A Toolset to Estimate the Effects of Human Activities in Maritime Spatial Planning

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Abstract. Marine space is overall under increasing pressures from human activities. Traditionally, the activities taken place in oceans and seas were related to fishery and transport of goods and people. Today, offshore energy production – oil, gas, and wind, aquaculture, and sea-based tourism are important contributors to the global economy. This creates competition and conflicts between various uses and requires an overall regulation and planning. Maritime activities generate pressures on the marine ecosystems, and in many areas severe impacts can be observed. Maritime spatial planning is seen as an instrument to manage the seas and oceans in a more sustainable way, but information and tools are needed. The current paper describes a tool to assess the cumulative impacts of maritime activities on the marine ecosystems combined with a tool to assess the conflicts and synergies between these activities.

Keywords: Maritime spatial planning · Maritime activities · Cumulative impact assessment · Conflict and synergies · Multi-use · Decision-support tools

1 Introduction

In the Blue Growth initiative from 2012 [1], the European Commission (EC) identifies a potential for further job-creation and innovative technology development in the sea area, like new offshore renewable energy technologies, sustainable aquaculture, maritime coastal and cruise tourism, marine mineral resources, and biotechnology utilising marine organisms. With expanding human uses at sea, the objective of EU maritime spatial planning (MSP) to promote sustainable coexistence between marine uses becomes an increasingly important task. On one hand, human activities are not always compatible with the needs of nature, and may lead to several threats like eutrophication, habitat damage, and proliferation of invasive species, especially if they are more spatially-temporally concentrated [2]. On the other hand, marine activities in close spatial-temporal proximity and with an area interest overlapping with many other marine activities might conflict with each other to a high degree, if they are not located in a manner that increase use-use synergies and decrease use-use conflicts [3].

Thus, to assess potential locations for new maritime activities, both use-use interactions and use-environment interactions need to be explored and the costs and benefits in broad terms balanced against each other.

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In the sea, everything is connected. Fish, nutrients, and hazardous substances move from one location to another without barriers. The marine space is characterised not only by a three-dimensional water column supporting multi-functional use (different uses at the same location but at different depths) but is strongly four-dimensional (seasonal and diurnal cycles appears in many forms in the marine environment). Hence, Maritime Spatial Planning (MSP) needs to be based on this context different from terrestrial planning which traditionally only needs to address two dimensions – the earth surface. Accordingly, the EC launched a new directive on maritime spatial planning which entered into force in 2014. It requires its member states to establish maritime spatial plans by 2021 [4].

According to the MSP Directive, the member states are required to follow an ecosystem-based and thus holistic approach to marine spatial planning. Such an approach can also be linked to the UN Sustainable Development Goals. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDG), and they entered into force by 1st January 2016[1]. Number 14 of the 17 SDG's concerns the *conservation and sustainable use of the oceans, seas and maritime resources*. Careful management and regulation of the global marine resources is a key element in obtaining a sustainable future. To make this operational, a set of ten targets for Goal 14 are defined with deadlines. Target 14.2 urges EU to already by 2020 sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, strengthening their resilience, and act for their restoration in order to achieve healthy and productive oceans.

In order to follow an ecosystem-based approach and avoid too much pressures on the environment, impacts from maritime human activities and their options for co-location need to be investigated as part of MSP. For this purpose, open-source, free spatial decision support tools are needed. Therefore, the aim of the current research has been to develop a comprehensive package of spatial tools to assess the environmental impacts and use-use interactions of societal activities under different maritime spatial planning proposals. First, a description will be given of the background and theory behind cumulative environmental impact assessment and use-use interactions. Next, follows the design and implementation of the new toolbox, and some examples of its use. The paper ends with a discussion of the proposed approach to tools targeted towards cumulative impacts assessment on marine ecosystems from anthropogenic activities and targeted towards co-location.

2 Theory

Ecosystem-based maritime spatial planning (MSP) is a complicated process comprising several steps - including identification of the planning needs, pre-planning, and stakeholder engagement, defining and analysing existing and future conditions, preparing and approving the spatial management plan, implementation of the plan, and finally, monitoring and evaluating the performance [5]. MSP is characterised by being a

[1] https://www.un.org/sustainabledevelopment/development-agenda/.

continuing and iterative process adapting over time to adapt to new realities and visions. Practical tools supporting MSP and supporting cross-border coordination and participation are still limited, and spatial tools should always be designed to be used at specific stages of the MSP process, and they are more likely to be used if they have a clear, task-limited functionality, and if their methods are transparent, and they are open-source [6]. The tools in this article, have been designed with such guidelines in mind.

An ecosystem-oriented maritime spatial planning support tool needs to respond to a number of challenges to integrated planning and management, including to consider effects on the ecosystems of various and/or alternative economic/recreational/cultural activities in the maritime space – and to communicate benefits and trade-offs of different alternatives with stakeholders in the planning phases. This requires a framework for assessment of effects that can: a) integrate societal effects of multiple human activities, b) integrate the impacts of spatially explicit maritime human activities on multiple ecosystem services related to the sea and coastal ecosystems, c) address ecosystem services related to waters, seabed, sub-seabed, as well as to coastal ecosystem services, d) point out economic and social impacts related to involved and affected stakeholders, e) ensure conservation of biologically and ecologically sensitive marine areas, and f) support governance of maritime activities at various governance levels and between horizontal authorities and stakeholders. A large number of impact assessment frameworks for terrestrial activities exist along lines of Environmental Impact Assessment (EIA) [7], Strategic Environmental Assessment (SEA) [8] or sustainable development criteria [9]. At the top level of many of the frameworks you find the driving forces representing different kinds of needs for humans [10]. Examples are more basic needs e.g. for food, for water, for shelter, and more advanced needs e.g. for transport, for culture, etc. The number of people, their age structure, and their education levels are important factors, affecting the total strength of each driver. The driving forces lead to human activities like food production (e.g. fishery) or transportation (e.g. sailing). These human activities exert pressures on the environment – often trough emission of substances, noise, radiation, etc. The pressures subsequently change the state of the environment e.g. reduce biodiversity in the seas and oceans or cause fewer fish due to overfishing. If the impacts on the ecosystems go beyond what is acceptable by the societies, some response is required in order to reduce the pressures on the ecosystems. This may be done by regulation e.g. through higher taxation of the human activities being the reason to the adverse effects, or by maritime spatial planning dictating what is allowed and what is forbidden in specific sea areas.

2.1 Assessing the Effects on the Marine Environment

Although the aim of the MSP Directive from 2014 is to facilitate the Blue Growth vision, it is emphasized that this should be done without harming the environment and the ecosystems providing services for maritime activities. Prior to the MSP Directive, the European Union back in 2008 adopted the Marine Strategy Framework Directive (MSFD) [11]. It marked an important step forward in the EU marine environmental policy. MSFD was the first legal framework, which specifically aimed at protecting and preserving the marine environment by setting rather precise criteria and methodological standards for the implementation of the Directive. To better link the ecosystems and the

anthropogenic pressures the Annex III MSFD Directive was amended in 2017 [12]. Thus, proper regulation of maritime activities is a prerequisite for reaching the goals on Good Environmental Status of the Ecosystems.

Like the MSP Directive, the MSFD directive requires the EU member states sharing the same marine region (i.e., Baltic Sea, and the North Sea) to collaborate to develop marine strategies and plans in order to ensure coherence in the environmental assessments, setting environmental targets, and monitoring efforts. The regional platforms for developing coherent marine strategies are the Regional Sea Conventions[2], which are mandatory regional coordination structures under the UN Environment Programme. Furthermore, the MSFD states that the marine strategies shall apply an ecosystem-based approach to the management of human activities.

Achieving a Good Environmental Status in the European marine regions require appropriate planning decisions which furthermore requires the comprehensive knowledge of the impacts induced by different anthropogenic activities and natural changes. Therefore, methods and techniques are required to efficiently estimate the cumulative impacts from multiple and interactive human activities and their pressures enabling planners and decision makers to apply science-based information to assess different efforts in marine management by using scenarios.

Most often the impacts on marine ecosystems is not only the result of a single human activity but of cumulative effects of several human activities.

The concept of cumulative impact assessment (CIA) on the marine environments was originally defined by Halpern et al. [13] and has since inspired further research. Halpern et al. [13] developed an index to assess the cumulative impact on the marine environment at a rather high spatial resolution in a global perspective.

According to Halpern et al. [13], cumulative impacts are determined from three components: maps of pressures from different human activities; maps over different ecosystems, and a matrix describing the sensitivity of each ecosystem to each pressure. Thus, the cumulative impact (I_a) on the environment within a square pixel can be estimated by multiplying the values for each pressure (P) with the values for each ecosystem component (E) and its specific sensitivity μ. Finally, these impacts are summarised over all pressures and ecosystems:

$$I_a = \sum_{i=1}^{n} \sum_{j=1}^{m} P_i \times E_j \times \mu_{i,j} \tag{1}$$

Here n is the number of pressure layers and m is the number of ecosystems. The sensitivity variable μ represents the sensitivity of ecosystem j to pressure i and are most often derived by expert judgment in a rather complicated process – see for example the way this is done in HELCOM's assessment of the cumulative impacts in the Baltic Sea [14].

[2] https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/working-regional-seas/regional-seas-programmes/regional-seas.

2.2 Use-Use Conflicts and Synergies

For co-location options to be considered in MSP, it is important to supplement a cumulative environmental impact focus with knowledge about use-use interactions. Therefore, one needs to know the types of interactions that can take place between different marine human activities. The co-location concept highlights the situations with positive use-use links where marine uses successfully can be located close to each other without too high a cumulative environmental impact [15]. However, marine uses can both experience negative and positive links with each other, and often they experience negative links. If one marine activity benefits from an interaction with another marine activity, it is not necessarily a synergic relation. To be a synergic interaction, no marine use should experience overall negative impacts due to that interaction. That conclusion can be deduced from the scale by Klinger et al. [3] that describes use-use interactions as a spectrum from *competition* (negative impacts to all interacting activities), *antagonism* (benefits to one activity on behalf of another activity), *amensalism* (negative impacts to one interacting activity), *commensalism* (positive impacts to one interacting activity without harmfully affecting other activities) to *mutualism* (benefits to all marine activities). Thus, only commensalism and mutualism constitute synergies, since antagonism, even though it provides benefits to one marine use, is not without harmful impacts. An antagonistic relation could be when either fishers or sand extraction ships exclude the other from a fish- and sand-rich seamount [3].

Four types of spatial-temporal links have been found to exist individually or in groups for closely located marine activities: location links, environmental links, technical links, and user attraction links. Location links are connections between the extents and duration of marine activities. The spatial-temporal attributes of marine uses such as their horizontal and vertical location, and whether they are fixed, mobile and/or seasonal influence location links. Environmental links are when marine activities are positively or negatively affected by environmental processes or environmental by-products from other marine activities. Technical links are links that concern safety zones, shared infrastructure and/or shared tools. User attraction links are when nearby marine activities affect the user attraction of other marine activities [15].

Not much knowledge is available about how synergic different marine activity combinations are. Many studies only examine the compatibility degree between marine activities, meaning their ability to be located together [15], without diving into the actual benefits that co-location can provide to marine activities. Studies that only consider compatibility include Kannen [16], Baltic SCOPE [17], Plan Bothnia [18], and the UNESCO-step-by-step MSP guide [5]. However, the Horizon 2020 Multi-Use in European Seas (MUSES) project is an exception, since it has put a focus on opportunities, advantages, and challenges for combining activities into multi-use in Europe. MUSES should thus be acknowledged for its systematic research on promising multi-use constellations in Europe (https://muses-project.com). To synthesis all knowledge about potential use-use conflicts and synergies into a table, knowledge from all the previously mentioned compatibility studies, the MUSES project [19], as well as findings from the PartiSEApate project [20] and the AquaSpace project [21] have been systematically gathered. The information has been used to estimate conflict-synergy

degrees for pairwise use-use combinations in a matrix on a scale from −3 to 3. The scores are not actual scores estimated by experts but are based on ordering the different marine use combinations after their compatibility degree, their number of potential conflicts and synergies, and their multi-use potentials according to existing literature. When use-use synergy-conflict knowledge improves over time as current best knowledge gets updated, the categorisation of individual pairwise combinations might change. However, a systematic, matrix-based, and iterative approach to existing knowledge can help planners visualise current known trends.

By providing the matrix with a spatial dimension by summing up potential conflict-synergy scores on maps based on the distribution of maritime activities, it is possible to gain an overview over spatial patterns of potential use-use conflicts and synergies. Such maps are useful in MSP processes to enable co-location where use-use synergies are highest and use-use conflicts lowest, and to separate very conflicting marine uses. Combined with the cumulative environmental impact approach, co-location can be decided to take place only when the cumulated negative impacts on the environment is not too high.

For a given spatial distribution of marine activities, the total conflict-synergy score (S) within a square pixel can be estimated by multiplying the presence of each marine activity category (A_1) with the presence of each different marine activity category ($A_{2,\ A1 \neq A2}$) and with the specific conflict-synergy score input ($s_{A1,\ A2}$) belonging to each activity pair, and then by summarizing these multiplications for all unordered, unique pairwise activity combinations:

$$S = \sum_{A_1=1}^{n} \sum_{A_2=A_1+1}^{n} A_1 \times A_2 \times s_{A_1,A_2} \tag{2}$$

Here, n is the number of unique marine human activity combinations. The pairwise activity conflict-synergy input score is derived from the previously mentioned conflict-synergy matrix. The formula and the conflict-synergy matrix inputs are further introduced in [22].

3 Implementation

During the last few years several tools have been developed to calculate the cumulative impact on ecosystems and assessing conflicts between different human activities in the marine space. They are all based on the principles on cumulative impact assessment as described by Halpern et al. [13] but typically adding some additional features. The most well-known software packages for cumulative impact assessments are EcoImpactMapper [23], Tools4MSP [24], Symphony [25], and MYTILUS [26] with different advantages and disadvantages, and although most of the tools are freely available they cannot be considered as traditional software with user guides, and other kinds of support. Rather, they are all developed under research and development projects, with limited further development after project ends. However, the source code is typically available for further development. The current research has used the MYTILUS software as a basic container.

The overall aim of developing this new extended toolbox is to provide a more comprehensive set of tools to assess the effects of maritime activities on the ecosystems – but also to assess potential conflicts and synergies between human activities. Maritime spatial planning aims to organise the use of the marine space, considering as well the interactions among human uses (e.g., fisheries, aquaculture, shipping, tourism, renewable energy production), for which reason it is a needed tool improvement to add options to also explore potential use-use interactions, based on the inputted use-use synergy-conflict score matrix presented in Sect. 2.2.

3.1 Systems Design

The modelling system applies native ESRI ASCII raster data facilitating an easier exchange of data between MYTILUS and GIS software like ArcGIS and QGIS. In this way, MYTILUS can be used as a decision-support tool while doing data preparation and advanced visualisation in general purpose GIS-packages. The cumulative impact tool contains several options to assess the impacts on the ecosystems [26]. The conflict-synergy score tool contains several options to assess areas with overall high/low potential synergies and conflicts. The calculations are carried out according to Eq. (2) with the options to select all activities or selected sets of activities, the latter to provide more detailed information of the potential conflicts and synergies from just one activity. This is particularly relevant when looking for an appropriate synergic or neutral area for locating new activities with known high conflict potential that needs to be minimised. The user interface is illustrated on Fig. 1.

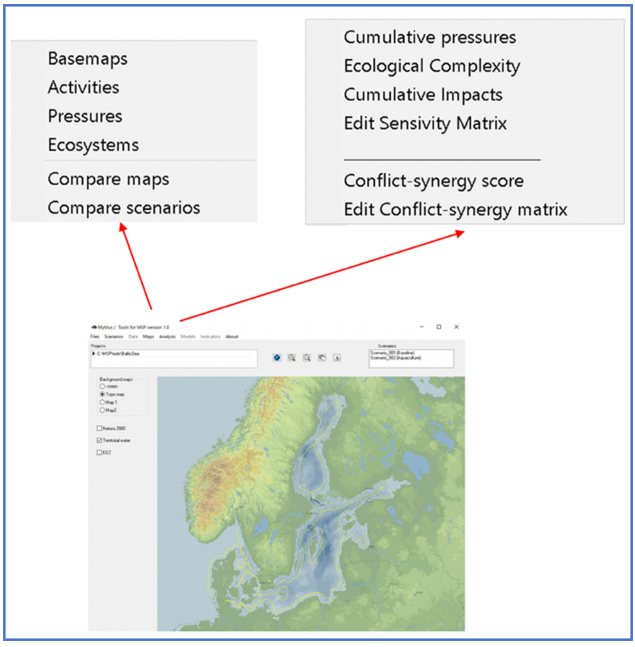


Fig. 1. MYTILUS user interface.

4 Examples from the Baltic Sea

The MYTILUS toolbox is being tested in the Baltic Sea, where HELCOM[3] provides freely available Baltic Sea wide data on human activities, pressures, and ecosystems. The activity layers from the HELCOM portal used for conflict-synergy analysis are transformed into a binary raster-format where the value 1 indicates that the specific activity exist in a raster cell. Otherwise the value is 0. The pressure layers available from HELCOM's data portal are used for their own assessment of the Baltic Sea Environment and follows the pressure layers mentioned in the Marine Strategy Framework Directive (MSFD) [11]. The following examples illustrate the flexibility and analytical capacity of the MYTILUS toolset. Figure 2 visualises the spatial distribution of the cumulative impact from all pressures on all ecosystems. The maximum cumulative impacts are observed in the South-Western Baltic Sea and along the Southern coast of Finland and around Stockholm. In addition, the user can also select a single pressure or groups of pressure layers and combine with a single ecosystem or groups of ecosystems thus getting possibilities for better understanding cause-effect relationships. Finally, the user can calculate the max-pressure index – i.e. the pressure in each grid cell providing the highest impact (Fig. 3). This is important in identifying needed actions regarding reducing pressures from human activities in certain areas. Such reduction strategies have to be considered in maritime spatial plans. Figure 3 illustrates that the heavy impacts in South-Western Baltic Sea as well as along the Southern coast of Finland are mainly due to phosphorus emissions.

With the MYTILUS extension in the form of the conflict-synergy score tool, it is possible to compare cumulative environmental impact maps with total synergy-conflict score maps. Figure 4 visualises how a user can zoom in on the same area for both tool outputs to compare the outputs. Specifically, the Southern Baltic Sea is used in Fig. 4 as demonstration. From a visual comparison, it is apparent that many of the highly conflicting red areas of the Southern Baltic Sea conflict-synergy map do not overlap with highly pressured red areas of the Southern Baltic Sea cumulative impact map. This illustrates that the two map results are not redundant. Some exceptions where both map outputs experience high total pressures and conflicts are at the Eastern coast of the island of Bornholm, at the Eastern coast of the island of Gotland, and in the Northern end of the inner Danish waters. In these areas, ecosystems are extra pressured at the same time as the marine activities in these areas might experience high competition and negative impacts from other activities. In the Bothnian bay, on the other hand, many areas with less environmental pressure and higher total synergies exist, indicating less pressured and less conflicting areas. However, it is important to emphasize that the green-coloured areas in the two maps are not necessarily environmentally and socioeconomically thriving areas. Smaller environmental impacts are still negative impacts in an absolute sense, and green-coloured total synergy areas might still

[3] HELCOM (Helsinki Convention).

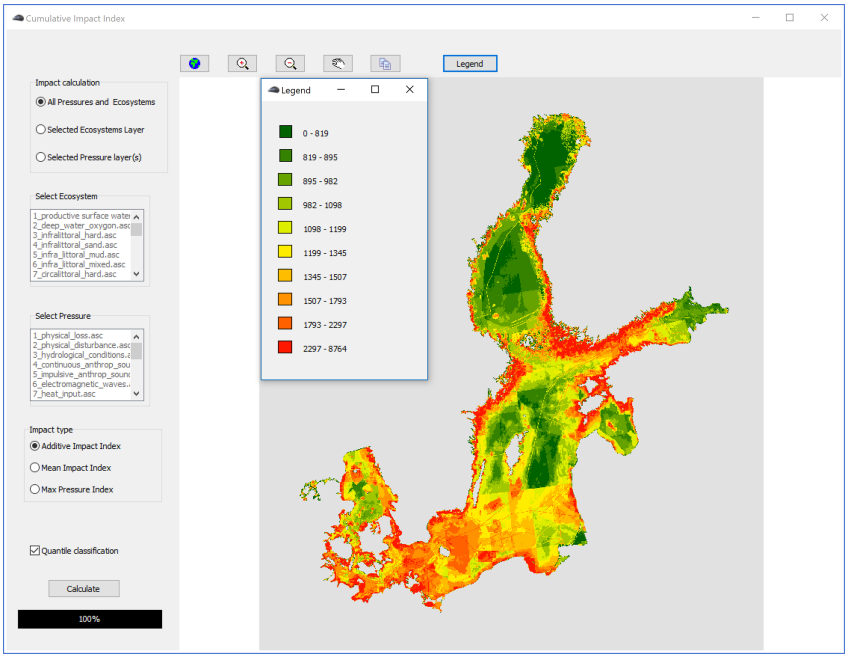


Fig. 2. Cumulative impact assessment from all pressures on all ecosystems

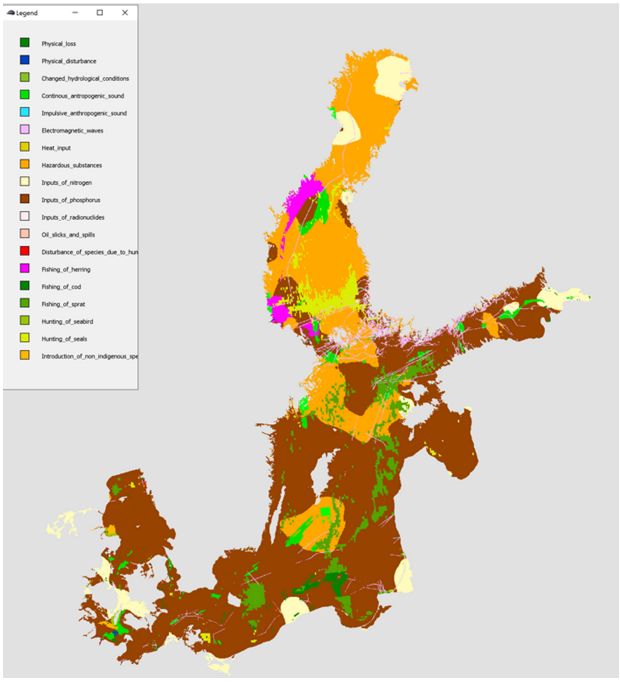


Fig. 3. Identifying each pressure that provides the maximum local impact

experience many conflicts (just more synergies than conflicts). However, the combination of these maps does provide an overall overview at a rough, general level over where areas exist that need more precaution and where areas exist that might contain co-location potentials.

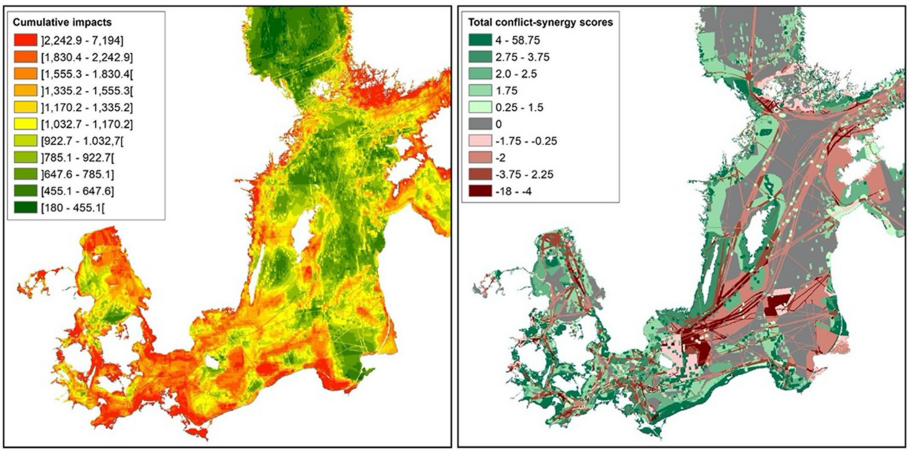


Fig. 4. Comparing the cumulative impact on the marine environment (left map) with potential conflict-synergies between human activities (right map).

Used in scenario analysis, the comparison can provide a means to spatially visualise areas where ecosystems might become endangered, areas where competition/conflict might arise, and areas where synergies might cause potential for co-location; all important factors to compare different scenarios.

5 Discussion

Since the adoption of the EU Blue Growth initiative, a growing interest of investing in maritime activities has emerged. Therefore, a new approach to allocate space to various maritime activities was needed. The Maritime Spatial Planning Directive by the European Union in 2014 [4] was a first step in this process. Herein, there is a requirement to adopt an ecosystem-based approach. Particularly, the assessment of cumulative impacts on global marine waters by Halpern et al. [13] has initiated an academic interest in developing tools to carry out the assessments. The tools being developed like EcoImpactMapper [23], Tools4MSP [24], Symphony [25], and MYTILUS [26] are all fine examples on tools to support the ecological assessment in the MSP process. However, except MYTILUS and Tools4MSP all of them have until now only considered the impacts on the ecosystems and not the interactions between human activities. Such interactions are important to consider in a world where marine space is increasingly becoming sparser – especially in order to assess the possibility of multi-use.

By combining conflicts and synergies between human activities with impacts on the ecosystem from the same activities into one toolbox such as done in this MYTILUS update, marine spatial planners have the possibility to generate maps illustrating:

- The overall impact on the ecosystems from all (or selected) activities and pressures on all ecosystems within the study area
- The overall potential conflict-synergy) score between all (or selected) activities for the same area
- Options to compare the two maps within the same tool in order identify areas with a) high environmental impact and high conflict; b) high environmental impact and synergy; c) low environmental impact and high conflict; d) high environmental impact and synergy;

The main challenges with such tools are the quality of the data and particularly the values in the sensitivity matrix for the cumulative impact tool and in the conflict-synergy matrix related to the conflict-synergy score tool. The values used in the ecological sensitivity matrix are typically science-based and created by ecology experts, while the values in the conflict-synergy matrix can be assessed by literature reviews or through interviews with spatial planners and relevant stakeholders representing the various activities. MYTILUS provides input schemes for easily changing values for the sensitivity matrix as well as for the conflict-synergy matrix. Especially, it makes sense to discuss and potentially improve the values in the conflict-synergy matrix – partly because they are not evidence-based in the same way as the sensitivity matrix (it is a relatively new focus area), and partly because the technological development may change the conflict or synergy potential between various human activities in marine space. Technological advances may also have an effect on the impact of maritime activities on the ecosystems – for example by introducing new kinds of feed in fish farms, and therefore all the score inputs should be updated when best available knowledge is updated. The MSP Directive requires all marine plans to be based on best available knowledge.

The concerns about uncertainty may be the reason why only very few maritime authorities have used cumulative impact assessment of the ecosystems or conflict-synergy analysis in the preparations of their maritime spatial plans. One example regarding cumulative impact assessment is the Swedish Agency for Marine and Water management, who have carried out extensive analysis of the cumulative impacts on the ecosystem of the marine activities [25]. Another reason may be the lack of appropriate and up-to-date data and information. One approach could be to apply a distributed database structure instead of the centralised database currently being applied for example by HELCOM. The Baltic Lines project developed a prototype for such a distributed database solution for the Baltic Sea [28].

6 Conclusion

Maritime spatial planning (MSP) is a rather new discipline, which in most European countries mainly has received attention due to the adoption of the MSP Directive in 2014. Use of marine space has until recently mainly been regulated by various sector

plans without mutual coordination. The new maritime spatial plans have to be implemented before 2021, and they have to allocate marine space without harming the ecosystems and avoiding conflicts between uses. This require up-to-date information and tools to assess the current status as well as the future situation whether or not the marine space will be used according to the plan.

Recently, several tools have been developed to estimate the cumulative impacts from various anthropogenic pressures on the ecosystems. Various tools like EcoImpactMapper, Tools4MSP, and MYTILUS are good examples of tools for cumulative impact assessments. However, human activities do not only provide pressures on ecosystems, they also interact with other human activities – generating conflicts or synergies. The current paper has described the further development of the MYTILUS toolset by adding capacity to carry out conflict-synergy analysis, thus facilitating the allocation of activities to marine space considering not only the impact on the ecosystems but also how they interact with other activities. Hereby, the decision-making processes can be based on a more holistic approach and provide support for discussing multi-use options of marine space. It is expected that the updated MYTILUS toolset can contribute to more knowledge-based maritime spatial plans among the EU Member States, as well as contribute to the process of aiming to reach the targets set by the UN SDG goal 14 on the marine environment.

The next step in the development of MYTILUS will be to address the concerns regarding uncertainty by introducing uncertainty maps in order to support the decision-makers in the discussion with stakeholders, who often raise question about the validity of the analysis and modelling results.

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