Lost in space and time? A conceptual framework to harmonise data for marine spatial planning*

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Abstract. Despite a list of national and international efforts to harmonise data management procedures, the categorisation of space and time within datasets in marine spatial planning (MSP) has not been addressed so far. This paper proposes a conceptual framework to categorise the spatial and temporal dimensions of data used in MSP and introduces a method to jointly manage non-spatial information and spatial data in the same geographic information system (GIS). The presented categorisation provides easy and intuitive classifications for a more detailed and transparent data description of spatial and temporal data properties, which can be applied both in attribute tables and in metadata. It allows the differentiation of the vertical and the horizontal dimensions, enabling users to focus on operations taking place at specific parts of the marine environment. The categorisation with predefined attribute domains allows space and time based automatic analyses. The inclusion of non-spatial data within GIS repositories ensures the availability of all relevant data in one database minimising the risk of incomplete data. Overall, the framework provides effective steps towards a more coherent data management and subsequently may foster better use of information in MSP processes.

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1. INTRODUCTION

Marine spatial planning (MSP) is a complex, data intensive, and evidence-based process (MSP Data Study, 2016). The success of a MSP process largely depends on the quality and availability of pertinent data and the capacity for their analysis (Stamoulis & Delevaux, 2015). Consequently, in a world of data, where it is possible to gather an unlimited amount of datasets, data collection, processing, management and storage need to be handled with great care.

Challenges arise especially through different concepts of data management, e.g. during the transition from local or national planning to international, cross-border operations (Stamoulis & Delevaux, 2015) when different administrative structures, languages and procedures, different stages of planning, and respective data requirements and standards need to be coordinated.

Several international efforts to establish coherence among datasets that are collected at various geographical scales and institutional domains exist. Already in the early 1960s, it was recognised that international efforts are needed to coordinate oceanographic data exchange, which led to the establishment of the International Oceanographic Data and Information Exchange programme (IODE). Since 2009 the European Marine Observation and Data Network (EMODnet[1]), a network of more than 150 organisations provides and processes data of the European marine environment. Data, metadata and information are available via the EMODnet portal following international standards and supported by the EU integrated maritime policy[2].

A major general development in data management is the Directive 2007/2/EC establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) which came into force in the member states of the European Union in 2007 (Bartha & Kocsis, 2011). It aims to improve consistency, availability, and re-use of spatial information to support environmental policies (European Union, 2007). Worldwide, the FAIR principles support a similar agenda to improve the Findability, Accessibility, Interoperability, and Reuse of digital assets (Wilkinson et al. 2016). Thereby, the principles emphasize the automated, computational admission of datasets. However, neither INSPIRE nor the FAIR principles do

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[1] http://www.emodnet.eu/ (last visit 23.07.2019)
[2] https://ec.europa.eu/maritimeaffairs/policy_en (last visit 23.07.2019)

consider all thematic aspects related to data needs in MSP (MSP Data Study, 2016).

In the Baltic Sea region, several institutions foster the development of common standards in MSP data management. The HELCOM-VASAB MSP Working Group (HELCOM – Baltic Marine Environment Protection Commission and VASAB – Vision and Strategies around the Baltic Sea[3]) is promoting advances in MSP data management (Ehler, Zaucha, & Gee, 2019; HELCOM-VASAB, 2019, Zaucha, 2014). The European MSP platform developed a pan-Baltic model for MSP as well as provides a handbook on MSP Indicators for Blue Growth (European MSP Platform, 2018). Both efforts aim to outline a framework to harmonise datasets in the Baltic Sea Region on the most important activities such as offshore wind farms, pipelines and subsea cables, platforms, marine aggregate extractions, and nature conservation areas. The pan-Baltic model emphasizes a Baltic-wide joint graphical design for data management in MSP with joint legends and symbols as well as low language barriers (Zaucha, 2014). Still, each neighbouring state of the Baltic Sea Region defines individual MSP indicators for Blue Growth to fit in national planning contexts and national targets, hampering the preparation of common transboundary maritime plans (European MSP Platform, 2018).

The importance of introducing data harmonisation measures to more efficiently communicate space and time as the spatial and temporal dimension in data is repeatedly discussed in the literature as a pressing need in MSP (Ehler, 2008; Hattam et al., 2015; MSP Data Study, 2016; Stamoulis & Delevaux, 2015). Spatial information is recognised as one of the most critical elements in decision making as it provides geographic context to planning and management (Strain et al., 2014). Marine ecosystems may undergo changes over time (e.g. changes in nutrient loads, species occurrences, exhaustion of resources), and consequently the basis for compatibility of the sea uses may reform as well. Therefore information on the temporal dimension is likewise important for the management of human activities at sea (Schaefer & Barale, 2011). The place-based and dynamic nature of ecosystems and the spatial and temporal qualities of human activities raise a demand to manage marine areas in a way that includes both the three-dimensional aspects as well as the time-dependent perspective of data in the marine environment (Crowder & Norse, 2008; Ehler, 2008; Shucksmith & Kelly, 2014). Besides the two horizontal dimensions, it is increasingly relevant to take the vertical and temporal dimensions into account as MSP aims to avoid potential conflicts and foster synergies (HELCOM, 2010, 2016, 2017; Uusitalo et al., 2016).

[3] http://www.helcom.fi/helcom-at-work/groups/helcom-vasab-maritime-spatial-planning-working-group (last visit 23.07.2019)

Despite the afore mentioned directives and initiatives, the actual implementation of spatial and temporal aspects in datasets remains challenging (Shucksmith & Kelly, 2014) and coherent solutions are still lacking. Furthermore, even though it is commonly mentioned that MSP requires both spatial and non-spatial information (Shucksmith & Kelly, 2014), the data discussion in the literature is highly focused on spatial data, maps, and geospatial analysis. Non-spatial data (datasets that are not presented in spatial format but refer to a certain location, and indirectly include spatial information) may serve as important sources of evidence for spatial planning. Since the spatial representation is missing, these datasets remain unaccounted in MSP data repositories. Consequently, non-spatial data are often excluded also from discussions on data harmonisation.

Additional challenges arise with the wide range of data formats and tools used for data processing in MSP. Linked Ocean Data 2.0 (Leadbetter et al., 2017) addresses integration of heterogeneous data from many different scientific domains through the use of ontology design patterns. The CF Conventions for Climate and Forecast Metadata are designed to promote the processing and sharing of files created with netCDF (NetCDF Software Package), and provide a definitive description of data variables including spatial and temporal properties of the data (Eaton et al., 2011). However, the software library is specialised in sharing array-oriented scientific data.

For planners, evidence needs to be of a certain quality and reliability irrespective of the data source. Since often, data and information are not produced by the planning authority itself, it is crucial that metadata provide a clear and transparent description (MSP Data Study, 2016).

The conceptual framework presented here was developed in the BONUS BASMATI[4] project. Data management within the project and preparing project results as input to MSP in the Baltic Sea region posed the following challenges: (I) harmonisation and integration of different dimensions of space and time to datasets in a meaningful way, (II) managing spatial data (GIS data) and other types of information that may have indirect spatial implications (e.g. socio-economic data and policies), and (III) ensuring data quality in a transnational environment (e.g. common language).

The aim of the current paper is to provide a conceptual framework to describe spatial and temporal data properties in MSP datasets and associated metadata, using a systematic categorisation and common wording. Second, the objective is

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[4] https://bonusbasmati.eu (last visit 23.07.2019)

to show how spatial and non-spatial information can be managed jointly in the same geographic data repository.

2. HETEROGENEITY OF MARINE DATA

2.1 Data types in marine spatial planning

Data in MSP cover a variety of topics as well as different phases of the planning cycle. Evidence is needed about the current state (stocktaking), future scenarios and visions, as well as policies and planning decisions (Ehler & Douvere, 2009).

The European Commission's technical study on 'Evaluation of data and knowledge gaps to implement MSP' (MSP Data Study 2016) identifies four broad types of data that have been used in existing plans and corresponding planning processes: (I) administrative boundaries, (II) data on the geophysical environment and biological/ecological features, (III) data relating to relevant human activities and sectors, and (IV) socio-economic and policy-related data. Most data available and accessible belong to data types (I) and (II). The amount of data belonging to type (IV) is currently increasing. Especially policy related data including data on human pressures for impact assessments will become more important in the future (HELCOM, 2016, 2017; Uusitalo et al., 2016). The majority of available data within all data types is descriptive and of applied evidence, meaning data gathered by measurements, sample analysis or models. Strategic evidence describing future scenarios or visions is still rare.

2.2. Diversity of spatial and temporal information

2.2.1 Spatial dimensions

The characteristics of spatial information in datasets can be described and documented in several ways. The geographic positions can be given as coordinates. The features can be presented as points, lines, or polygons. The spatial coverage can be addressed by the spatial scale or the resolution of a dataset (Lam & Quattrochi, 2018).

Spatial information for MSP purposes is in general embedded in the three-dimensional nature of the marine environment (Gilliland & Laffoley, 2008). Hence, the horizontal as well as the vertical dimension of a dataset need to be documented. The horizontal dimension is sometimes addressed by text attributes referring to the spatial coverage of the dataset (e.g. local, regional, or national). However, the vertical dimension is often not documented even though the data can be strongly associated with a specific water layer, such as the sea surface (e.g. ferry lines), or the seafloor (e.g. sea cables).

2.2.2 Temporal dimension

The same area can host multiple uses either if they are compatible with each other or if they are occurring at different times (for instance, one activity dominates the summer season and another occurs only during winters). Therefore, the temporal dimension of human activities plays a central role in the compatibility of sea uses. Similarly, it will influence planning decisions whether activities take place once a year or are ongoing several hours each day.

Three aspects of 'time' may be differentiated within a dataset. (I) time of data collection or sampling; referring to a point in time and commonly expressed as date in a dataset. (II) time as a process step; referring to a timeline (e.g. past, present, future). For instance, objects can be under construction or operational, permits can be active or already expired and datasets can include historical data as well as future scenarios. Similarly, marine spatial plans have a different status from preparation phase to full legal force. (III) time as a feature within the data itself referring to the occurrence and temporal frequency of activities. Regularly operating ferry lines are periodically occurring activities. Bird migration is a seasonal phenomenon and installation of new infrastructures is a single period.

2.2.3 Spatial and non-spatial data types

The majority of data used in MSP are spatial data as such. Still, there are many datasets which are not presented in spatial format but actually include spatial information. Many statistics useful for planning purposes are presented at a national or regional level without a reference to individual locations. Strategic documents are non-spatial evidence useful in spatial planning. Siting decisions related to marine activities may need information from economic baseline studies or impact studies (MSP Data Study, 2016). National laws and regulations, as well as international agreements and policies, are important sources of background information (Cornu et al., 2014) even though they may lack direct references to space.

As a forward-looking process, MSP manages activities and guides future development in a sea area (Schaefer & Barale, 2011). Consequently, future-oriented information is needed besides the stocktaking of data on current activities. Still, future scenarios such as climate change related information, trends or forecasts cannot be mapped precisely. Information on future economic developments or impacts of technological and knowledge advances may be presented without spatial reference at all. Even many important MSP stakeholder groups do not have a clear vision about their future uses of marine space (Zaucha, 2012).

The social dimension (e.g. stakeholder values, cultural services) is essential in planning and management of public assets (Strickland-Munro et al. 2016; Chan et al. 2012). Socio-economic datasets can include, among others, statistics about economic indicators, traditional knowledge of local residents, or evidence on the willingness of communities to contribute towards conservation efforts. The great majority of the social indicators used in planning are not of spatial character (Cornu et al., 2014). Cultural values may have direct linkages to specific places, but often linkages may be indirect or even completely inappropriate (Gee et al., 2017).

3. METHODOLOGY AND RESULTS

We propose a conceptual framework to document information on the spatial and temporal dimensions of datasets adequately for MSP purposes. It is applicable to both the attribute tables and the metadata. The categorisation includes the vertical and the horizontal dimensions as well as the complexity of the temporal dimension. Furthermore, we propose a straightforward method to include and manage non-spatial datasets within a geographic information system (GIS).

3.1 Basis for the data framework

The framework builds on the data specification scheme by the HELCOM-VASAB MSP Working Group (HELCOM-VASAB, 2019) and develops it further. The data scheme introduces a set of technical requirements (data specifications) based on INSPIRE land use data specifications to facilitate the interoperability and harmonisation of spatial datasets. Predefined code list values and an inclusive list of attribute codes along with descriptions structure information on data features in detail (HELCOM-VASAB, 2019).

Our approach drives this scheme further by including categories for the spatial and temporal dimensions of datasets. The categories are applied to code list values, attribute domains and additional descriptions (Figure 1). The suggested way of writing the attribute domains follows the approach of the original data scheme to maintain consistency and to aim for harmonised language. While the HELCOM-VASAB proposal is designed for spatial datasets corresponding to the MSP output data (i.e. the marine spatial plans depicting the possible sea-use in the future), our approach considers all data types, including both input and output data. This widens the applicability of the scheme to all phases of MSP processes.

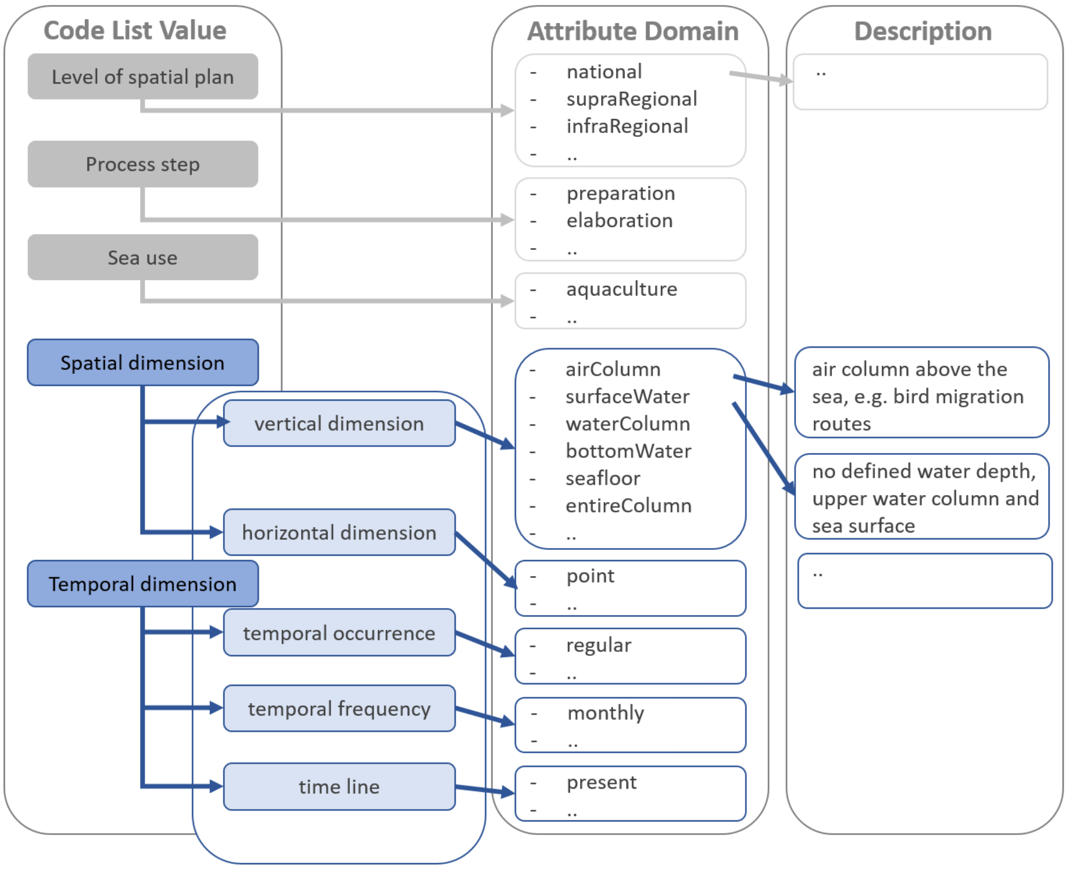

Figure 1: Relation of HELCOM-VASAB MSP output data specification (grey) and the proposed conceptual framework for a categorisation of spatial and temporal dimensions (blue). Code list values with respective attribute domains (named 'attribute codes' in HELCOM-VASAB, 2019) and descriptions are selective (only for illustration purposes).

3.2 Categories for spatial and temporal information

We introduce two categories to describe the spatial dimension: the 'vertical dimension' and the 'horizontal dimension' (Table 1). The main goal of adding a category for the vertical dimension is to provide approximate background information on whether the objects of interest occur in the surface water layer, at the seafloor, or somewhere in between (Figure 2). The vertical dimension includes additional attribute domains to cover data themes not directly in contact with the sea itself, but strongly related to it. This comprises topics related to the air column above the sea surface as well as activities along the coast or in the coastal region (Figure 1, Figure 2, and Table 1). The horizontal dimensions represent different spatial scales from local to international. We adopt a Baltic Sea perspective and therefore suggest attribute domains such as 'BalticWide' and 'EU' (Figure 1, 2; Table 2). However, attribute domains can be adjusted for other sea areas and regions around the world.

Table 1: Categorisation of the vertical and horizontal spatial dimensions with predefined attribute domains

spatial dimension	attribute domain	description
vertical	airColumn	air column above the sea, e.g. bird migration routes, scenery values
	surfaceWater	upper water column including water surface, no defined depth description
	waterColumn	whole water column, e.g. aquaculture
	bottomWater	near water body above the seafloor, no defined depth description
	seafloor	solid ground and sediment of the marine environment, e.g. seagrass, cables
	entireColumn	seafloor, water column, and the air above them, e.g. offshore wind power, bridges, other infrastructure
	coastalRegion	near shore, coastline and coastal area, where maritime induced activities and infrastructure dominate, e.g. lighthouses, hotels, diving schools
	unknown	the information is not available
horizontal	point	Point like features with specific coordinate information, e.g. ship wreck
	local	small spatial extent, a few km or km^2, e.g. protected area, dredging plume
	regional	spatial scale reflecting ecological, historical, political, climatic or morphological zone, e.g. estuarine
	national	administrative boundary, e.g. state borders, exclusive economic zone
	basinWide	spatial scale following morphological characteristics of sea basins, e.g. Bornholm Basin
	BalticWide	spatial scale reflecting the whole geographic extent of the Baltic Sea
	EU	European Union wide information, e.g. EU policies and agreements

Information on the temporal dimension is divided into three categories: 'temporal occurrence', 'temporal frequency', and 'timeline' (Table 2). 'Temporal occurrence' reveals whether e.g. activities are completely absent, occur only once or more often, or are present all the time. ‘Temporal frequency’ provides further information on the frequency of the activities that have more or less regular occurrence patterns (Figure 3). ‘Timeline’ gives an indication whether the datasets represent past, present, or future activities, scenarios or conditions.

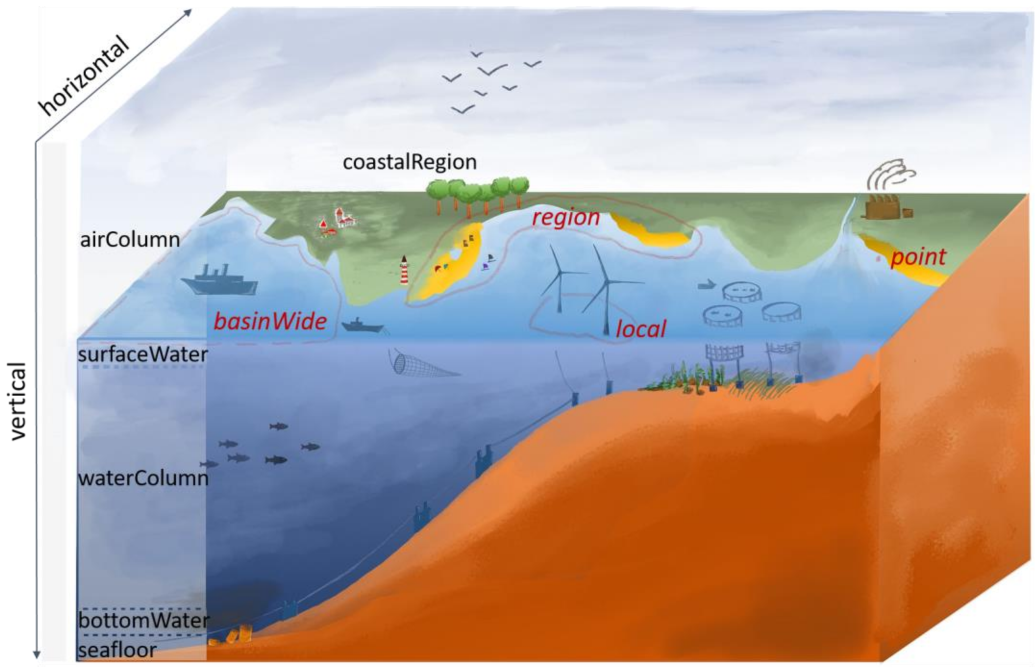

Figure 2: Illustration of the vertical (black) and horizontal (red italic) dimensions of marine environments.

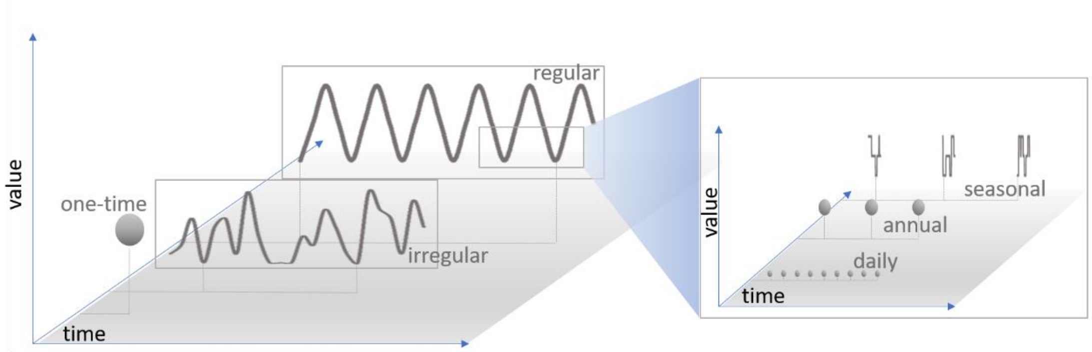

Figure 3: Illustration of ‘temporal occurrence’ and ‘temporal frequency’, representing information on time in a dataset.

Table 2: Categorisation of the temporal dimension with predefined attribute domains

temporal dimension	attribute domain	description
temporal occurrence	absent	e.g. for species that are not present anymore in a region, or for not existing data on marine spatial plans
	oneTimeEvent	can be applied for disastrous events, e.g. oil leak
	irregular	e.g. activities that follow no pattern, such as dredging events, which depend on weather conditions, supply and demand and administrative authorisations
	regular	e.g. cargo shipping, dive sites
	static	permanent and ongoing status e.g. maritime infrastructures
	notApplicable	no characteristic temporal occurrence can be applied to the data in a meaningful way
	unknown	the information is not available
temporal frequency	daily	event or activity that occurs (almost) every day, e.g. ferry
	monthly	event or activity that occurs (approximately) once a month, e.g. service trips to wind park
	seasonal	event or activity that occurs during specific seasons, e.g. algae bloom, bird migration, blockade of a shipping route with floating ice in winter
	annual	event or activity that occurs once a year, annual updates of socio-economic statistics
	decadal	reoccuring events on a long, at times irregular frequency, e.g. fresh water inflows from the North Sea to the Baltic Sea, extreme weather events
	otherPeriod	to describe unique frequency patterns that differ strongly from the listed classes above
	notApplicable	no characteristic temporal frequency can be applied to the data in a meaningful way
	unknown	the information is not available
timeline	past	e.g. historical data, data of outdated marine spatial plans, historic coastlines
	recent	data that are collected in the past but describe the most current situation, e.g. environmental data, model derived data
	present	data on existing uses or present state, e.g. legally adopted documents (INSPIRE guideline), mariculture facilities
	future	applicable for planned infrastructures, future climate predictions, e.g. planned wind park, sea level rise
	notApplicable	no characteristic timeline can be applied to the data in a meaningful way

3.3 Technical design

The technical design of the conceptual framework can be implemented in two ways: in the attribute table or in the corresponding metadata. Advantages, challenges and limits of transferring information either as attribute encoded in the data or as description in the metadata are given below (Table 3). In addition, an example for the use of an auxiliary file to include non-spatial data in a GIS repository is presented.

3.3.1 Attribute table

Information in the attribute table is linked directly to the spatial feature (line, point, or polygon) and appropriate columns are created for each spatial and temporal category. Respective attribute domains can be selected according to the description. The risk of losing information during data exchange is diminished to a minimum.

The attribute table of datasets is directly accessible for GIS applications and other automated, multifunctional tools (Table 3). The user can identify spatial and temporal overlap by queries. Analysis can focus, for example, on seasonal events such as bird migration or algae blooms. The 3-dimensionalty of the marine realm can be addressed more efficiently when information on the vertical and temporal dimension are directly accessible for data analysis.

Implementation in the attribute table raises two technical challenges. First, the file size of a dataset increases, depending on the amount of information included. Even though automated tools and systems can process a large amount of data, file size tends to increase the processing time in general. It can further hamper data exchange between users due to the volume limits of exchange-tools. Second, for each spatial and temporal category only a single attribute domain can be selected. There might be datasets that are difficult to categorise using a single attribute domain. However, a combination of multiple choices in the attribute table hinders proper workflow with the data. Moreover, it may lead to conflicts and misinterpretation between users when data are exchanged. Automated analysing algorithms may not be able to handle multiple combinations of attribute domains, leading to false results. A more detailed description within the metadata is hereby mandatory.

3.3.2 Metadata

Similar to the attribute table, information can be stored in the metadata using the same categorisation. Contrary to the limited options of expressing spatial and temporal dimensions in the attribute table, metadata descriptions allow running text to categorise, describe, and define data in more detail (Table 3). Besides choosing from the same predefined attribute domains, additional text phrases, tags, and keywords can be noted. Multiple attribute domains can be applied to describe more complex data types, where the selection of a single one is not appropriate. When information is placed in the metadata, the file size of the original dataset does not increase. Therefore, processing time for data analysis is not affected by the amount of metadata.

Data queries and automated processing with analysis tools or GIS applications is not yet possible with information stored in the metadata. Metadata is stored in a separate file alongside with the dataset and needs to be transferred in parallel with each data exchange. The risk of losing this information during data exchange is not neglectable even for advanced practitioners. During data exchange, both systems (consignor and recipient) need to have the same technical and software standards to process data and metadata at the same high-quality level. Institutions with different technical capacities, both transnationally and nationally, need to overcome such obstacles.

Table 3: Overview on advantages (+) and limits (-) of transferring information (I) as attribute encoded in the data and (II) as description in the metadata.

Attribute encoded	**Metadata**
+ Information is included in dataset (risk of loss during data exchange diminishes) + Accessible for data analysis + Access with multifunctional tools	+ File size does not increase (process time not affected) + Multiple attribute domains can be applied + All additional information for the dataset in the metadata (additional text phrases, tags and keywords)
- Increasing file size (processing time might be affected) - No multiple choices in attribute domains - Additional information (detailed description, tags, keywords, etc.) needs to be placed separately in the metadata	- No automated access for multifunctional tools - Separate file (risk of loss during data exchange) - Same technical system and software standards necessary to share and process data

3.4 Inclusion of non-spatial data

Non-spatial data can be given a suggestive spatial frame. By referring to an auxiliary spatial data layer, such as a shapefile in vector format, non-spatial data can be included in a geographic database. The shapefile is delineated by the target area of the information in the non-spatial dataset. The actual dataset can be uploaded to the database in its original format and attached to the auxiliary file. Alternatively, the information can be linked to its original source if it is available online. The method allows including further information on the dataset the same way as for spatial datasets, for example on the spatial and temporal dimensions of the data.

The status of MSP processes in the Baltic Sea countries is used as an illustrative example for including non-spatial data in a GIS-application. Here, national waters are chosen as target areas for the spatial auxiliary file (Figure 4). Information about the planning area and the status of planning may as such be included in the metadata or in the attribute table (Table 4). Links to the official planning documents and further information not directly relevant for data queries may be included in the metadata alone (Table 4, grey background). Additional columns can be implemented to specify more detailed information about the dataset.

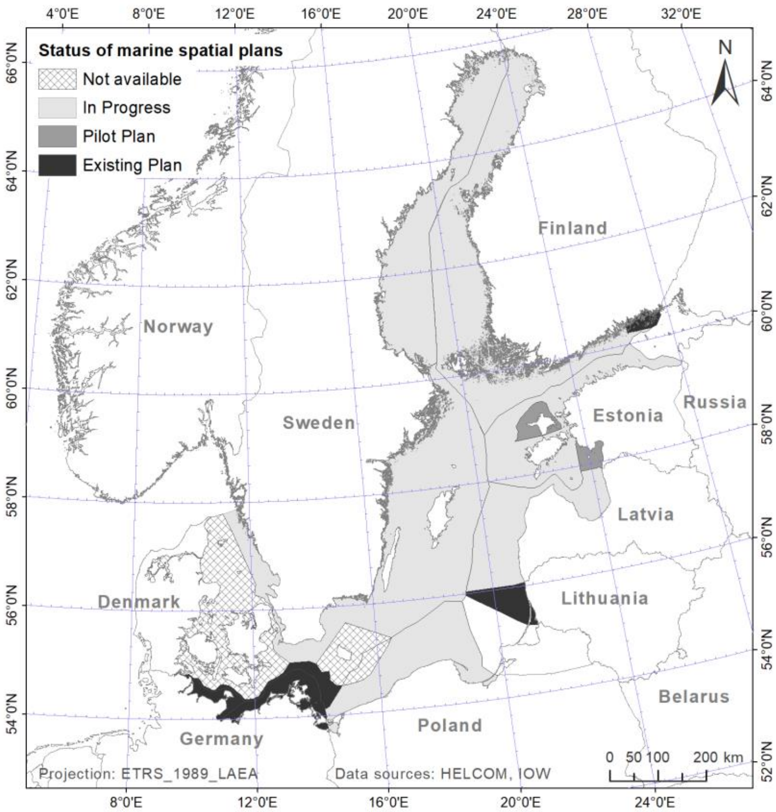

Figure 4: The status of marine spatial planning in the Baltic Sea EU countries as an example of implementing non-spatial data in a GIS-application using an auxiliary file.

Table 4: Information for an attribute table and/ or metadata (grey background) of an auxiliary file that visualises non-spatial data. The example corresponds to Figure 4, representing the status of marine spatial plans in the EU.

Planning area	**Status**	**Link to original data**	**Further information**
Denmark	Not available		www.msp-platform.eu/countries/denmark
Estonia Hiiu Island	Pilot Plan		https://www.msp-platform.eu/countries/estonia
Estonia Parnu Bay area	Pilot plan		https://www.msp-platform.eu/countries/estonia
Estonia	In progress		https://www.msp-platform.eu/countries/estonia
Finland	In progress	https://www.merialuesuunnittelu.fi/en/	https://www.msp-platform.eu/countries/finland
Finland Kymenlaakso Region	Existing plan		https://www.msp-platform.eu/countries/finland
Germany EEZ	Existing Plan	https://www.bsh.de/EN/TOPICS/Offshore/Maritime_spatial_planning/maritime_spatial_planning_node.html	www.msp-platform.eu/countries/germany
Germany MV	Existing Plan	https://www.bsh.de/EN/TOPICS/Offshore/Maritime_spatial_planning/maritime_spatial_planning_node.html	www.msp-platform.eu/countries/germany
Germany SH	Existing Plan	https://www.bsh.de/EN/TOPICS/Offshore/Maritime_spatial_planning/maritime_spatial_planning_node.html	www.msp-platform.eu/countries/germany
Latvia	In progress		https://www.msp-platform.eu/countries/latvia
Lithuania	Existing plan	https://www.msp-platform.eu/practices/supplement-lithuanian-master-plan-marine-spatial-solutions	https://www.msp-platform.eu/countries/lithuania
Poland	In progress		https://www.msp-platform.eu/countries/poland
Sweden	In Progress	https://www.havochvatten.se/en/swam/eu--international/marine-spatial-planning/consultation.html	www.msp-platform.eu/countries/sweden

4. DISCUSSION

Applying the data harmonisation concept holds several benefits for different user groups. The accessibility, understandability and transparency of different data types in MSP will improve in different aspects (Table 5).

4. 1. Potential user benefits

Besides the complexity and heterogeneity of datasets utilised in MSP, various user groups (e.g. planners, stakeholders, technology) have different requirements and needs for datasets related to the planning processes.

Planners need information, not only to understand the object of planning and the developments there, but also to ensure proper communication and stakeholder involvement throughout the planning process (Zaucha, 2012). For stakeholder integration, it is important to pay attention to the language and terminology used in presenting the information. The presentation format affects how easily spatial and temporal information is understood by users (Shucksmith & Kelly, 2014). Stakeholders with varying backgrounds may perceive maps, visualisation methods, and choices of words differently, which in turn may cause unnecessary misconceptions or biases interpreting the evidence. Here, it is crucial to understand both the spatial and temporal coverage of the information.

The proposed conceptual framework provides a basis to document and compare information using a common language. Simple wording and intuitive categories may reduce the potential of misinterpretation and enable easy access and understanding for planners, stakeholders or other users. In reality, building a system of data harmonisation in which all of the spatial and temporal dimensions will be properly addressed is nevertheless very challenging. Maximal benefit from the categorisation is gained when all datasets are structured the same way. However, adapting old datasets to the proposed model may be difficult.

Providing information on the vertical and temporal dimension besides the horizontal extent, helps to decide whether activities can occur simultaneously (without affecting each other). It is highly relevant for both the planners and the stakeholders to fully consider the influence that activities are causing on the environment and on other sea use sectors (HELCOM, 2016, 2017). Highlighting the versatility in dimensions in human uses may also help to identify opportunities for co-location. Also here, planners and stakeholders could benefit from more detailed information on spatial and temporal dimensions in datasets.

While in general, planners are interested in incorporating social data in planning evidence, data availability and integration of social and biophysical data can be challenging (Cornu et al., 2014). The visibility and availability of inherently non-spatial information in traditionally spatial domains of MSP data can be enhanced by storing the knowledge in a common database. The suggested auxiliary file method presented in this paper is straightforward and easily adaptable. Comparing different data types is additionally improved by the use of a common categorisation with predefined attribute domains.

The application of Spatial Decision Support Systems (SDSS), multi-functional tools, interactive mapping, and automated analysing instruments are standard procedures within MSP processes (Fiduccia et al., 2016; Dapueto et al., 2015; Greco et al., 2018; Janssen et al., 2015; Pinarbaşi et al., 2017). In general, applied technical devices do not set requirements on data e.g. categorisation, relations, or other specifications. Nonetheless, for robust analyses, all data need to be compatible. The proposed categorisation including the predefined attribute domains meets the need for harmonious wording and facilitates the access with automated tools. The spatial and temporal categorisation can support transparent visualisation at the user interface, facilitate navigation and data queries, as well as enhance data organisation and management. Data on the temporal dimension can potentially enable data exploration methods such as the animation of seasonal variations in data.

The proposed conceptual framework meets the fundamental FAIR data principles: Findability Accessibility, Interoperability and Reusability (Wilkinson et al. 2016) for good data management for users as well as automated instruments by harmonious wording and terminology, transparent and intuitively structured categorisation and widespread descriptions of information.

4.2 Applicability of spatial and temporal categorisation to MSP data types

4.2.1 Administrative boundaries

In general, 'administrative boundaries' represent a rather static type of data, although there are a general trend towards larger administrative units. Additional information on the spatial and temporal dimension of the datasets provides little practical benefits (Table 5).

Administrative boundaries do not have vertical limitations; they usually cover the whole column of the marine environment, from the depths of the seafloor to the sea surface and the air column above it. Therefore, a more detailed description of the vertical dimension is rarely applicable. The horizontal dimension on the contrary may add useful information, e.g. when searching for information on a specific administrative level, such as municipal boundaries on a local scale.

Information on the temporal dimension can be useful but also redundant within ‘administrative boundaries’ datasets. State borders or economic zones represent static information where temporal occurrence and temporal frequency are not applicable. Changes may occur in the timeline as information represents either past, present, or future situations.

4.2.2 Environmental data

‘Environmental data’ (including model data) is usually based on field measurements or observations. This means that data are derived at specific coordinates, describing a temporary situation, such as current direction or intensity at a certain location.

For some environmental data, the vertical component is specified by providing the depth of measurement: e.g. methane concentration in 35 metres depth below sea surface. However, without information on the total water depth at the sampling location, such data does not imply whether the sample originates from close to the seafloor or rather from the topmost water layer (in relative terms). Thus, a categorisation of the vertical dimension can help users to assess whether the data is suitable for their purposes.

Information about the temporal dimension is beneficial with environmental datasets. Recurring events such as bird migration, algae blooms, tidal activities, and weather conditions can be described more accurately when adding information on occurrence and frequency. Datasets of modelled environmental conditions may reconstruct the past or predict the future, which can be referred to in the category ‘timeline’.

4.2.3 Human activities

The data type ‘human activities’ seems to be categorised most naturally into the proposed spatial and temporal attribute domains. Human activities have pronounced spatial and temporal aspects.

Leisure boating or surfing affects merely the surface water layer, whereas installed pipelines or cables have an impact on the seafloor. Wind energy infrastructure, sediment dredging, or oil ricks, on the contrary, are examples of activities that have an effect on the entire water column. Maritime transport activities can include one-time voyages or operate on a regular basis. There are many activities that are strongly seasonal, such as recreational activities along the coastline. The timeline can include information on past activities as well as predictions and scenarios on future developments.

Overall, a detailed description of space and time for human activity data can facilitate the identification of synergies and conflicts of these. The detailed categorisation meets the demands of more transparency and better description of spatial and temporal aspects for impact and pressure assessments (HELCOM, 2010, 2016, 2017; Uusitalo et al., 2016).

4.2.4 Socio-economic and policy-related data

With spatial auxiliary files, non-spatial (socio-economic and policy-related) information can be handled as spatial data, which allows all information to be accessible in one place. Moreover, it allows using a coherent categorisation on space and time in the same way as for naturally spatial datasets.

Concerning the spatial dimension, e.g. national laws or sector development plans can be linked to an auxiliary file (shapefile) with the national borders as target areas. Socio-economic data, such as the willingness of residents to contribute to a nature protection scheme (e.g. acquired via interviews or workshops), may address very local settings. In these cases, a shapefile can include the area to be protected as a polygon feature or locations of individual events as point features.

Considering the vertical dimension, the attribute domain ‘coastalRegion’ can be selected for activities that are not operated directly in water. Such activities may relate to statistics of overnight stays in the area. Evidence on cultural values can be assigned to the above sea surface environment (attributes domains ‘airColumn’, ‘coastalRegion’) if it considers scenery values or to ‘seafloor’ if it lists underwater cultural heritage sites. Offshore wind park developments have multiple vertical impact layers. The above sea surface parts of the constructions can have an effect on migratory birds or landscape values, and at the same time, the submarine parts affect seafloor habitats or influence local currents. Here, the attribute domain ‘entireColumn’ is appropriate.

Similar to ‘administrative data’, ‘socio-economic and policy data’ can be rather static in nature and a detailed description of temporal occurrence and frequency is not applicable. However, it can be distinguished whether the data represents past, present, or future conditions. The majority of data represents either existing activities or the most recent, up-to-date information available. The future is represented in scenarios of climate change impacts and economic developments and the past in historical datasets and outdated documents, where newer versions are already available.

Table 5: Overview of strengths and limits of the data harmonisation concept focusing on the perspective of users and addressing different data types used in MSP processes.

	Strengths	Limits
Planners, stakeholders, other users, technology	+ structural basis to document and compare information	- categorisation approach requires training of planners, users, etc.
	+ usage of common language, simple wording	- integration of older data is challenging: data with no categorisation needs modulation (time consuming)
	+ fast access	
	+ facilitates the identification of synergies and conflicts	
	+ transparent information for impact assessment of activities	
	+ incorporation of non-spatial data possible	
	+ application in Spatial Decision Support Systems	
	+ facilitation of navigation, organisation, and data exploration	
Administrative boundaries	+ description of horizontal dimension possible	- static data type, categorisation provides little practical benefit
	+ description of timeline possible	
Environmental data	+ model derived data allow visualisation of past and future condition	- most data describe particular situation at specific location at certain time in the past
	+ compilation of data on reoccurring environmental phenomena	
Human activities	+ facilitates identification of synergies and conflicts of simultaneously occurring activities	
	+ compilation of data on reoccurring activities	
	+ transparent information for impact assessment of activities	
Socio-economic and policy-related data	+ information accessible in GIS-system	- static data type, categorization provides little practical benefit
	+ inclusion of information of coastal region in MSP	
	+ description of timeline possible	

4.3 Data quality control

A highly challenging aspect in data management, in general and in working with a categorisation system such as presented here, is the quality control. Data portals should have quality control systems as incoming dataset and metadata sometimes have errors despite common guidelines and data quality requirements (Underwood et al., 2018). This includes aspects such as correct and harmonised classification, regular updates, and accessible storage of information.

To maximise the benefits of data categorisation, it must be ensured that attribute domains are used in a harmonious way. Harmonisation is especially important in enabling transnational data exchange processes (Abramic et al., 2018; Jay et al., 2016). Even though the scope and level of detail in data may be simpler in cross-border planning, the coherence and harmonisation of the datasets remains a major task, which begins with a challenge of finding a common language and consistent vocabulary (MSP Data Study, 2016). The predefined attribute domains along with simple descriptions presented here can help to reduce false or ambiguous categorisation.

Datasets and corresponding metadata need updates. A national strategy document may represent ‘present’ information at the time of uploading. However, the information becomes ‘past’ or outdated whenever a new updated version of the document is published. In such cases, the old document can be stored in the database as a historical reference, which in some cases may be appropriate, but the timeline category of the evidence ought to be changed irrespective of the fact whether a new document is available in the portal or not.

One option to maintain high quality data and to ensure the suitability of datasets for different user needs is to store information within the dataset itself (in the attribute table) as well as in the metadata. As attribute domains in the attribute table are rather short, information in the metadata can give more details and additional explanation. However, providing data and metadata should be easy and intuitive in order to make data sharing attractive. If data and metadata descriptions are too complicated and time-consuming to produce (Kalantari et al., 2014; Olfat et al., 2011) data providers may lose interest in data exchange. Consequently, effort should be paid to avoid or lower any hindrances to the users to provide and share their own data and information in MSP processes. Moreover, involving the data providers to keep the data harmonisation updated is a further challenge that requires concrete solutions.

5 CONCLUSION

The presented conceptual framework categorises the spatial and temporal dimensions in a meaningful way for MSP purposes. It facilitates analysis of potential areas of conflict or for co-location of activities. The simple and intuitive language in predefined attribute domains can contribute to data harmonisation in cross-border planning. To ensure high quality of datasets, the framework may be implemented in both the attribute table and the metadata depending on the needs of the user. The inclusion of non-spatial data within GIS repositories ensures the availability of all relevant data in one database. This may foster a more holistic approach to planning. Overall, the conceptual framework provides effective steps towards a more coherent data management in line with the FAIR principles and subsequently better use of information in MSP processes.

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