SPACEA: A Custom-Made GIS Toolbox for Basic Marine Spatial Planning Analyses

Miriam von Thenen[1,2(✉)], Henning Sten Hansen[2], and Kerstin S. Schiele[1]

[1] Leibniz Institute for Baltic Sea Research Warnemünde, Seestraße 15, 18119 Rostock, Germany
{miriam.thenen, kerstin.schiele}@io-warnemuende.de
[2] Aalborg University, A. C. Meyers Vænge 15, 2450 Copenhagen, Denmark
hsh@plan.aau.dk

Abstract. Marine Spatial Planning (MSP) requires the analysis of the spatial distribution of marine uses and environmental conditions. Such analyses can be carried out with GIS, but standard GIS programs do not feature a toolbox that combines the most needed functionalities for such analyses. The SPACEA toolbox presented here was created to bundle and adapt existing functionalities in one toolbox. SPACEA consists of several script tools that have been designed to be user-friendly and applicable to different analyses for MSP. This includes the processing of different input layers with regard to marine uses and environmental conditions. The main functionalities of SPACEA are exemplified in a fictional case study in the Baltic Sea, where the tools are applied to find potentially suitable areas for mussel farming. The tools feature a user-friendly interface and more experienced users may also use the provided sample codes to run it from the python window or as a stand-alone script. As such, the tools can be applied by users with different levels of GIS knowledge and experience.

Keywords: Marine Spatial Planning · GIS analyses · Toolbox

1 Introduction

Marine Spatial Planning (MSP) is a public process to analyze and allocate the distribution of marine uses over space and time with the aim of achieving economic, social and ecological objectives [1]. MSP was originally developed as a nature conservation measure in the Great Barrier Reef Marine Park in the 1970/80s, which established different zones for marine uses, resource exploitation, and nature conservation to avoid both user-user and user-environment conflicts [2]. Nowadays, MPS is understood as an iterating process, which includes different steps, such as pre-planning, organization of stakeholder involvement, defining and analyzing existing as well as future conditions, drafting and approving the spatial plan, and implementation, evaluation, and adaptation [1]. In Europe, the establishment of maritime spatial plans until 2021 is a legal requirement for all Member States adjacent to the sea [3].

Spatial data analyses for MSP include the mapping of existing marine uses as well as the physical, chemical and biological features in a planning area. The analysis of

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12252, pp. 394–404, 2020.
https://doi.org/10.1007/978-3-030-58811-3_28

future conditions includes the prediction of changes in the marine environment and the trends for marine uses [4]. Both traditional and emerging marine uses are expected to increase in the future due to a shift to blue growth and blue economy [5]. Such developments in the seas and oceans will increase the pressure on marine ecosystems and thus require careful planning to ensure sustainable development. This includes the selection of appropriate sites for different marine uses. Site selection for marine uses should take into account the spatial distribution of other uses, environmental conditions on which the use may depend, and sensitive or threatened habitats. In an MSP process, it can be decided that such vulnerable areas should be protected and that all activities are excluded from those areas.

The spatial analyses for MSP can be accomplished by GIS software, such as ArcGIS or QGIS. This can support the decision-making process for choosing appropriate sites for aquaculture, for example [6]. GIS analyses for site selection can furthermore be combined with Multi-Criteria Evaluation methods, sustainability indices, the use of parameter-specific suitability functions or modelling approaches [7–10]. The underlying methods in these studies are well described and the analyses can be implemented with the tools offered in standard GIS software. However, so far and to our knowledge, there is no toolbox specifically designed for MSP analyses for use in standard GIS software.

The aim of the current research was, therefore, to develop a toolbox that simplifies essential GIS analyses for MSP and bundles them in one toolbox with user-friendly documentation. In the next chapter, it is described how the tools were developed and which analyses they can perform. Subsequently, an example of the functionalities of the toolbox is provided. The paper discusses the application of the toolbox and further research needed.

2 Implementation

The "suitable space in the sea (SPACEA)" toolbox consists of five tools and the overall structure of the toolbox is presented in Fig. 1. The main output is a raster that shows the potential sites, where a maritime activity could be placed from an environmental and spatial perspective.

2.1 System Design

The starting point for the development of the SPACEA toolbox was existing functionalities in ArcGIS that have been used previously for the identification of suitable aquaculture sites [11]. These functionalities have been bundled and adapted to create a user-friendly toolbox targeted at spatial analyses for MSP (going beyond aquaculture site selection). SPACEA is based on custom-made script tools using ArcPy, a Python site package for ArcGIS.

The development of SPACEA is focused on two major aspects: User-friendliness and flexibility in the sense of multi-purpose use.

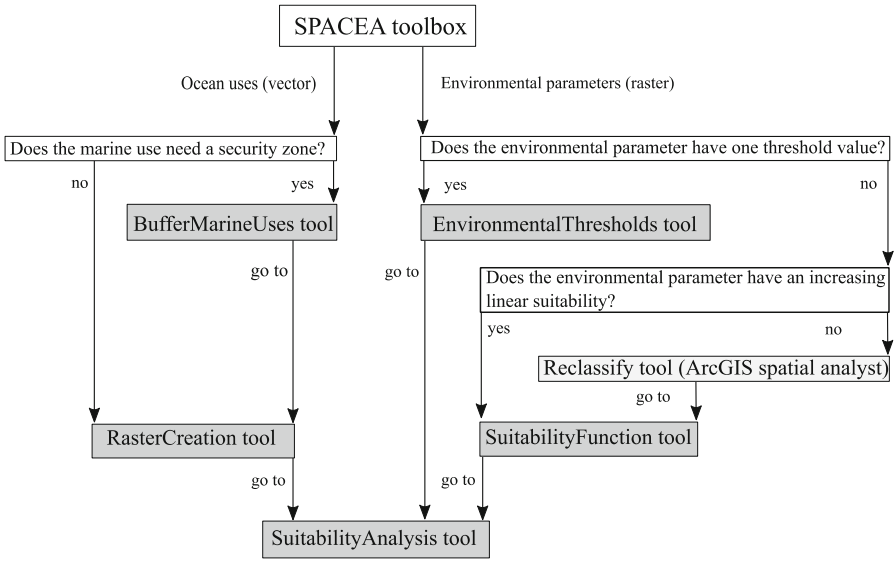


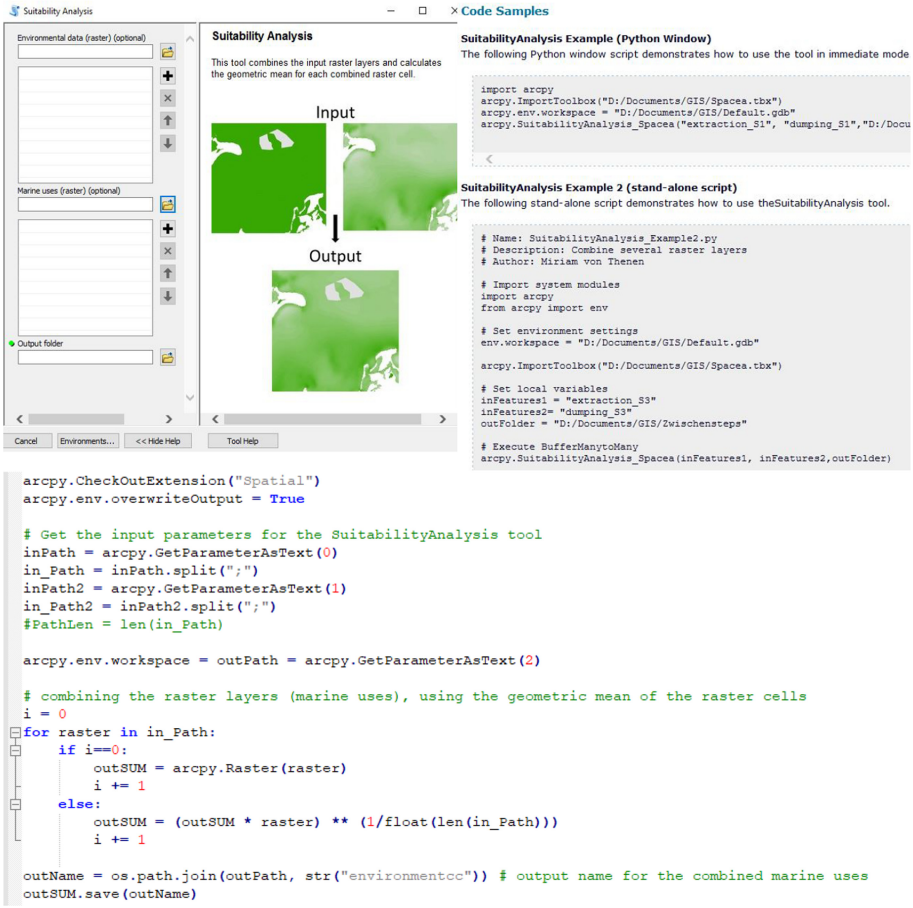
Fig. 1. Structure of the SPACEA toolbox

User-Friendliness. The user-friendliness was achieved through three different aspects. The tools are designed such that only a minimum input by the user is required. For most of the tools, the users only have to locate the input files and the output folder. Additional entries, such as a threshold value or cell size, are kept to the minimum. The output file names, for example, are created automatically by the tools and consist of the original file names with tool-specific naming attributes.

The naming conventions are clearly documented in the tool window. Transparency and clear documentation is another important aspect of user-friendly tools. The tools and their functioning are described in the tool window and in the item description, which also contains sample codes. The underlying Python scripts are furthermore annotated to disclose the purpose of each function (Fig. 2).

The tools can be accessed in three ways for different kinds of users. The least experienced user can use the tool window, which resembles the interface of standard ArcGIS tools. More advanced users may use the provided sample codes to run the tools in immediate mode (in the ArcGIS Python window) or access and modify the python scripts as they see fit.

Flexibility. Flexibility is achieved at the level of the toolbox and individual tools. SPACEA is a modular toolbox, i.e., the tools can be used independently from one another and for different purposes (Table 1). For suitability analyses, the tools build upon each other (Fig. 1), alternatively the tools can also be used as stand-alone tools. At the level of individual tools, the focus was on the combination of several functionalities within one tool. The SPACEA tools can process multiple input layers at the same time. The tool BufferMarineUses can assign individual buffer zones to multiple input layers and also the EnvironmentalThresholds tool matches individual threshold




```
arcpy.CheckOutExtension("Spatial")
arcpy.env.overwriteOutput = True

# Get the input parameters for the SuitabilityAnalysis tool
inPath = arcpy.GetParameterAsText(0)
in_Path = inPath.split(";")
inPath2 = arcpy.GetParameterAsText(1)
in_Path2 = inPath2.split(";")
#PathLen = len(in_Path)

arcpy.env.workspace = outPath = arcpy.GetParameterAsText(2)

# combining the raster layers (marine uses), using the geometric mean of the raster cells
i = 0
for raster in in_Path:
    if i==0:
        outSUM = arcpy.Raster(raster)
        i += 1
    else:
        outSUM = (outSUM * raster) ** (1/float(len(in_Path)))
        i += 1

outName = os.path.join(outPath, str("environmentcc")) # output name for the combined marine uses
outSUM.save(outName)
```

Fig. 2. The user-friendly tool interface on the upper left hand side with an excerpt of the item description showing the code samples on the right. At the bottom, an excerpt of the python script with annotation for the tool "Suitability Analysis" is shown.

values to multiple layers. This is accomplished by using the MultiValue parameter option in the script tool properties and the zip() function in Python. At the same time, the tools can assign one buffer or threshold value to multiple layers or one input layer with multiple values. This is also the case for the SuitabilityAnalysis tool, which can be used to combine only environmental input raster into one output suitability raster or both marine use and environmental input raster into one overall suitability raster.

2.2 Structure and Application

SPACEA features two tools each to process data on marine uses and the marine environment (Table 1). The fifth tool (SuitabilityAnalysis) combines both types of data and requires raster layers with values of "zero" and "one" as input. Both the

Table 1. Application areas of the tools in SPACEA

Tool	Application
BufferMarineUses	Some marine uses (e.g., wind parks and pipelines) have official security zones. The tool allows buffering several input layers with different buffer distances at the same time
RasterCreation	This tool is used to turn vector layers into raster layers based on the presence/absence of marine uses in a planning area
EnvironmentalThresholds	The tool can identify areas where certain environmental conditions are met for marine uses that depend on environmental parameters. The tool can also be used to identify risk areas with regard to environmental parameters, e.g., areas with oxygen deficiency
SuitabilityFunction	This tool applies a continuous suitability function to environmental parameters, e.g., current speed may be increasingly suitable for some types of aquaculture due to decreased impacts on benthic fauna and flora
SuitabilityAnalysis	This tool combines several raster layers and can be used to identify suitable areas for marine uses based on spatial availability and environmental suitability

RasterCreation tool and the SuitabilityFunction tool can be used to prepare such input raster layers (Fig. 1).

The underlying principle is the analysis of different input data with respect to their suitability on a scale between "zero" and "one". It is assumed that some of the data need pre-processing, such as creating security zones or threshold values in case of environmental data. Some of the marine uses and infrastructures do exclude other uses from their immediate location and from adjacent areas. Wind parks, for example, have a security zone of 500 m, which precludes any other activities [12]. In other planning areas, oxygen conditions may be close to hypoxia, and a goal of MSP could be to exclude any activities, which aggravate the situation, from these areas.

The analysis is based on a study area extent (the planning area), which combines all marine uses, and provides output maps indicating the available space. The output is in raster format, where values of "zero" indicate the area of marine uses and security zones (not suitable for other uses) and values of "one" show areas suitable from a spatial perspective. The tools for the environmental input data follow the same principle and provide output raster with values of "zero" and "one" (not suitable/suitable, tool: EnvironmentalThresholds) or between "zero" and "one" (increasingly suitable, tool: SuitabilityFunction). The SuitabilityFunction tool assumes increasing linear suitability, which may require additional pre-processing of the input data by using the ArcGIS Reclassify tool (Fig. 1).

The SuitabilityAnalysis tool combines all raster data, applying raster calculation and using the geometric mean, which results in three output raster indicating spatial availability, environmental suitability, and overall suitability.

3 Example

The SPACEA toolbox is based on generalized functionalities so that it can be applied to various geographical areas, multiple scales, and for different purposes. Here, we show an application in the Baltic Sea. Publicly available data for the Baltic Sea can be obtained from the HELCOM[1] Map and Data Service.

To demonstrate the functionalities of SPACEA, we use a fictional case of site selection for mussel farming, taking into account several selection criteria. These include wind parks, cables, and Nature 2000 areas as constraining factors and salinity and water depth as enabling factors. The required tools and inputs are illustrated in Fig. 3. The first step is to determine if the marine uses need a security zone. This is the case for wind parks and cables according to national regulations (e.g., [12]). Natura 2000 areas may not be a direct marine use as such but it is a man-made boundary "drawn" on the sea. Here, it is treated as a constraining factor, without an additional security zone. Nature 2000 areas do not necessarily exclude aquaculture activities [13], but here we take a conservative approach.

The BufferMarineUses tool is used to create buffers around wind parks and cables simultaneously and subsequently, the RasterCreation tool is applied to turn all three input layers of marine uses into raster layers with values of "zero" and "one". The first questions that should be answered for the environmental parameters is whether one threshold value can be applied (Fig. 1). Such a case could occur when the objective is to mark all areas with oxygen deficiency as unsuitable.

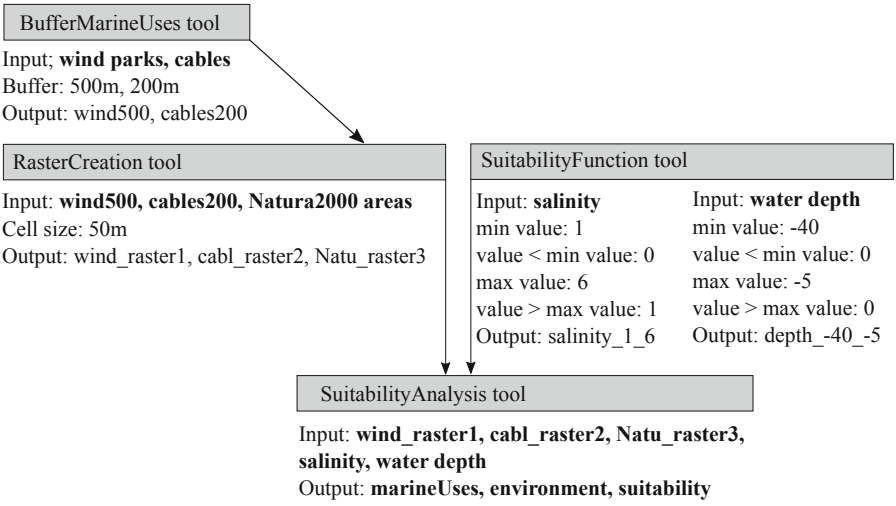


Fig. 3. The step-wise process that was applied to the fictional case study on Baltic-wide site selection for mussel farming.

[1] The Baltic Marine Environment Protection Commission, also known as Helsinki Commission (HELCOM).

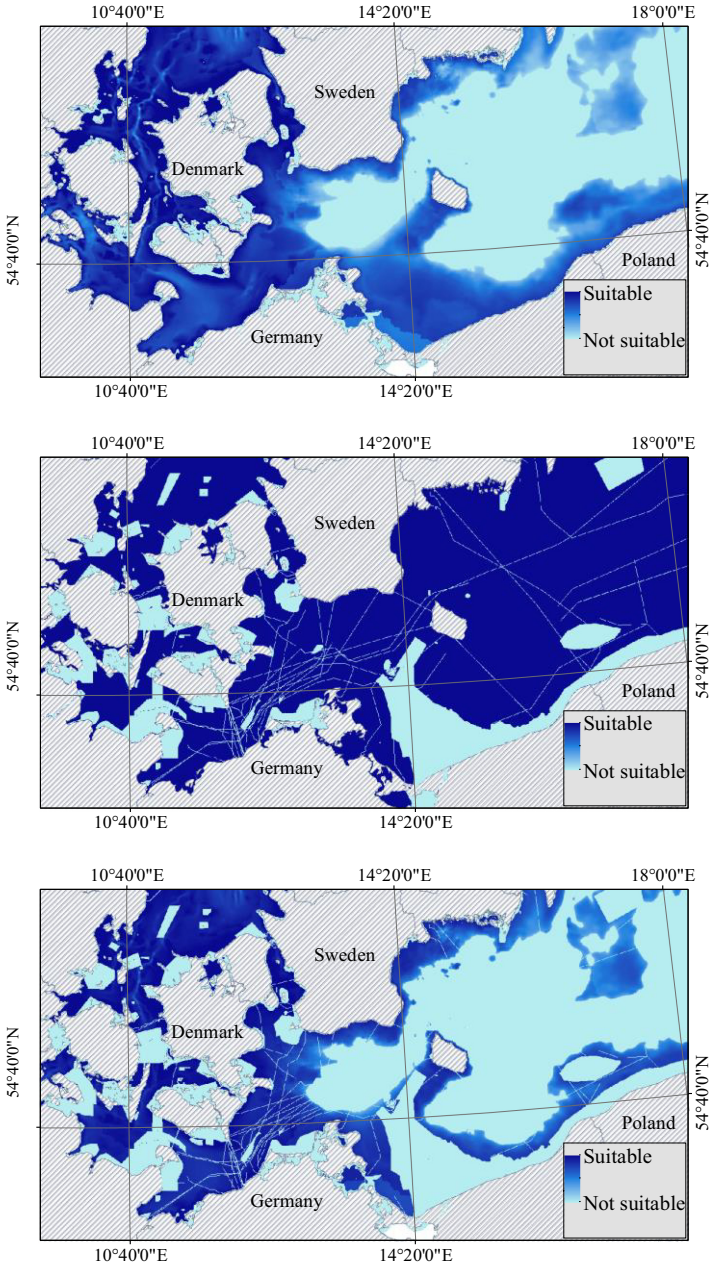


Fig. 4. The SuitabilityAnalysis tool produces three outputs: a map of environmental suitability (top), spatial availability (middle), and overall suitability (bottom). Excerpt from the south-western Baltic Sea.

In the case of salinity and water depth, however, continuous suitability is more appropriate. The salinity data from HELCOM is already classified with six classes, ranging from very low salinities (<5 PSU, class 1) to high salinities (>30 PSU, class 6). Blue mussels show a growth response to salinity, where low salinities result in decreased size and speed of growth. In the Baltic Sea, mussel farming is not feasible in waters with salinity below 5 PSU [14]. Therefore, a continuous suitability curve can be assumed (from class 1 to 6), where class 1 is assigned with "zero", class 6 obtains the highest score, and the classes in-between show increasing suitability. In case of water depth, the same tool is used to restrict the suitability curve between −5 m depth and −40 m depth, with increasing suitability the shallower the water becomes. Mussel farms are typically located in the upper water column and increasing water depth makes the anchoring of the farm more difficult. Applying the suitability analysis tool combines the input layers and results in three different output maps concerning spatial availability (output layer: marine uses), environmental suitability (output layer: environment), and overall suitability (output layer: suitability) (Fig. 4).

The three outputs enable a quick visual analysis which factors (environmental or marine use) contribute the most to the overall suitability or non-suitability. The stepwise approach, furthermore, allows to retrace also individual contributions from the factors and changes can be made at each step. For example, it could be investigated how the extent of the suitable area changes if security zones around wind parks substantially increase or projections of salinity changes are included.

4 Discussion

The example shows that SPACEA can be used to provide a quick analysis and overview of spatial availability and environmental suitability in a planning area. The HELCOM data is suitable to illustrate the functionalities and main outcomes of the tools. The data used in the example are already pre-processed and feature, e.g., an appropriate coordinate reference system and can thus be directly used as input to the tools. The HELCOM data come, however, in a relatively low resolution, which is suitable for Baltic-wide assessments, but generally too low for detailed regional or local analyses. In current planning scenarios, the planning area would be at national, regional, or even local scale. A thorough site selection analysis furthermore takes into account additional criteria; the criteria in the example above were chosen to illustrate the main functionalities of SPACEA but do not constitute a complete list of criteria for aquaculture site selection. Since the SPACEA tools do not require a certain quality or quantity of input data, it is possible to carry out the analyses even in data-scarce regions or with low-resolution data. However, care needs to be taken when analyzing these data as the results of the analysis are only as good as the quality of the input data.

The tools offer a 2-dimensional analysis of marine uses and environmental conditions. The marine environment, however, is a 3-dimensional space, and marine uses can exist at the sea bottom, in the water column, on the sea surface, and can also extend above the sea surface [15]. A 2-dimensional overlap of marine uses, therefore, does not necessarily result in conflicts, and co-location and synergies are possible [16]. The SPACEA tools do not take this into account directly but it is possible to include

such considerations. As mentioned above, Natura 2000 areas and mussel farms are not necessarily mutually exclusive, i.e., the Natura 2000 areas could be removed from the analysis. Also, cables may not be restrictive for certain marine activities taking place at the surface, in which case they could also be excluded from the raster overlay. A fourth dimension in the marine environment is the temporal variability. The environment undergoes seasonal and annual variations and marine uses may change, too (e.g., ferry routes that are only frequented in the summer months) [15, 17]. With the tools provided in SPACEA, such variations can be taken into account by running scenarios with input data from different seasons, for example. It is also possible to make assumptions about future conditions and consider these in the analyses.

When all tools are applied, the final outcome is a raster showing which areas might be suitable for a specific marine use. The SuitabilityAnalysis tool is based on raster data and uses raster calculation to combine the input data. The input raster are treated as equally important, there is thus an equal weighing of the criteria. In Multi-Criteria Analyses (MCA), it is common to apply priority weights to the criteria, e.g., through pairwise comparison of the criteria by experts or stakeholders using the Analytical Hierarchy Process [9, 18]. This has not yet been implemented in SPACEA and presents an area for future improvement.

5 Conclusion

There is an increasing demand for the seas' resources and space due to a focus on blue growth and blue economy. Inevitably, this will lead to conflicts between different users and between users and the environment. MSP is a process that aims at allocating space sustainably, avoiding conflicts and creating synergies. During the process, data related to the marine environment needs to be analyzed. Both on a spatial level – where are existing and planned marine uses located? – and from an environmental perspective. The environmental perspective can include the analysis of environmental data with regard to enabling conditions for a marine use, or with regard to critical conditions that should restrict uses from an area, e.g. when that area is in a bad environmental status. Such data analysis can be carried out with SPACEA, a custom-made GIS toolbox, which is presented in this paper.

SPACEA offers a user-friendly interface, which only requires to locate the input files and a few additional parameters for the least experienced user. MSP planers are not necessarily GIS experts and therefore it is important that such tools are easy to use and well-described. Depending on prevailing planning practices, however, GIS experts may be tasked with data analyses as input to the MSP process. In such a case, the more advanced users may use the provided sample codes to run the tools in immediate mode or modify the python scripts to adapt them to their needs.

SPACEA includes several tools that can process both data related to marine uses and environmental data in a fast way through multi-value input options. The tools build upon each other if the purpose is a suitability analysis but they can also be used as stand-alone tools. This flexibility allows the user to explore data on marine uses and environmental conditions in more detail and to retrace individual contribution to the overall suitability. It facilitates scenario building, which is an important part of

MSP. The tools may be used to explore the effects on spatial availability when security zones around uses increase, or on environmental suitability, e.g. when shifts in temperature occur. SPACEA furthermore allows the consideration of vertical overlaps between different uses and the temporal variability of uses and environmental parameters. In the MSP context, this consideration of vertical and temporal dimensions is in particular important for avoiding conflicts and creating synergies. The raster overlay on which the suitability analysis rests furthermore inherently offers the opportunity to include different weighs to the input data. This form of MCA has not yet been included in SPACEA but currently presents the next step in the development.

As it is a modular toolbox, SPACEA is designed to be extended and to include more functionalities if needed. While SPACEA was developed for MSP analyses, the current functionalities are generic and may also be applied in terrestrial planning. The spatial suitability analyses can provide useful input for the management of both terrestrial and marine areas.

Acknowledgements. The research has been carried out within the BONUS BASMATI project, which has received funding from BONUS (Art. 185), funded jointly by the EU, Innovation Fund Denmark, Swedish Research Council Formas, Academy of Finland, Latvian Ministry of Education and Science, and Forschungszentrum Jülich GmbH, Germany.

References

1. Ehler, C., Douvere, F.: Marine Spatial Planning. A Step-by-Step Approach toward Ecosystem-based Management. Intergovernmental Oceanographic Commission and Man and the Biosphere Programme. UNESCO, Paris (2009)
2. Hassan, D., Alam, A.: Marine spatial planing and the Great Barrier Reef Marine Park Act 1975: an evaluation. Ocean Coast. Manag. **167**, 188–196 (2019). https://doi.org/10.1016/j.ocecoaman.2018.10.015
3. EC: Directive 2014/89/EU establishing a framework for maritime spatial planning. Off. J. Eur. Union. L257, 135–145 (2014)
4. von Thenen, M., Frederiksen, P., Hansen, H.S., Schiele, K.S.: A structured indicator pool to operationalize expert-based ecosystem service assessments for marine spatial planning. Ocean Coast. Manag. **187**, 105071 (2020). https://doi.org/10.1016/j.ocecoaman.2019.105071
5. van den Burg, S.W.K., Aguilar-Manjarrez, J., Jenness, J., Torrie, M.: Assessment of the geographical potential for co-use of marine space, based on operational boundaries for Blue Growth sectors. Mar. Policy **100**, 43–57 (2019). https://doi.org/10.1016/j.marpol.2018.10.050
6. Nath, S.S., Bolte, J.P., Ross, L.G., Aguilar-Manjarrez, J.: Applications of geographical information systems (GIS) for spatial decision support in aquaculture. Aquac. Eng. **23**, 233–278 (2000). https://doi.org/10.1016/S0144-8609(00)00051-0
7. Benassai, G., Mariani, P., Stenberg, C., Christoffersen, M.: A Sustainability Index of potential co-location of offshore wind farms and open water aquaculture. Ocean Coast. Manag. **95**, 213–218 (2014). https://doi.org/10.1016/j.ocecoaman.2014.04.007
8. Longdill, P.C., Healy, T.R., Black, K.P.: An integrated GIS approach for sustainable aquaculture management area site selection. Ocean Coast. Manag. **51**, 612–624 (2008). https://doi.org/10.1016/j.ocecoaman.2008.06.010

9. Gimpel, A., et al.: A GIS modelling framework to evaluate marine spatial planning scenarios: Co-location of offshore wind farms and aquaculture in the German EEZ. Mar. Policy. **55**, 102–115 (2015). https://doi.org/10.1016/j.marpol.2015.01.012
10. Bricker, S.B., Getchis, T.L., Chadwick, C.B., Rose, C.M., Rose, J.M.: Integration of ecosystem-based models into an existing interactive web-based tool for improved aquaculture decision-making. Aquaculture **453**, 135–146 (2016). https://doi.org/10.1016/j.aquaculture.2015.11.036
11. von Thenen, M., Maar, M., Hansen, H.S., Friedland, R., Schiele, K.S.: Applying a combined geospatial and farm scale model to identify suitable locations for mussel farming. Mar. Pollut. Bull. **156**, 111254 (2020). https://doi.org/10.1016/j.marpolbul.2020.111254
12. Wulf, S., Säbel, A.: Marine Vorrang- und Vorbehaltsgebiete für Windenergieanlagen - Risikoanalyse (marine priority and reservation areas for offshore wind energy) (2016)
13. EC: Guidance document on aquaculture activities in the context of the Natura 2000 Network (2012)
14. Baltic EcoMussel: Mussel Farming: The New Baltic Sea Aquaculture Industry (2013). https://doi.org/10.13140/2.1.4849.0561
15. Holzhüter, W., Luhtala, H., Hansen, H.S., Schiele, K.S.: Lost in space and time? A conceptual framework to harmonise data for marine spatial planning. Int. J. Spat. Data Infrastruct. Res. **14**, 108–132 (2019). https://doi.org/10.2902/1725-0463.2019.14.art05
16. Bonnevie, I.M., Hansen, H.S., Schrøder, L.: Assessing use-use interactions at sea: a theoretical framework for spatial decision support tools facilitating co-location in maritime spatial planning. Mar. Policy **106**, 103533 (2019). https://doi.org/10.1016/j.marpol.2019.103533
17. Hansen, H.S.: Cumulative impact of societal activities on marine ecosystems and their services. In: Misra, S., et al. (eds.) ICCSA 2019. LNCS, vol. 11621, pp. 577–590. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-24302-9_41
18. Gagatsi, E., Giannopoulos, G., Aifantopoulou, G., Charalampous, G.: Stakeholders-based multi-criteria policy analysis in maritime transport: from theory to practice. Transp. Res. Procedia **22**, 655–664 (2017). https://doi.org/10.1016/j.trpro.2017.03.062