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Deliverable D.T3.3.1 Guidelines for spatial modelling and analysis to produce data and identify interactions of interests

Cross-border case

31.1.2019



PLAN4BLUE

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BACKGROUND

Spatial information forms the basis of spatial planning. It is present in the pre-planning stage, in the mapping of the current state of the planning area, analysing the interactions between interests and evaluating and communicating planning options. Compared to land-based spatial planning, Marine Spatial Planning (MSP) faces many additional challenges, including cross-border and data availability issues and the addition of the vertical dimension.

This guide aims at presenting a step-by-step approach to utilising spatial data in cross-border MSP. It seeks to complement existing MSP guides in a concise and practice-oriented way, instead of forming a comprehensive manual. Particularly, the guide refers to UNESCO IOC's guide "Marine Spatial Planning – A step-by-step approach to ecosystem-based management" (Ehler & Douvère 2009). This guide introduces each step of the MSP spatial data process in a general way and includes practical tips, arising from experiences of an MSP pilot project (Plan4Blue in the Gulf of Finland). It is prepared in four steps, conforming to the workflow of an ordinary MSP process:

- Guidelines for identifying and sharing relevant spatial data in MSP (ready in April 2017)
- Guidelines for harmonising, producing and managing cross-border spatial data (July 2017)
- Guidelines for spatial modelling and analysis to produce data and identify interactions of interests (January 2019)
- Guidelines for visualising spatial MSP information effectively on maps (June 2019)

The guide is prepared as part of the MSP development project Plan4Blue - Maritime Spatial Planning for Sustainable Blue Economies (2016-2019; <http://www.syke.fi/projects/plan4blue>) funded by the EU European Regional Development Fund (Interreg).

FREQUENTLY USED TERMS

CRS – Coordinate reference system

MSP – Maritime/Marine spatial planning

PGIS – Participatory GIS, collecting spatial information in digital format using participatory methods

GUIDELINES FOR SPATIAL MODELLING AND ANALYSIS TO PRODUCE DATA AND IDENTIFY INTERACTIONS OF INTERESTS

In this third part, methods in geoinformatics are applied to model new data, analyse spatial interactions and to transform analysis results into meaningful implications for MSP. In the marine environment, temporal dynamics (see 9.G) and three-dimensional patterns (see 9.J) may need to be analysed in addition to the two-dimensional interactions. In the sea, processes often operate at an international level, making it mandatory to extend the analyses from the planning area into larger geographical areas and across boundaries.

Majority of the principles described in this part apply both inside and across administrative and sectoral boundaries, but cross-border evaluation of input data (see previous part of the guidelines) is crucial for the validity of the analysis results. This part is related to “Step 5” and “Step 6” in Ehler & Douvère (2009).

Step 7. Model new data

7.1 Apply correlative spatial modelling to produce new spatial layers

Practical tips

- While high-resolution survey data should always be preferred, correlative modelling can be utilised to extend information from a limited number of point observations to a larger geographical area. Use appropriate survey data as input and scientifically evaluated methodology and report analyses following scientific principles.
- The point observations of a dependent variable are mathematically related to multiple high-resolution layers of e.g. environmental factors and the probable distribution of the dependent variable is calculated based on the mathematical equation.
- Examples of the modelling frameworks include species distribution modelling or climate envelope modelling. A limited number of observations of a species are mathematically related to multiple factors of the bio-physical environment and the probable distribution of the observed species is calculated based on the multivariate model. Furthermore, the probable future distribution of the species in different climatic conditions (or e.g. sea use scenario) can be calculated by replacing the bio-physical layers with data of the new environment.
- Document the input data and modelling methods carefully (e.g. size or resolution of the input data, citation to the methodology, main restrictions), to give a realistic impression of the reliability of the results.

Step 8. Plan spatial analyses

8.1 Identify interaction types

Practical tips

- Prepare for spatial analysis by setting the goals in collaboration with planning authorities and subject experts (Figure 1).

Note that the exact procedures and names of the tools differ between GIS software: they are described very generally in this guide. This guide merely offers useful keywords for searching software-specific instructions.

9.A Grouping and reclassifying spatial data

Open data and results of surveys and PGIS processes can be summarized and simplified to produce more useful classifications for MSP. This is a highly subjective process and should be done in communication with subject experts.

- Input data requirements: Vector or raster data.
- In practice: With raster layers, this is done by reclassifying cell values (using reclassify tool). With vector layers, map items (points, lines or polygons) are selected (manually or using query / select by attributes tool) and given new attribute information that determine inclusion in new classes. Optionally, existing attribute information or item geometry is used for calculating the new attribute values based on criteria (calculate field / calculate geometry tool).
- Example 1: Locations where an activity is expected to claim new area or increase in volume may be grouped if there is a limited amount of data or separate classes ultimately represent the same phenomenon.
- Example 2: A raster layer, such as commercial fisheries catches or modelling results for the occurrence probability of *Zostera marina*, can be simplified by classifying the cell values e.g. into high, medium and low.

9.B Simplifying distributions of vector data

Geographic distributions of map items (points, lines and polygons) can be summarized or simplified for creating new data, for visualisation purposes or for comparing distributions. Mainly, the analyses replace multiple map items with one item (e.g. points to point or points to polygon) that represents the entire group of items.

- Input data requirements: Vector data.
- In practice: Centographic statistics or computational geometry methods are used for determining a central location and, potentially, the distribution or directional trend of a vector layer.
- Example: A group of point locations (e.g. of individual offshore wind turbines) can be replaced by one point that represents the mean location of the group (e.g. location of the offshore wind farm; Figure 2).
- Example: The directional distribution tool can be applied to mathematically summarize point distributions into polygon features (e.g. Roose et al. 2017). The individual offshore wind turbine locations can be transformed into one polygon representing the wind farm (Figure 2).
- Example: The distributions of two phenomena can be summarised into central locations and thus more easily compared. Similarly, the distribution of the same phenomenon measured at different times can be more easily compared by calculating central locations for the distributions.
- Example: Cluster and outlier analysis based on spatial autocorrelation (Anselin Local Moran's statistic) examines the attributes of point or polygon layers to create a map of statistically significant hot spots, cold spots and spatial outliers. Instead of simplifying the input data layer into fewer map items, it identifies those input map items that are part of a hot (cluster of high values) or cold spot (cluster of low values) or those that are outliers.

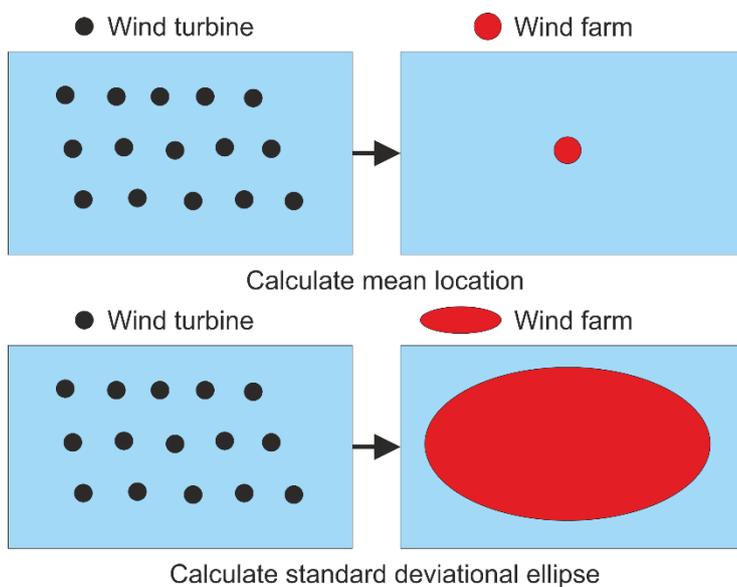


Figure 2. An illustration of calculating the mean location of points (above) and standard deviational ellipse (below) to summarize a point distribution.

9.C Analysing geographical distributions as surfaces

Spatial patterns of locations (or values related to each location) can be mathematically simplified and characterised as continuous surfaces. The analysis generalises information from a set of vector items to a larger area and transforms vector data into raster data. This can be used for visualisation purposes.

- Input data requirements: Vector data.
- In practice: Surfaces can be calculated from vector data for example with density analysis tools (calculating the number of map items per certain spatial unit) and hot spot analysis tools (locating clusters of high and low values).
- Example: Heatmaps can be calculated to summarise the distribution of map items resulting from PGIS (e.g. with Kernell density tool; Figure 3).

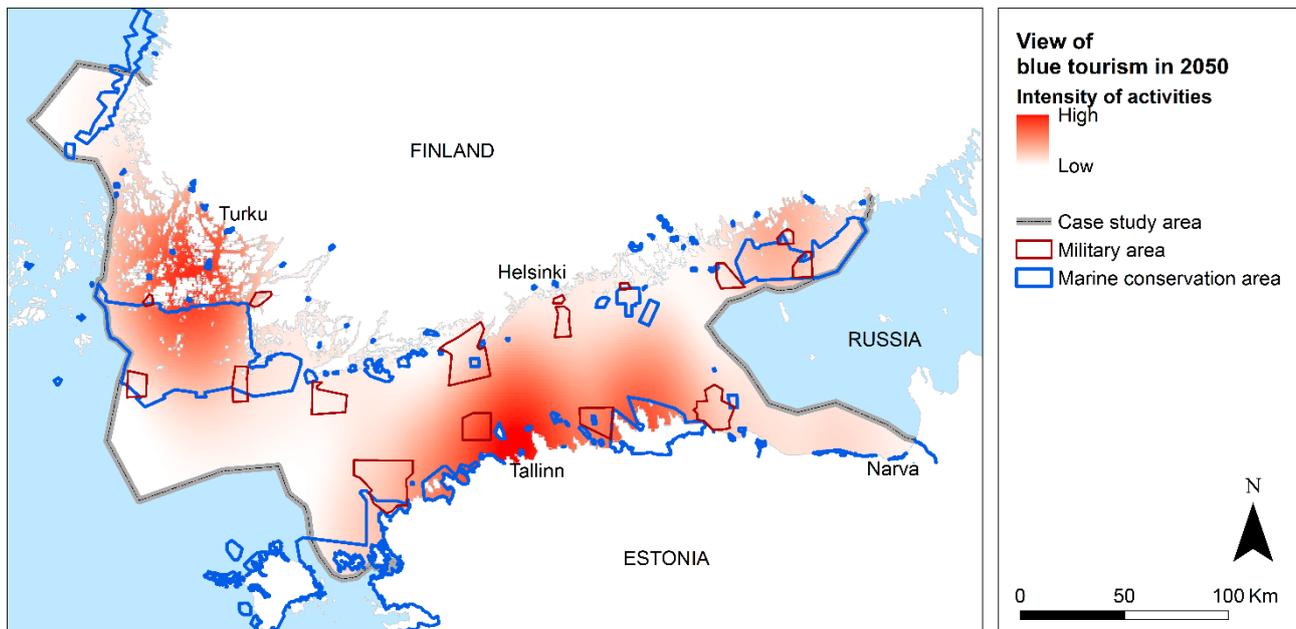


Figure 3. Example of the density of map items of energy sector activities in the future, resulting from expert PGIS process (Tolvanen et al. s.a.).

9.D Analysing distances (neighbourhood analysis)

Neighbourhood analysis (also called buffer analysis) can be used to calculate "caution zones" around locations of activities or plans. In addition, neighbourhood analysis can be used to weigh the influence of activities based on their distance. Typically, the closer the activity, the higher its influence.

- Input data requirements: Vector data.
- In practice: Multiple ring buffer tool and inverse distance weighing (calculate field tool) can be used to calculate weights for distance zones.
- Example: Caution areas with certain radius may be considered around offshore wind energy constructions or deep water navigation areas (potentially depending on the other considered activity).
- Example: The influence of marine traffic (waves, noise etc.) from different locations on the nature can be weighed by determining distance zones around conservation areas. To consider the entire network of conservation areas, the distance zones can be calculated separately for each conservation area and summed to create a cumulative distance surface.

9.E Determining co-location (overlay analysis)

To analyse the spatial interactions of activities, overlay analysis can be applied. It allows the determination of areas where activities (or their influence zones) or ecosystem values (or their caution zones) do and where they don't overlap. These can be further interpreted into "no conflict" and "conflict" areas or "no synergy" and "synergy" areas depending on the interaction. The analyses need to be adapted to the data structure or the data to be transformed.

- Input data requirements: Vector or raster data.
- In practise: In a simplest case, two polygon layers are compared with vector overlay methodology (e.g. calculating the union of the two layers). In raster overlay, raster algebra (raster calculator tool) can be used to calculate different combinations of two raster layers.

- Example: The potential conflicts between an established nature conservation network and shipping can be quantified and located with overlay analysis. First, shipping density can be classified into “traffic” and “no traffic” and transformed into polygon data. Second, the union of conservation area polygons and traffic polygons can be calculated and reclassified into conflict/no conflict area.
- Example: “Caution areas” for biodiversity hotspots (where human activities would be too close without overlapping) can be analysed by first determining “caution zones” around the hotspots (neighbourhood analysis) and then performing the overlay analysis.

9.F Calculating influence area or caution area

The influence area of an activity or the caution area of an environmental distribution is as important as the location of the activity or environmental values. The determination of these areas is complicated and case-specific and requires a notable amount of expertise and data. Influence and caution areas are often roughly estimated by calculating buffer zones (neighbourhood analysis). Depending on the case however, the size, shape, vertical dimensions and temporal patterns of the influence and caution areas may differ notably from simple buffer zones.

- Input data requirements: Vector or raster data.
- In practise: The selection of the analysis method is highly case-dependent. Visibility analysis methodology can be applied for estimating the influence area of those marine activities whose influence spreads easily along the sea surface but is delimited by coastline. Calculation of an isarithm (line connecting points of equal values) can be used to determine influence area based on survey points.
- Example: Visibility analysis framework can be applied to calculate rough estimates of the propagation of light, sound and waves (Figure 4) from sources to targets. Alternatively, the analysis can be used for mapping potential source areas for specified targets. This may be useful in e.g. archipelagos where islands complicate the propagation. However, visibility analysis is unable to account for reflection and refraction processes. The visibility area can be weighed based on distance to targets by applying neighbourhood analysis (9.D; Figure 4).
- The influence area of a river that acts as a point source of nutrients into the sea may be estimated from point observations of nutrient content in sea water by statistically determining a threshold level of nutrient content and calculating an isarithm for the threshold value.

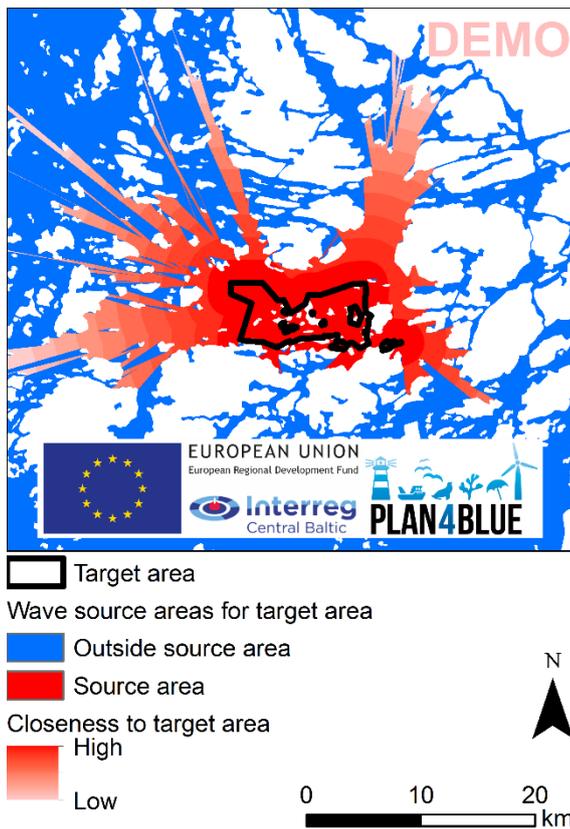


Figure 4. Illustration of simple estimation of wave source area for a single target area using the visibility analysis methodology. Shipping in the wave source area is expected to cause waves and other disturbance in the target area. The influence of shipping in the visible area is expected to decrease with distance to the target.

9.G Identifying temporal variation and trends

Temporal variation and trends may be relevant for MSP in many cases. They may prevent or allow co-locating activities, make the analysis of ecological implications more complex or require changing the control of sea use in the future. GIS methodology supports information of time in addition to location and attributes. Therefore, time can be treated, visualised and examined correctly.

- Input data requirements: (Mainly) vector data.
- In practise: Time can be stored into the attribute data of map items and assigned as a temporal attribute field. There are multiple choices for visualising the temporal data, depending on the type of the case.
- Example: Points indicating sightings of a marine species can be coloured depending on the year, month or date of the sighting. This may be useful for visualising seasonal movement or year-to-year increase of the species or quality of the data.
- Example: Map items with different times stamps can be visualised as a set of maps or as animations (items appearing and disappearing from the map according to the time stamp) to examine past trends.
- Example: Point data of ship routes or GPS-tracked animal routes can be visualised by creating routes.
- Example: To analyse temporal trends, the distribution of the map items can be summarized individually for each time slot and compared (e.g. the shifting of the centre of the distribution from season to season or year to year).

9.H Analysing cause and effect

Spatial data contain useful attribute information that can be statistically analysed to examine potential causal relationships. Statistical models estimate the relationships of variables with mathematical equations and enable the evaluation of the importance of the relationship. The models can be further utilised to predict values into other areas (see 7.1) or to future conditions (see 9.I). With spatial data, the spatial structure of the data need to be taken into account, since it may violate the assumptions of standard statistical methods.

- Input data requirements: Vector or raster data. Observations of multiple variables (attributes/cell values) for the same locations to form a coherent dataset.
- In practise: The spatial structure of the data need to be taken into account, since for example spatial autocorrelation violates against the assumption of independence of the observations. This is done by applying modelling methods specifically designed for spatial data (e.g. spatial regression) or examining spatial autocorrelation and when it is insignificant, proceeding with non-spatial statistical methods. Statistical modelling methods can be broadly classified into regression models and machine learning models and spatial and non-spatial models, each with different preconditions and advantages. Moreover, the modelling can be classified into predictive modelling (with purpose to efficiently predict values outside the sample; see 7.1) and hypothesis testing (with purpose to drive reliable conclusions on causal relationships), which influences to validation of the models.
- Example: Hypothesis testing can be applied for analysing the potential dependency of water quality on shipping density and other factors. For example, two multiple linear regression models can be fitted into point observations of water quality and biophysical data: one model excluding and the other including shipping density. The predictive power of the two models can be statistically compared to examine the independent influence of shipping on water quality.

9.I Projecting future distributions

Future distributions and patterns can be estimated based on past trends, future scenarios and correlative modelling (e.g. "climate envelope modelling"; see 7.1). MSP should prioritise modelling results that are based on scientific research and reported following scientific principles.

- Input data requirements: High-resolution vector or raster layers of current and/or future conditions. Non-spatial trend estimate or a statistical model (see 9.H).
- Example: The simplest type of a spatial future projection is using a quantitative but non-spatial estimate of future change and apply the uniform estimate for calculating new values. For example, if shipping in the Gulf of Finland is estimated to grow by 15 % from 2018 to 2030, then all cell values of a raster layer of shipping densities in 2018 are multiplied by 1.15. The new layer will then represent current-day patterns and future level of the phenomenon.
- Example: A statistical model for the dependence of water quality on shipping and biophysical factors (see example in 9.H) can be used for estimating water quality in future assuming certain changes in shipping density. If biophysical factors as assumed to be constant, shipping density is replaced by new values in the equation and new water quality values are calculated.

9.J Working with 3D patterns (incorporating depth)

The vertical dimension may be more important in MSP than in land-use planning. Depth may influence the interaction of specific activities and the allocation of sea space for activities. Many activities interact at the surface of the sea: for example, cargo shipping and leisure boating compete for the use of sea surface space

and ship-induced waves travel the shallow surface layer influencing littoral species. However, cables and other constructions at the bottom of the sea may only limit the use of the sea surface in very shallow areas while for example cables and fish farms may coexist on top of each other in many areas.

- Input data requirements: 3D vector data, surface data or 2D vector data in combination with surface data
- In practice: Depending on the type of analysis and the activities considered for MSP, it may be useful to work with three-dimensional data and methods. In GIS, even two-dimensional data can be incorporated into three-dimensional analyses and visualizations: their z-coordinates will simply be assumed to be zero. However, three-dimensional data are more difficult to create and edit than two-dimensional data, and it is therefore not advisable to add the third dimension to all data. Depth (or height) can be added to two-dimensional data from existing surfaces.
- Example: To examine co-location issues in multi-use areas, 3D data of offshore wind farms, cables and key natural habitats can be visualised with 3D extensions of GIS software. They also enable construction of animations.
- Example: A two-dimensional line representing the location of a pipeline at the bottom of the sea can be visualised in a three-dimensional space by using an existing bathymetric model of the seafloor.

Step 10. Transform spatial analysis results into meaningful implications for MSP

10.1 Determine terminology and format of the spatial implications

Practical tips

- Spatial analyses at Step 8 produce output data layers with a wide range of numerical scales. Often, the “raw” analysis results are difficult to interpret and compare to other results, at least without a deeper knowledge of the each maritime sector and the spatial analysis methodology. The work of planners, authorities and stakeholders across sectoral borders is facilitated by transforming the result layers into meaningful implications for MSP. In the simplest case, this is done by (re)classifying the values of the result layers and (re)naming the classes in a meaningful way.
- Find out what the expected format of the output information is. For example, one choice would be to extract the output information as one raster layer, with values indicating the implication for MSP at each cell location.
- Find out what would be a suitable classification for the output information and if there is a predefined terminology for the classes. If all analysed interactions have similar preconditions and implications for MSP, a uniform classification scheme should be applied to facilitate examination and comparison of the results. For example, a possible classification for the analysis results of the interaction between shipping and nature conservation could be: “No conflicts” (areas where shipping does not disturb nature conservation areas based on an analysis), “Increased shipping not recommended” (areas where shipping might disturb nature conservation but where there is no significant traffic at the moment) and “Shipping requires special attention” (areas with heavy traffic and where shipping causes disturbance in the nature conservation area based on an analysis).
- Number of the classes (different types of implications for MSP) influences the precision of the output information and the strength of the message. The classification should be designed individually for each analysis, since the analyses have different preconditions and implications for MSP. The less

classes, the stronger the message (and the stronger the influence of the analyst on the interpretation). However, the analysed interaction may in some complex cases require a higher number of classes to adequately describe the complexity.

10.2 Prepare spatial implications

Practical tips

- Use existing spatial data, results of the analyses of spatial interactions (Step 8) and expert opinions to derive meaningful spatial implications for MSP. In case multiple scenarios have been developed and analysed in Step 9, there will be multiple alternative implications.
- For example, reclassify a raster layer of negative interactions into 1) no interaction, 2) potential or weak interaction and 3) probable or strong interaction and give the classes the appropriate names. In another case, reclassify “union” features into 1) conflict (overlap of activities), 2) caution (overlap of activity and the caution zone of another activity) and 3) no interaction areas.

10.3 Apply decision support tools

Practical tips

- In some cases, MSP allows the rearrangement of multiple activities or allocation sea space in a new way (instead of simply documenting current zonation and making few small-scale adjustments). In these cases, it may be useful to explore many different ways of using the sea space in an objective way.
- Spatial optimisation modelling using decision support tools is one way of quantitatively optimising sea use. For example, the spatial layers describing the interaction between all activity pairs could be used as “cost layers”. The model would then calculate the optimum arrangement of the activities in a way that minimises the cumulative “costs” based on predefined criteria.
- The model proposal for the optimum sea use could be used as a basis for discussions by planners and stakeholders. The model criteria and input data can be edited and the modelling repeated to explore alternative scenarios.

10.4 Finalise boundaries

Practical tips

- Background information and recommendation for the MSP process should be directly based on existing data, the results of quantitative analyses and simple classifications. However, at later stages of the MSP process when planning results are produced, the precise boundaries of “zones” (areas allocated for different uses) may be edited for practical reasons.
- Boundaries of sea use zones should be as simple as possible, e.g. consisting of straight line segments. This way they can be reported as a few coordinate pairs (and information on the CRS). In addition, the zones should follow relevant existing boundaries and exploit clear landmarks where possible (e.g. one corner of an area located at the tip of a headland).
- The spatial planning result layers are used at multiple spatial scales. They potentially need to be shown on top of multiple scale versions of the background data (such as coastline 1:100 000 and 1:1 000 000). Therefore, simple borders should always be preferred.

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