Location Analysis for Placing Artificial Reefs

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Abstract. Location analyses are among the most common tasks while working with spatial data and geographic information systems. Automating the most frequently used procedures is therefore an important aspect of improving their usability. In this context, this project aims to design and implement a workflow, providing some basic tools for a location analysis. For the implementation with jABC, the workflow was applied to the problem of finding a suitable location for placing an artificial reef. For this analysis three parameters (bathymetry, slope and grain size of the ground material) were taken into account, processed, and visualized with the *The Generic Mapping Tools* (GMT), which were integrated into the workflow as jETI-SIBs. The implemented workflow thereby showed that the approach to combine jABC with GMT resulted in an user-centric yet user-friendly tool with high-quality cartographic outputs.

Keywords: Geoinformatics, Location analysis, Exclusion mapping, The Generic Mapping Tools, Geo-visualization, Artificial reef, Balearics.

1 Introduction: Workflow Scenario

The aim of the presented workflow is to find suitable areas for placing an artificial reef in the waters of the Balearic Islands (Spain) in the Mediterranean Sea. An artificial reef is a man-made structure placed in the sea to attract and support marine wildlife [25]. These structures can be discarded and cleaned vessels [29], rail wagons or special objects made for instance out of concrete. Their objective is to become – similar to natural reefs – a hot-spot for plants and fishes. Whether these spots only attract the surrounding flora and fauna or also increase the biomass is a matter of scientific discussion [21]. Regardless, increasingly signs can be found that suggest a positive impact and the reefs certainly do provide shelter and protection to destructive forms of fishing. Furthermore or as a consequence, these reefs often become dive sites and attract a kind of tourism known to be environmentally thoughtful [27]. The installation of artificial reefs is therefore a method for helping the marine wildlife at least locally in a sustainable way.

To make sure that an artificial reef fulfills its purpose, it is necessary to keep the characteristics of the natural habitats of those species in mind, which are meant to benefit from its installation [21]. And to characterize the needs of a species, different parameters (e. g. water depth and temperature) are important. Some plants, for example, need more daylight than others, thereby suggesting

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locating the reef in shallower waters. Moreover, it is essential to ensure the structures safety and to prevent any kind of movement caused by unstable or steep ground material or strong currents. Since the purpose of this project is to show a possible design and implementation of the workflow, only a selection of the wide range of important parameters is taken into account:

Bathymetry is the underwater depth of the ocean floor, which is the height of the water column between ocean floor and water surface.

Slope is the angle of the ocean floor and specifies the slanting compared to a completely horizontal plane.

Grain size of the ground material is given in millimeter and refers to the diameter of particles of the ocean floor.

This simplified approach is reasonable because the consideration of more aspects would be easily implemented by transferring the developed procedure to the new parameters. In any case, this parameter-based approach is typical for location analyses (especially with geographic information systems (GIS)) where every relevant parameter is included via one thematic layer [2]. These layers are intersected to exclude unsuitable locations – a procedure referred to as *Exclusion Mapping*, which is often used and not as error-prone as the analysis of conventional maps. The placing of an artificial reef is therefore an appropriate example for a location analysis and suitable for showing the benefits of this workflow.

The wide range of different species with their specific ecological requirements and the aim of developing a tool that is capable of finding suitable reef-spots for all these various settings, make it necessary to keep the data processing as adjustable and user-based as possible. At the same time, the project also aimed to produce high-quality visualizations in an automated procedure, which focuses the interaction with the user to the content but not the layout. To implement this concept using the *Java Application Building Center* (jABC) [24], some basic datasets containing graphical elements, such as labels for map elements and color scales for the data representation, which are not meant to be changed by the user, are provided and complemented by one spatial grid for each of the three parameters.

In the first step the workflow, the user will process any of the given parameter by itself and one at a time (see Fig. 1). To do so, the user will first get the chance to examine the spatial distribution for the parameter. With the support of this overview a range for the values is declared, beyond which the data will be classified as unsuitable. This classification is subsequently visualized and confirmed or redone. In a second and final step the results for all parameters are summarized in one map, showing suitable locations for placing an artificial reef. This map also depicts for each unsuitable spot which parameter is out of the range entered by the user.

2 Service Analysis

The services chosen to implement the described workflow were *The Generic Mapping Tools* (GMT) developed by the *University of Hawaii* and the *National*

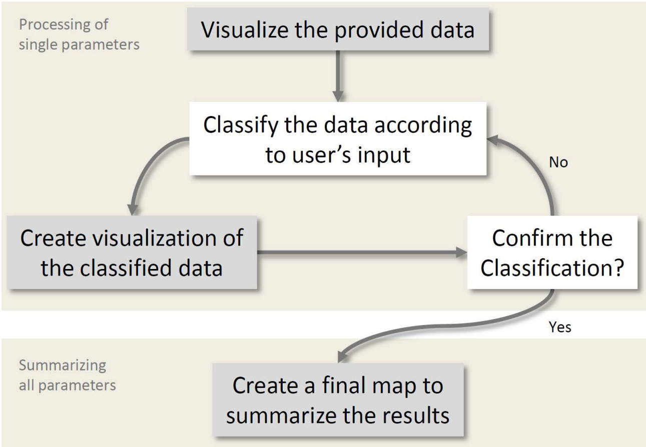

Fig. 1. Schematic diagram for the workflow with stages asking for user's input (white) and automated procedures (grey)

Oceanic and Atmospheric Administration [31] [30]. GMT is an open source command line tool available for the operating systems UNIX/Linux, OSX and Windows and bundling approximately 65 features for spatial data processing and visualization writing, such as in *PostScript*-files. The specific commands used for this workflow are listed and described below:

`pscoast` is used to plot the coastline of the Balearic Islands and to fill the land and water areas with a specified color. In addition it is used to add a frame, title and scale bar to a map.
`grdimage` imports and displays a two-dimensional gridded data.
`pstext` places text strings on a map.
`psscale` adds a legend with a color scale bar to the map.
`grdclip` clips gridded data by limiting the z-values to an upper and/or lower boundary.
`grd2xyz` converts a two-dimensional gridded dataset to a XYZ-table with columns for x- and y-coordinates and the z-value.
`psxyz` plots vector data stored in a XYZ-table.
`ps2raster` converts a PostScript-file to a raster image using the interpreter *Ghostscript* [1].

With GMT it is possible to create new files and also to add content to an already existing file and the added layer is than put on top of the content of the updated file. A creation of a map with GMT is therefore a sequence of commands, building the content from the back- to the foreground (see Chap. 3).

To use GMT (and Ghostscript) as a single tool it may to be installed locally on a platform. But for implementation within a jABC-workflow, an other approach has to be used, since the structure of the commands does not match the requirements of the ExecuteCommand-*Service Independent Building Block*

(SIB). To avoid this problem, the needed tools were integrated via the *Java Electronic Tool Integration Platform* (jETI) [12]. The commands were implemented as single jETI-SIBs with two versions per tool, one for writing in a new file and one for writing in an already existing file. Since some of the GMT commands need input data to be read from a directory and included in the workflow (e. g. the gridded data for `grdimage`) or data to be written to a directory (e. g. the finalized map written as an raster image with `ps2raster`) the jETI-SIBs *ReadFile* and *WriteFile* were necessary to realize the workflow.

3 Workflow Realization

To realize the workflow with jABC the jETI-SIBs were combined with the common jABC-SIBs *ShowConfirmDialog* and *ShowMessageDialog* (showing explanations), *ShowInputDialog* (asking for user's input), *ShowBranchingImageDialog* (showing the maps and asking for confirmation for the classification) and *PutString* (creating a string to pass in the workflow) to create a self-explaining and smooth workflow.

Before explaining the single steps of the workflow, a closer look at the provided data is necessary. The three parameters are included via two-dimensional gridded datasets (GRD-files), which will be processed during the workflow. For the bathymetry an *Earth Topography Digital Dataset* (ETOPO) was used with a spatial resolution of 2 minutes in each direction and the depth values measured in meters [28]. The grid containing the slope values was created from the bathymetry dataset and thus has the same spatial resolution with the angles given in degree. Since data regarding the grain size was not available for the area of interest, a fictitious dataset was created with the same spatial resolution as the first two grids. The datasets additionally provided are not manipulated in the workflow and contain labels and legends (TXT-files) and color scales (CPT-files).

The structure of the workflow – as mentioned in Chapter 1 and illustrated in Figure 2 – shows three parts for the processing of the single parameters bathymetry, slope and grain size, and one part for the generation of the final map summarizing the results. The processing of the different parameters is thereby very similar (simply the topic of the gridded data is exchanged) and below only described exemplary for the bathymetry.

The part of processing a parameter consists of two main steps, which are implemented in jABC with submodels. The first is to create a map showing the spatial distribution of the parameter (see Fig. 3) and the second to get the user's input and create a classification for the parameter based on the input (see Fig. 5). Since the creation of figures with GMT is done in sequences of commands, the visualization of the data basis concerning one parameter (shown in Fig. 3) is created by the following sequence (shown as a workflow in Fig. 4):

1. `pscoast`: specifies the extent of the map and colors the land and water areas
2. `pscoast`: creates a mask following the coastline and the following commands will therefore only alter the water area

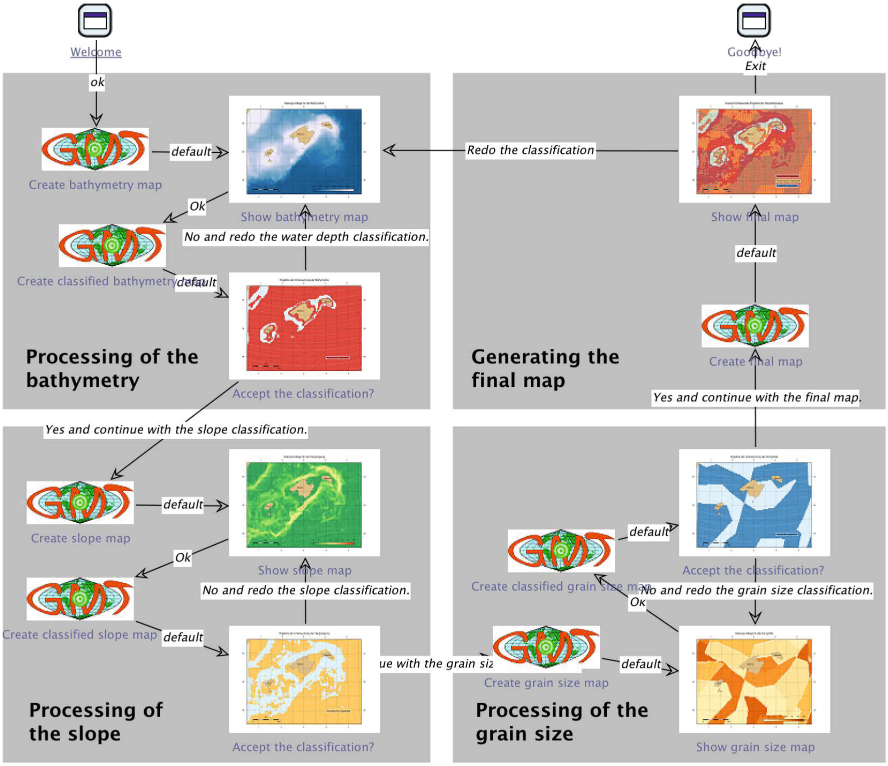

Fig. 2. Realization of the workflow with jABC. The SIBs symbolized with the GMT-logo represent submodels either for creating a map with the original dataset (see Fig. 4) or for classifying and mapping the data according to the user's input (see Fig. 6).

3. grdimage: the spatial grid containing the values for the parameter is added on top of the water area
4. pscoast: the mask for the coastline is deleted
5. pscoast: a mapframe with a scale bar and a title is added
6. pstext: labels for the Balearic Islands are added
7. psscale: a legend is added corresponding to the colors of the previously added grid
8. ps2raster: the final map is converted from PostScript to the *Portable Network Graphics* (PNG) file format

After the map is created and exported to a PNG image, it is shown to the user in order to get an overview of the data. On this basis and with the knowledge of the natural habitats of the species to be supported with the artificial reef, the user should be capable of depicting a range of suitable values, which will lead to a data classification of the processed parameter (see Fig. 5). The sequence of GMT-commands using the user's input is shown in Figure 6. The most important steps are:

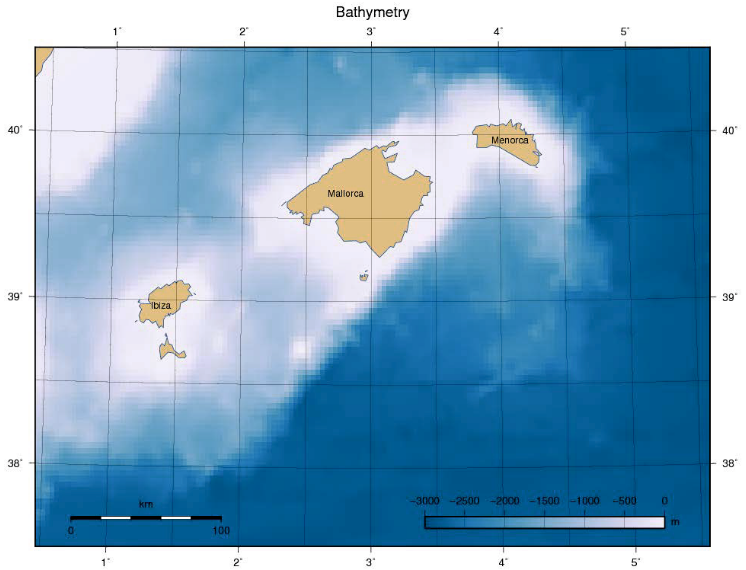

Fig. 3. Map showing the data basis regarding the bathymetry. This map is created with the submodel illustrated in Figure 4 and shown to the user while going through the workflow to help choosing the range for classifiying the water depth.

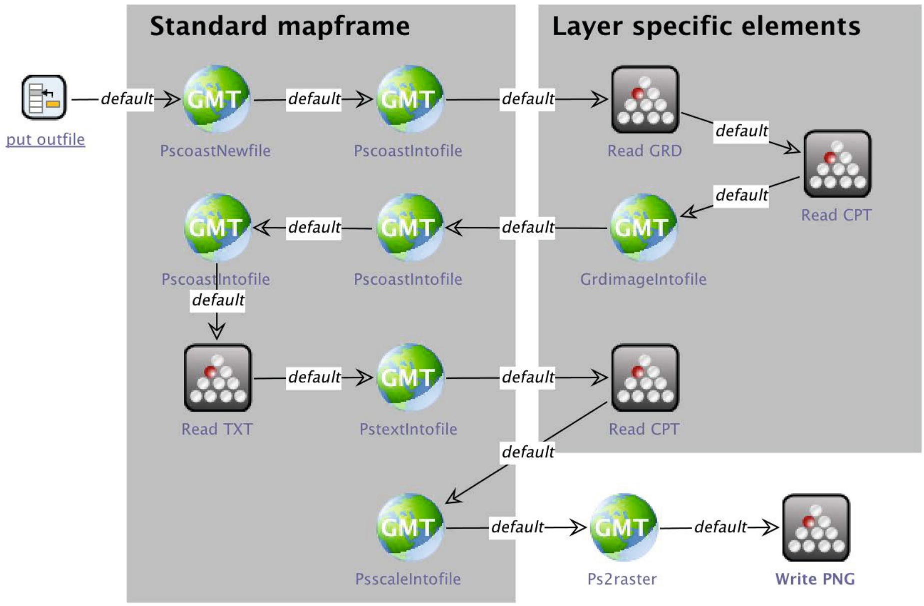

Fig. 4. jABC-Submodel for creating a map showing the data basis for one of the parameters (see Fig. 3). It is emphasized which SIBs create the standard mapframe used for all maps and which SIBs include the thematic layer presented in the map.

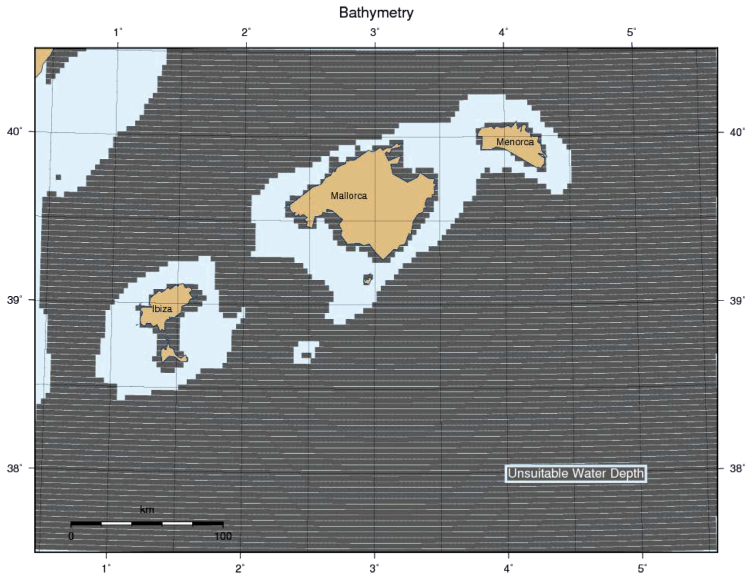

Fig. 5. Map showing a classification regarding the bathymetry. The range used here was −500 to −35 m. This map is created with the submodel illustrated in Figure 6 and shown to the user after choosing the range to review the classification.

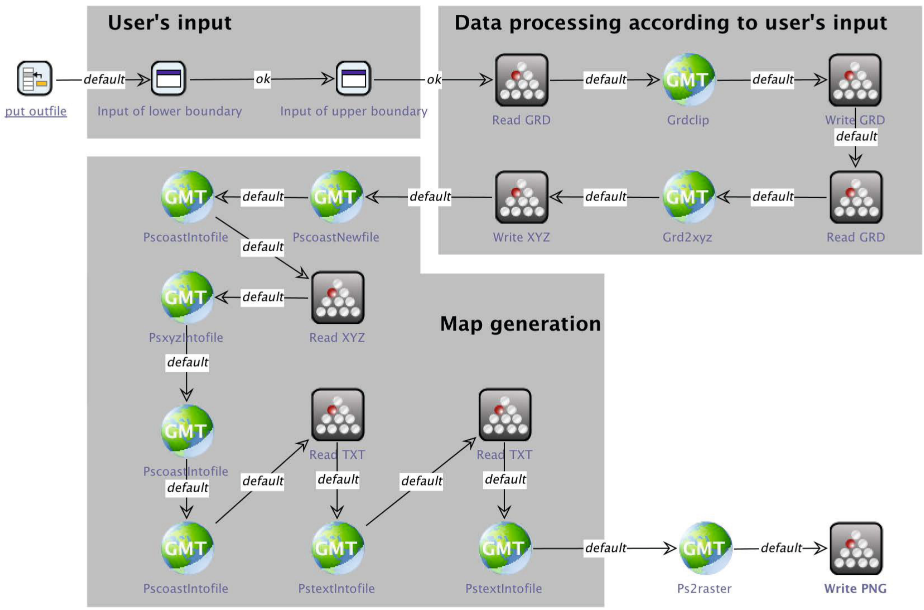

Fig. 6. jABC-Submodel for classifying the data for one parameter and creating a map showing the results of the classification (see Fig. 5). It is emphasized which SIBs take the user's input, which do the data processing according to this input and which create the map with the results.

1. `grdclip`: creating a new version of the original GRD-file with z-values limited to the range specified by the user – the values lower than the lower boundary and higher than the upper boundary are classified as *Not a Number* (NaN)
2. `grd2xyz`: converts the clipped grid to a table (XYZ-file) with one column for the x-, one for the y-coordinate and one for the z-value (containing the value for the parameter)

The following process of the map generation is similar to the submodel previously described; the only difference being that it uses the xyz-table instead of the gridded data. The content is therefore not included as a raster but as single points, each one representing an unsuitable location with an area of the cell size of the original raster. After the classification is done, the results maybe reviewed and redone, if necessary or desired. Otherwise the workflow will continue with the processing of the next parameter.

When the processing of the single parameters is completed, the final step of the workflow will summarize the results in a single map (see Fig. 7). The corresponding submodel is shown in Figure 8 and uses the XYZ-tables created in the previous steps of the workflow. Using these files, the map generation of the final map is similar to the one described above, albeit with a small alteration: since the results for all three parameters have to be included and displayed at the same time without covering one another, a symbolization with different point sizes was chosen, drawing the points on top with the smallest symbol. Thereby it is not only possible to make out suitable spots regarding all parameters, but also to see why (because of which parameter) a spot is marked as unsuitable.

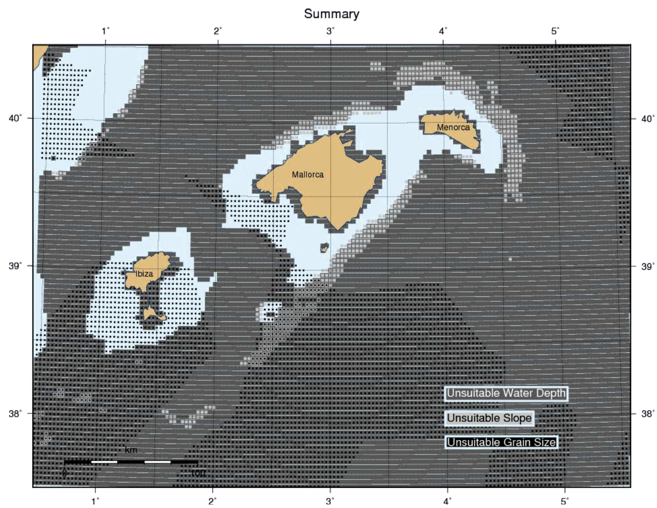

Fig. 7. Final map created with the submodel illustrated in Figure 8 and showing a possible classification for all parameters in one frame. The used ranges were -500 to -35 m for bathymetry, 0 to 4° for slope and 0.01 to 20 mm for grain size.

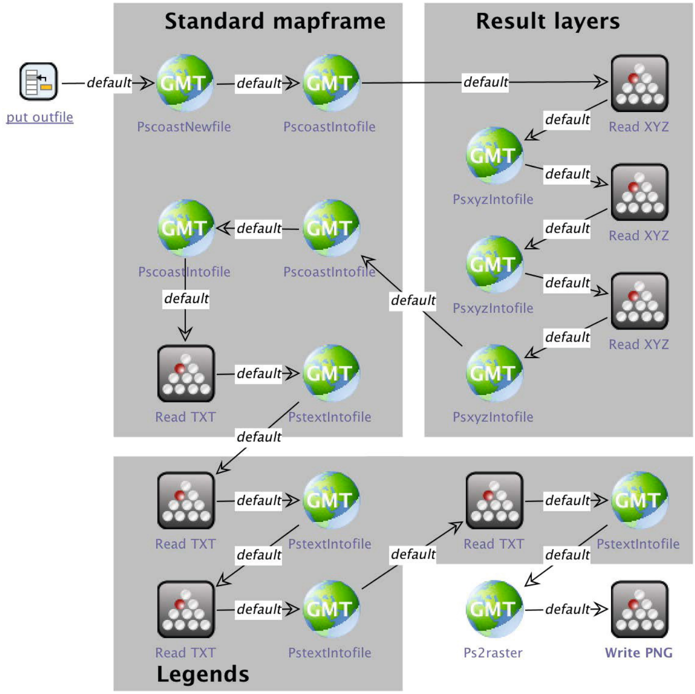

Fig. 8. jABC-Submodel for the final map summarizing the results for all parameters (see Fig. 5). It is emphasized which SIBs create the standard mapframe, which include the classified layers and which add the corresponding legends.

With the final map generated, the user gets the chance to review the results and exit the workflow or redo the classification, starting with the first parameter.

4 Conclusion

The goal of this project was to implement a scientific workflow with jABC that is capable of performing a location analysis and working with the method of exclusion mapping. It aimed to develop a user-centric procedure with adjustable content and high-quality cartographic output.

The scientific problem used as setting for the workflow was the identification of suitable locations for placing artificial reefs in the waters of the Balearic Islands. Artificial reefs are of interest because they can have a positive effect on local marine wildlife by providing an environment similar to the natural habitats of specific species of flora and fauna. The individual needs of various species for different conditions and the importance of many other parameters (e.g. ground stability) made it necessary to realize a workflow that allows the user to specify the limits of acceptable values for the considered parameters. At the same time it was important to achieve a visualization easy to interpret and not prone to errors.

To implement the workflow with jABC, eight GMT-commands were integrated as jETI-SIBs and combined with some common jABC-SIBs. In providing some basic datasets for the three selected parameters bathymetry, slope and grain size and for some graphical elements (like labels and scale bars) the user is able to process the single aspects and to summarize these results. The thematic data is thereby included as gridded data coming with a given spatial resolution. This data has to be acquired and prepared in advance to match the requirements of GMT and jABC. While going through the workflow the unsuitable locations are excluded and visualized for every single parameter, resulting in a final map showing the results in one frame.

The outputs of the workflow can be used in multiple approaches. The easiest and most straightforward is to use the final map and examine suitable locations for placing an artificial reef, retrieved by classifying all parameters. In addition, the symbolization of the parameters in the final map allows a deeper analysis in that spots marked as unsuitable can also be subjects to a qualitative analysis. This might be useful if some parameters are more important than others. In some cases for example, the water depth might be much more relevant than the ground material, which could lead to an overall suitable reef location, even though the values for the grain size are out of the preferred range. If the knowledge of these special circumstances is available, the results of the realized workflow allow the user to establish a ranking of suitability for the different areas, ranging from suitable (e. g. shallow water, flat slope and medium grain size) over suitable with reservations (e. g. shallow water, flat slope and coarse grain size) to unsuitable (e. g. deep water, steep slope and coarse grain size). Thus, even though this step of post-processing is not included in the workflow itself – which might be a useful addition and done in future work – the stage of the workflow already implemented is capable of providing a basis for a profound analysis.

To be suitable as a decision support system, however, many additional parameters would have to be included. Besides some basic parameters describing the natural conditions – like water temperature and current velocities – human interaction would also have to be considered. For instance the trawling and shipping lines are a crucial aspect for a suitable location [2]. Similarly, already existing reefs and highly productive areas might be taken into account. Since the procedures used in the workflow process the parameters one-by-one, this completion is feasible and the most time-consuming part would probably be the acquisition of the data basis for the added parameters.

At the same time the parameter-based location analysis and the design of the workflow is transferable for solving of a lot of other problems related with GIS. This workflow could therefore be used as a kind of template and be adjusted and extended to solve location analyses in other contexts, but with similar databases.

For further development, the integration of vector data might also be useful approach, as it was chosen and described by Tobias Respondek (see corresponding paper in this composure). The support of a combination of raster and vector data would increase the usability of the workflow and further expand the field of application.

In any case, the efforts made to develop an automated and user-friendly workflow for performing a location analysis – especially the design of the process and way the parameters are included and visualized – turned out to be of value and warrant further exploration.

This article is part of a larger evaluation [8], which aimed at illustrating the power of simplicity-oriented development [16] by validating the claim that process modeling can indeed be handed over to the domain experts by providing them with a graphical modeling framework [24] that covers low-level details in a service-oriented fashion [18], integrates high-level modeling in the overall development process in a way that user-level models become directly executable [17,14], and supports ad-hoc adaptations and evolution [13,15].

The project described in this article can be characterized as follows:

- Scientific domain: geoinformatics
- Number of models: 8
- Number of hierarchy levels: 1
- Total number of SIBs: 142
- SIB libraries used (cf. [11]): common-sibs (29), jeti-sibs (113)
- Service technologies used: jETI services

The geoinformatics part of this volume contains eight other articles on workflow applications in this domain [6,20,5,26,4,22,3,23]. Further geoinformatics workflow projects with the jABC have recently been started. Ongoing work is also exploring how to apply semantics-based (semi-) automatic workflow composition techniques (as provided by, e.g., [19]) to support the workflow design process, as described in [9,10,7] for the bioinformatics domain.

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