevance and growing uncertainty with every step, but also computing power.

Finally, considering the needs of the planners, Lonsdale et al. (2020) consider that CIA outputs in the form of maps of impact are not sufficient for planners' use, as they don't necessarily relate to which activities, current or planned, are causing or predicted to cause large amounts of pressure (and impact). However, multiple tools (e.g. Tools4MSP, SPIA, Carpediem) contain statistics modules which can provide more insight and guide the interpretation of the CIA results.

Conclusion

Despite uncertainties in the accuracy of the models, Cumulative Impacts Assessments are a powerful and much needed tool for maritime spatial planners to organize human activities and reduce or keep human impacts on the environment within the boundaries of Good Environmental Status as: beyond its use as part of a project-based environmental impact study, it has the potential to explore planning scenarios (as was done in Sweden) and to synthesize the results of holistic assessments at sea basin scale (as was done in the Baltic Sea).

However, while the Cumulative Impacts Assesment procedure already has important uses, it has potential for improvement in several places. In general, there is a lack of scientific research in several fields related to Cumulative Impacts Assessments. The relationship between pressure intensity and environmental impact (or rather, the impact on an ecosystem component) have not yet been studied in-depth for all pressures and all environmental components involved in the assessment, leading to the working assumption that the relationship is linear. Similarly, the combination of several pressures, or impacts, is assumed to be cumulative (a sum) rather than synergistic (combination higher than the sum) or antagonistic (combination lower than the sum), which has not been fully explored yet. These two assumptions are major drivers of uncertainty in Cumulative Impacts Assessments, along with the lack of hard evidence in pressure sensitivity of ecosystem components. Finally, the research to demonstrate the representativity of Cumulative Impacts with regard to the status of the environment is still ongoing.

The application of Cumulative Impacts Assessment to Maritime Spatial Planning faces various challenges. At a local scale, the non-homogeneous classification of habitats in all mappings (for instance using EUNIS classification) means that in order to use high-precision data, a matching of classifications must be completed. Besides, in an environment as open as the sea, only focusing on the pressures exerted in a single area can mask pressures diffused from a further area. In general, pressure diffusion is not always well handled by Cumulative Impacts models. In the North Sea, beyond the issues of trans-national data availability and homogenization, there is not yet an international political agreement at the scale of the sea basin to tackle the issue of environmental protection, like there is in the Baltic Sea with the Helsinki Commission (HELCOM).

However, there are many opportunities for the use of Cumulative Impacts Assessment in Maritime Spatial Planning. For instance, correspondences between various habitat classifications (e.g. CORINE and EUNIS) have already been published. Various environmental data sources (e.g. EU SeaMap for habitats, Marine Strategy Framework Directive data) are gathered at the European level (including the European Union, but also United Kingdom and Norway) and data portals such as EMODNet provide a large part of the data necessary for the calculation of Cumulative Impacts at a sea basin scale. The Greater North Sea Basin Initiative, established in November 2023 by the nine countries bordering the Greater North Seas (Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden, United Kingdom) and the European Commission services, aims to connect various actors, planners, organisations, etc. across the nine countries to better align spatial planning, environment management, development processes etc. in order to protect and restore the marine ecosystems. Notably, Cumulative Impacts are one of the working tracks of the initiative.

In any case, while such opportunities make it possible to include Cumulative Impacts Assessment into Maritime Spatial Planning, in order to obtain the best results, the scope and purpose of the assessment need to be defined first, along with the spatial and temporal extent, as detailed in the synthetic framework described in this report. The planning scenarios to be studied can then be derived from the scope, which also allows the surveyors to define a list of prioritized activities and ecosystem components, which can then be selected based on relevance or data availability.

Finally, during the assessment, it is essential for studies officers performing the assessment to keep in mind which information is essential for the planners beyond the Cumulative Impact scores of each grid cell, such as the scenarios, data availability, assumptions and weights, and also the uncertainty assessment.

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Appendix 1

Table of Detailed overview of gaps and challenges in Cumulative Effects Assessment, from Melaku Canu et al., 2024

Data Gaps and Inconsistencies	Limited availability and quality of data on various pressures and ecological components can hinder accurate assessments. Poor or absent knowledge on some pressures may increase uncertainty on the assessment.
Tools to detect the Spatial and Temporal Variability	Marine systems exhibit considerable spatial and temporal variability, making it challenging to capture the full range of ecological responses and pressures. The analysis should be conducted at an appropriate spatial and temporal resolution, according to the resolution of the pressures and responses.
Interactions and Synergies	Cumulative effects assessments often assume additive pressure effects, but interactions and synergies between different pressures can lead to non-linear and unexpected outcomes. Most of the outcomes are poorly known, and ecological studies and more data are needed to assess them.
Lack of Baseline Data	Incomplete or missing baseline data for certain pressures and ecological components make it difficult to establish reference conditions for assessing changes. Data of pristine conditions are needed to assess the response to the alteration.
Sensitivity Weights and Expert Judgment	Reliance on sensitivity weights derived from expert judgment introduces subjectivity and uncertainty, especially when the understanding of ecosystem responses is incomplete.
Non-linear Ecological Responses	The assumption of linear ecological responses to pressure may not hold true, as ecosystems often exhibit non-linear responses that may include thresholds and irreversible changes.
Spatial and Temporal Scales Mismatch	Mismatches in the scales of pressure data and ecological response data can lead to inaccurate assessments, particularly when pressures and ecological features operate at different scales.
Cascading Effects	Cumulative effects assessments may struggle to capture cascading effects through trophic levels and ecosystem components, resulting in an underestimation of overall impacts.
Model Complexity and Uncertainty	Complex ecological models used in cumulative effects assessments introduce uncertainties, and the sensitivity of results to model parameters may be challenging to quantify.
Ecosystem Connectivity	Many marine ecosystems are interconnected, and pressures in one area may have far-reaching effects in distant areas, making it challenging to attribute impacts to specific sources.
Climate Change Interactions	The influence of climate change on marine systems introduces additional complexity, with changing ocean temperatures, acidification, and other climate-related factors interacting with existing pressures.
Management and Policy Integration	Integration of cumulative effects assessments into marine management and policy frameworks is often challenging due to the need for interdisciplinary collaboration and coordination among various stakeholders.
Public Engagement and Communication	Communicating complex cumulative effects assessments to the public and decision-makers can be challenging, requiring effective strategies to convey uncertainties and potential impacts.

(Source: Table 2 in Melaku Canu, D., Leiknes, Ø., Unnuk, A., Rumes, B., Zeppilli, D., Sarrazin, J., Canesi, L., Schückel, U., Fianchini, M., Korme, I., 2024. A common handbook: Cumulative effects assessment in the marine environment. JPI Oceans: Brussels. 38 pp, https://dx.doi.org/10.48470/77)

Appendix 2

Assessment of a few existing Cumulative Impacts Assessment tools

Table A2.1 -

Common CEA weakness	Carpediem	SPIA
Integration of indirect impacts (e.g. if a seagrass meadow is destroyed, it may affect herbivorous fish)	Not integrated natively Could be considered either by building custom matrices or by updating the code, both would necessitate work	Not integrated; would be difficult to integrate
Integration of trophic chains and population dynamics	Not integrated natively	Not integrated; would be difficult to integrate without extensive reworking of the tool
Endangered and rare ecosystems	Not integrated, adding it would require some work	Not integrated. Could be easily added by adding a weighting system.
Missing data	Depending on which data is missing: - Spatial distributions: thresholds of representativity can be set (if 15 % of a cell only have data, the cell can be dismissed) - Sensitivities: Different scenarios for comparison/combination of data (pessimistic, optimistic)	Not considered. Integration depends solely on the preparation work done before using the tool.
Climate change effects	Can be added as a pressure, sensitivities not included natively	Can be added as a pressure, sensitivities not included natively
Climate change hotspots and refugia	Not integrated	Not integrated
Assumption of constantly linear relationship between pressure and impact (i.e. little pressure = little impact, which is probably not often the case)	An option to simulate the variability of the impact caused by this effect: it works by attributing other types of relationships randomly (and comparing the outcomes of 1000+ simulations). Note: the simulation demonstrates which variability can be expected, it can't "deduce" the actual relationship	Not included.

Table A2.2 -

Tool	Advantages	Points to develop
SPIA	- Code in Python clear and easy to adapt and edit - The Python code was integrated into an ArcGIS toolbox - Possible to adjust the details of the analysis (input data, matrices) - Calculates several indices: Cumulative Impacts, Sum of pressures, ecological value, ecosystem services.	- Users must first prepare raster files for each pressure and ecosystem component to start the analysis (SPIA does not calculate pressures derived from activities, users must do that conversion themselves)
Carpe Diem	- Complete and advanced - Possible to adjust the details of the analysis (input data, matrices) - Code in R with some PostgreSQL, clear and accessible	- Complex code - Not user-friendly or intuitive, cannot be used by a non-expert

	- Includes various statistical analyses and graphs - Converts activities into generated pressures, allows users to include directly measured pressures (e.g. measured continuous noise)	
Symphony	- Scenario comparison in MSP - Tehcnical methodology specifically oriented for MSP use	- Complicated code in Java and Shell, many scripts referencing each other, difficult to understand, very difficult to adapt or edit - Architecture adapted for a webpage use, not on a personal computer