Bridging the Data Gulf: Designing a FAIR-Compliant Marine Spatial Data Infrastructure for Sustainable Coastal Governance in The Sultanate of Oman

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Abstract

The successful implementation of marine spatial planning (MSP) and mitigation against coastal hazards needs to have access to a variety of quality data. The marine information available in the Sultanate of Oman is typically dispersed across multiple ministries, institutions and in a variety of formats with different metadata. This form of insulation would complement the lack of interoperability, discoverability and reusability, and as such would have a direct impact on evidence-based policy and sustainable development of a blue economy. This study fills this gap by designing and testing a conceptual model of a national Marine Spatial Data Infrastructure (MSDI), which is clearly designed to be founded on the FAIR (Findable, Accessible, Interoperable, Reusable) guiding principles. Going beyond a generic SDI model, the framework offers a customised way of implementation in the Omani context. The methodology will incorporate an in-depth study of the best practices of international MSDI and a stakeholders' requirements analysis covering the top Omani government and research institutions. The proposed structure covers aspects of architectural components, metadata profiles, semantic interoperability protocols, and a governance model for the purpose of sustainability. This framework, as applied to the case study, can revolutionise the marine data situation in the Sultanate of Oman. A prototype metadata catalogue, a semantic ontology of alignment between national data and international vocabularies, and a policy roadmap are some of the major products. There is also a generalisable template for other coastal countries, and the study shows that FAIR-based MSDIs are not the technical systems and structures, but merely the basic elements of transdisciplinary ocean science, climate resilience and efficient maritime spatial governance.

1. Introduction: The Data Gulf in Oman

The Sultanate of Oman is becoming more aware of the need to develop its blue economy in a sustainable manner through the implementation of Oman Vision 2040, owing to its long and strategic

maritime region. There are, however, significant impediments to achieving these aims, which can be described as the "Data Gulf". The currently existing marine data in Oman is scattered among different ministries like the Ministry of Environment, the Ministry of Agriculture, Fishery and Water Resources, the Ministry of Transport, Communication and Information Technology and various research institutions.

This fragmentation leads to data that comes in all kinds of different formats, such as Shapefiles, CSV files, GeoTIFFs, and proprietary formats. Importantly, there is no standard metadata, making it hard to find the data. Moreover, it is not semantically aligned, and thus, there is no interoperability of data. The final impact of this Data Gulf is poor technical underpinning of policy decisions, becoming an impediment to sustainable development of the blue economy, marine spatial planning (MSP) and climate resilience.

2. Methodology

This study aims to solve these problems by introducing a complete process to design a Marine Spatial Data Infrastructure (MSDI) applicable in the Omani context that complies with FAIRness principles. The approach consists of four key steps:

1. Benchmarking International Best Practices: Comprehensive review of existing international MSDI frameworks (including EMODnet (Europe)) and national initiatives in Australia and Canada to find their work strategies and possible challenges.
2. Stakeholder Requirements Analysis (SRA): 12 structured interviews were held with key Omani government agencies and research institutions to gather detailed requirements for information, the services available, and issues related to governance.
3. FAIR Principles Integration: Using the FAIR principles (Findable, Accessible, Interoperable, Reusable) as the principles that underlie the design of the MSDI architecture.
4. Prototype Implementation: Creating a working prototype of the proposed solution, such as creating a catalogue of metadata and a semantic mapping, to show the feasibility and benefits of the proposed solution.

3. The FAIR MSDI Framework

The proposed FAIR-compliant MSDI framework for Oman includes several components that will assure discoverability, accessibility and interoperability of data:

Adoption of the ISO 19115-1 standard with additional FAIR extensions to fully describe the data.

- Catalogue: To create a strong metadata catalogue, for example, using GeoNetwork or CKAN, to facilitate the discovery of data.
- Semantic Layer: Ensuring semantic interoperability by ensuring the local data vocabulary is aligned with other international standards, such as SeaDataNet, ENVO (Environment Ontology), and GCMD (Global Change Master Directory).
- Access Mechanisms: Standardised access through OGC (Open Geospatial Consortium) Web Map Services (WMS) and Web Feature Services (WFS), and through REST APIs, and assigning Digital Object Identifiers (DOIs) for datasets.
- Governance: Creating a cross-ministerial steering committee to provide governance for the MSDI and maintain political mandate and sustainability.

4. Results: Prototype Deliverables

Several major outcomes of the application of the proposed framework proved the practical viability of the framework:

- Metadata Catalogue Prototype: A working catalogue with five example datasets covering key marine areas, including bathymetry, fisheries, coastal infrastructure, marine habitats and ocean models.
- FAIR-Aligned Metadata Records: Creation of standardised metadata records that conform to the defined FAIR profile.
- Semantic Alignment: development of an RDF/TTL (Resource Description Framework/Turtle) mapping file to link national data schemas with international data vocabularies for true interoperability.
- Policy Roadmap: A four-phase implementation plan that is structured to guide the national rollout of the MSDI.

5. Implementation Roadmap

To ensure a structured and sustainable deployment, a four-phase implementation roadmap is proposed:

Table 1 Implementation Roadmap

Phase	Timeframe	Focus Area
Phase 0	0–6 months	Establishing Governance structures and securing a FAIR mandate.
Phase 1	6–12 months	Deployment of the core Metadata catalogue.
Phase 2	12–18 months	Implementing Semantic interoperability and vocabulary alignment.

Phase	Timeframe	Focus Area
Phase 3	18–24 months	Developing full Infrastructure capabilities and APIs.
Phase 4	24–36 months	Building Capacity and ensuring long-term sustainability.

6. Impact and Contribution

The adoption of an FAIR-compliant MSDI has many benefits at both the national and global scales.

6.1. Impact for Oman

The blue economy strategy fully aligns with the blue economy vision of Oman Vision 2040. It offers a comprehensive, easy-to-use, and interoperable database which supports successful Marine Spatial Planning (MSP), contributes to better climate resilience strategies, and better coastal hazard mitigation.

6.2. Global Contribution

This study offers a replicable FAIR-MSDI template which can be adopted by other coastal countries that are experiencing similar data fragmentation issues. It exemplifies how FAIR is not just a technical practice but also a key tool for achieving transdisciplinary ocean science and successful maritime spatial governance.

7. Conclusions

The study findings reveal that the implementation of a FAIR-compliant Marine Spatial Data Infrastructure in the Sultanate of Oman is very feasible by building on existing international standards. The key to achieving full interoperability between different datasets is semantic alignment. Technical frameworks, however, have to be backed up by strong governance, and for long-term sustainability, a strong political mandate and commitment to financing mechanisms.

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