[DM-07-091] Marine Spatial Data Infrastructure

Abstract

Marine Spatial Data Infrastructure (MSDI), the extension of terrestrial Spatial Data Infrastructure to the marine environment, is a type of cyberinfrastructure that facilitates the discovery, access, management, distribution, reuse, and preservation of hydrospatial data. MSDIs provide timely access to data from public and private organizations of marine related disciplines such as hydrography, oceanography, meteorology and maritime economic sectors, to be used for applications such as the safety of navigation, aquatic and marine activities, economic development, security and defence, scientific research, and marine ecosystems sustainability. This chapter discusses the main pillars of a MSDI, its importance for facilitating public processes such as Marine Spatial Planning and Coastal Zone Management, the wide range of stakeholders, implementation challenges, and future developments, such as the FAIR design principles, new data sources and services.

Keywords: data architecture, FAIR Principles, hydrospatial, marine spatial planning (MSP), maritime big data, nautical charts, S-100, SDI, spatial data infrastructure

Author & citation

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Explanation

1. Definitions

Coastal Zone Management (CZM) involves public policies and processes for managing coastal areas to balance environmental, economic, human health, and human activities, aiming to preserve, protect, develop, enhance, and restore where possible, the coastal resources. (NOAA, 2021)

Cyberinfrastructure consists of systems, data, information management, advanced instruments, visualization environments and people linked together to improve productivity and enable knowledge breakthroughs and discoveries not otherwise possible. (Stewart et al. 2010)

FAIR Principles emphasize that data and associated metadata shall be Findable, Accessible, Interoperable, and Reusable by both machines and humans. (Wilkinson et al., 2016)

Hydrospatial includes the spatio-temporal physical, biological, and chemical data and information related to their position on or in the water surface, column, depth, bottom and sub-bottom of the oceans, seas, estuaries, rivers, lakes, the coastal zones, and the flooding areas. (Hains et al., 2021)

Marine Cadastre (MC) is a system to enable the boundaries of maritime rights and interests to be recorded, spatially managed and physically defined in relationship to the boundaries of other neighboring or underlying rights and interests (Robertson, 1999). The foundation of a MC is the United Nations Convention on the Law Of the Sea (UNCLOS) that serves as the international law of the marine space.

Marine Spatial Data Infrastructure (MSDI) is the component of a Spatial Data Infrastructure (SDI) that encompasses marine and coastal geographic and business information. A MSDI typically includes information on seabed bathymetry (elevation), geology, infrastructure (e.g., offshore installations, pipelines, cables), administrative and legal boundaries, areas of conservation of marine habitats and oceanography. (IHO, 2017)

Marine Spatial Planning (MSP) is the public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that have been specified through a political process. (UNESCO, 2021)

2. Marine Domain Importance and MSDI Benefits

The marine environment is vital to our planet's biosphere; it regulates the weather and produces the majority of the oxygen we breathe, while it serves as the backbone of the global economy with enabling important sectors such as fishing, tourism, and international shipping (Buonocore, 2021). Yet, human activities often impact the already fragile marine ecosystem: millions of tons of plastic end up in the sea every year, the majority of the world's wastewater is discharged untreated, and overfishing threatens the stability of fish resources (UNEP, 2021). The degradation of world's ecosystem increases the various challenges and risks humanity and especially the coastal communities are facing, such as sea level rise, coastal erosion, and extreme weather events.

State and local governments work to effectively manage coastal areas, aiming to providing public access for recreation, maintaining water quality, protecting the coastal population, preserving important habitats, and encouraging economic development (NOAA, 2021). A Marine Spatial Data Infrastructure (MSDI) facilitates this effort by, among others, reducing data gathering and duplication of effort among agencies/organizations, and supporting re-use of data for various projects ("collect once-use many times" paradigm). This result in cost reduction either by sharing cost or by re-assigning priorities where data does not exist rather than collecting data twice (or more) for the same area. Furthermore, value of geospatial information increases as it becomes discoverable and usable, hence helping national and local economies. In short, MSDIs (NRC, 2018):

- Provide a simple, efficient, expandable and transparent governance solution.

- Facilitate provision of targeted marine applications, tools and services.
- Promote access, visibility, and delivery of value-added products.
- Leverage existing federal and international initiatives.

3. MSDI, MSP, and Marine Cadastre

MSDI, Marine Cadastre (MC), and Marine Spatial Planning (MSP) have become key factors in developing marine ecosystem-based management a reality, initially driven by international and national interest in delineating marine protected areas (Douvere, 2008). MSP is a practical way to create and establish a rational use of marine space and the interactions among its uses, to balance demands for development with the need to protect the environment, and to deliver social and economic outcomes in an open and planned way (Ehler, 2009). MSP is the process of managing when, where, and how human activities take place in the three-dimensional marine space. Dealing with demands for marine space use, government officials are called to satisfy stakeholders and their increasing interests, balance competing interests, and ensure society benefits, while protecting the marine environment. Government authorities rely on a well-built system to achieve the above in an effective manner, where the spatial extent of rights, restrictions, and responsibilities in the marine environment need to be defined. A MC is the system that enables the boundaries of maritime rights and interests to be recorded, spatially managed and physically defined in relationship to the boundaries of other neighboring or underlying rights and interests" (Robertson, 1999). A MC is a base layer of a MSDI, the official infrastructure that facilitates the access and integration of multi-source marine spatial data.

4. MSDI Pilllars

MSDIs, being the extension of Spatial Data Infrastructures (SDIs) (see DM-60 - Spatial Data Infrastructures) in the marine domain, consist of four key pillars (Figure 1): Data along with their metadata; Systems, including the hosting platform architecture and the geospatial services; Spatial and domain Standards; Stakeholders, along with the overall operating model which includes policies and processes governance.

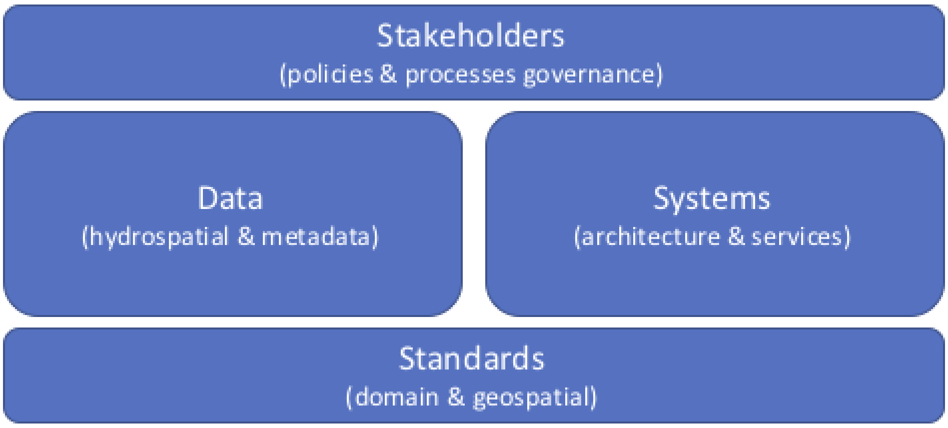

Figure 1. MSDI Pillars. Source: authors.

4.1 Data and Metadata

A MSDI typically includes hydrospatial data related to seabed topography, geology, marine infrastructure, resources, utilization, legal and administrative boundaries, areas of conservation, marine habitals, and oceanography. More precisely, a MSDI may include data and metadata related to (OGC & IHO, 2018):

- Hydrography, e.g.: shorelines; bathymetry and seabed characteristics; marine infrastructure (e.g., offshore installations, pipelines, cables); aids and dangers to navigation (e.g., lights, beacons, buoys, and wrecks, rocks, obstructions).
- Oceanography, e.g.: ocean currents, waves, and tides; water properties (e.g., water temperature, salinity, fluorescence, turbidity); geology, offshore minerals, oceanographic features; sea ice and iceberg presence, density, and velocity.
- Meteorology and Climate, e.g.: wind velocity and direction; air temperature, humidity, and atmospheric pressure; cryosphere Data such as areas of snow, ice, and frozen ground.
- Land & Marine Space Use, e.g.: Administrative and legal boundaries, areas of conservation; topographic base maps and coastal mapping; land cover, offshore cadaster, land ownership, flood hazards, and gazetteer; optical and radar imagery.
- Port & Vessel Tracking, e.g.: berth data for ports, anchorages, offshore terminals, marinas, fishing harbors; port call messages, vessels database including vessels characteristics; automatic Identification System (AIS) data.

4.2 Standards

SDIs are built based on standards that represent and store spatial information in data files and database systems, and serve spatial data, metadata and processes via web services. According to the International Organization for Standardization (ISO) and the Open Geospatial Consortium (OGC), standards are essential to enabling the spatial data interoperability among SDIs.

In regard to the marine domain and MSDIs, the International Hydrographic Organization (IHO) is the intergovernmental organization that establishes and maintains domain specific standards to assist in the collection and use of hydrospatial data and information with the aim to support safe navigation. IHO has developed the S-100 Universal Hydrographic Data Model, a versatile standard framework aligned with the ISO 19100 Geographic Information / Geomatics series of standards, that aims to supporting a wide range of users and applications beyond the core hydrographic (IHO, 2018) (see DM90: Hydrographic Geospatial Data Standards, forthcoming).

S-100 has been designed to address the limitations of its predecessor S-57, an established format for electronic navigational charts (ENC) but limited only to hydrographic data, and extend its use to other marine related geospatial applications. S-100 provides the universal data model for holding a wide range of data in a widely recognized format. It is adopted by the United Nations’ International Maritime Organization (IMO) to be the basis of IMO’s Common Maritime Data Structure (CMDS) of e-navigation (Hahn, 2016). E-navigation aims to improving the sharing of marine information through the use of modern technology and includes marine data such as electronic navigational charts, bathymetric data, tidal data, meteorology data, radar-image data, and the radio-based AIS data.

4.3 Systems

Architecture

A properly defined architecture is key for ensuring MSDI remains healthy and growing. Data architecture acts as a framework of rules, policies, models, and standards that dictate how data are stored, managed, and integrated. Besides establishing what data model to use, an important aspect is how and where to store the data. There are various options, with different advantages and disadvantages, with two being the Data Lake and Data Hub (Contarinis et al., 2020):

- **Data Lake** is a catch-all area for any data, typically built from a variety of different sources, where data is stored in its 'natural' form. It's optimized for quantity and is a place for data to sit untouched before its cleaned, interpreted, and transformed.
- **Data Hub** is a hub-and-spoke approach to data integration where data is physically moved and re-indexed into the MSDI. To be a Data Hub, the MSDI shall support discovery, indexing, and analytics.

Services

Most current MSDI implementations focus on data sharing and dissemination in the form of individual files, through HTTP, FTP and SSH protocols, web services for data access and web portals (Müller, 2020). The OGC has defined some of the most used web services for geospatial data, including:

- the web map service (WMS) that enables sharing of images (map tiles),
- the web feature service (WFS) that enables sharing of feature data with attributes,
- the web coverage service (WCS) that enables sharing of raster data,
- the web processing service (WPS) that enables sharing of algorithms to perform on data.

4.4 Stakeholders

MSDI Stakeholders may vary considerably, as Table 1 shows. End users require easy discovery, access, download and analysis of marine spatial data. Data producers' needs include the ability to publish, integrate, aggregate, and analyze geospatial data and related descriptive (non-geospatial) data, with a focus on the ease-of-use and effectiveness. Data producers expect from MSDIs the capability to harvest data from existing solutions in a secure, reliable manner. In addition, they expect real-time or archived availability, intellectual property rights management, reuse and indemnification rules, security and privacy settings, as well as the relevant financial arrangements.

Table 1. MSDI Stakeholders (OGC and IHO, 2018)

MSDI Stakeholders	Data Producers	End Users
Academic and educational institutions	yes	yes
Archeology, marine, hydrology, ecology science		yes
Authorities: Port Authority, Marine Authority	yes	yes
Commercial data / analytic providers	yes	
Diplomatic and national security officials		yes
Environmental Protection Agencies	yes	yes
Federal, state, provincial government agencies	yes	yes
Fishing companies		yes

MSDI Stakeholders	Data Producers	End Users
GIS and Information Technology	yes	
Insurance companies	yes	yes
Internet and Social Media providers	yes	
International Intergovernmental Organizations	yes	yes
Local Government Agencies	yes	yes
Mapping and GIS Experts		yes
Marine and Oceanographic boards and groups	yes	yes
Military Organizations	yes	yes
Mining companies		yes
NGO Service Providers		yes
Port managers and harbormasters		yes
Public Authorities	yes	yes
Researchers, various such as climate conservation		yes
Search and rescue officials		yes
Shipping and cruise ship companies		yes
Software developers		yes
Standards Developing Organizations		yes
The General Public	yes	yes
Transportation		yes
Utility companies/organizations: Oil & Gas, Power	yes	yes

5. MSDI Examples

There are several examples of deployed MSDIs such as those by Australia, Canada, European Union, and USA. In the United States, the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management partners with other organizations to provide data, tools, and information for the marine community. Datasets range from economic to satellite imagery. A web platform named 'Digital Coast' provides access to data, as well as visualization and predictive tools, and online training courses that make data easier to find and use. The National Centers for Environmental Information (NCEI) alone, one of the major partners to this effort, hosts and provides public access to over 37 petabytes of atmospheric, coastal, oceanic, and geophysical data, one of the most significant archives for environmental data globally.

On the other side of the Atlantic, the European Marine Observation and Data Network (EMODnet) is the regional MSDI for Europe offering a range of data archives managed by local, national, regional, and international organizations. Through online platforms, users have access to standardized observations, data quality indicators, and processed data products across seven discipline-based themes:

Bathymetry data (water depth), coastlines, and location of underwater features such as wrecks.

1. Bathymetry data (water depth), coastlines, and location of underwater features such as wrecks.

2. Biology data on temporal and spatial distribution of species abundance and biomass from several taxa.
3. Chemistry data on the concentration of nutrients, organic matter, pesticides, heavy metals, radionuclides and antifoulants in water, sediment and biota.
4. Geology data on seabed substrate, sea-floor geology, coastal behaviour, geological events, and minerals.
5. Human activities data on the intensity and spatial extent of these activities at sea.
6. Physics data on salinity, temperature, waves, winds, currents, sea-level, light attenuation, ice, river outflow, underwater noise.
7. Seabed habitats data, including maps and models on the spatial distribution and extent of seabed habitats and communities.

6. Implementation Challenges

Main issues and challenges toward the implementation of a MSDI include:

1. The development of a seamless database to include coastal data. The land/sea interface has yet to be thoroughly described and understood, and it encompasses technical issues such as the discontinuity between land and marine cadastres, or that depth and elevation models may be referenced to different vertical systems (see Athanasiou et al, 2017).
2. Legal issues. UNCLOS defines the legal status in the maritime space and the jurisdiction of neighbouring states, however data overlaps and jurisdiction disagreements over the same marine areas may exist between neighbouring coastal states lacking agreed maritime boundaries (see Kastrisios & Pilikou, 2017).
3. Organizational. Coordination of efforts often becomes a matter of responsibility.
4. Funding. MSDI can be costly to implement at a national scale, especially for states with limited resources.

7. Future Developments

7.1 FAIR Principles

OGC, together with IHO, propose that the next generation of MSDIs shall be guided by the FAIR principles (OGC & IHO, 2018). The four FAIR principles, applicable to data, metadata, and the platform that hosts the infrastructure, are described as follows:

- **Findable**, metadata and data should be easy to find for both humans and computers. Machine-readable metadata are essential for automatic discovery of datasets and services, and, hence, the “FAIRification” process.
- **Accessible**, users need to know how the data can be accessed, possibly including authentication and authorization.
- **Interoperable**, the data usually need to be integrated with other data. Moreover, the data need to interoperate with applications or workflows for analysis, storage, and processing.
- **Reusable**, metadata and data should be well-described so that they can be replicated and/or combined in different settings.

7.2 New Services and Applications

OGC is undergoing a revolutionary effort around modernizing their API specifications to align with current technology and design patterns, such as REST, JSON, and OpenAPI. The OGC API efforts represent a clean break from the first generation WxS specifications. The modular nature of OGC API will allow for reuse of shared functionality (landing pages, conformance, collections, queryables, filtering, etc.) across various OGC APIs. Table 2 provides mappings between the widely used WxS specifications and the relevant emerging OGC API standards.

Table 2. Next Generation of OGC Web Services

WxS	OGC API
OWS Common	OCG API - Common
WMS	OGC API - Maps
WMTS	OGC API - Tiles
WFS	OGC API - Features
WCS	OGC API - Coverages
SLD	OGC API - Styles

7.3 New Data Sources and Processing Algorithms

The United Nations has declared 2021 - 2030 as the Decade of Ocean Science for Sustainable Development (DOSSD) that aims to provide a common framework to ensure that ocean science can fully support countries to achieve the 2030 UN Agenda for Sustainable Development. The Nippon Foundation-GEBCO Seabed 2030 Project has been formally endorsed as a Decade Action of the UN DOSSD. Seabed 2030 aims to bring together all available bathymetric data to provide the most authoritative publicly available bathymetry and produce the definitive map of the world ocean floor. In the global effort to achieve the above goals, a great amount of new data becomes available as new techniques and synergies emerge for the collection of hydrospatial data to fill the gaps.

Volunteered Geospatial / Hydrospatial Information (VGI/VHI), and satellite derived bathymetry (SDB) are two non-traditional, but with great potential, sources of hydrospatial data. Satellite imagery can be used to estimate bathymetry, especially in shallow, coastal areas. The concept of VGI/VHI (often called “crowed-sourced data”) is that users participate in data collection, in this case mostly non-specialized ships. For the processing of these big-data, new algorithms are being used and developed. For instance, deep learning techniques are used to estimate bathymetry where different methods are proposed in terms of accuracy, computational costs, and applicability to real data. Besides bathymetry, satellite imagery provides information for other uses such as benthic habitat mapping. In order to properly deal with big data, the next generation of MSDIs shall provide solutions based on the approach of processing data on the server side where data is stored (Yue et al. 2015, Müller 2020).

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