Deliverable 1.2
Revised Project Data Management Plan, Associated Specification and Supporting Tools for Data Generation and Exchange (WP1)
Version 1.0

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Executive Summary

D1.2 updates and augments D1.1 (Lear et al., 2025) by reporting concrete progress, decisions, and remaining actions to operationalise MARCO-BOLO's data and information management processes and provide support to Work Packages 2-5 in the description and publication of their knowledge outputs. The approach remains aligned to UN Ocean Decade and the program components of IOC-UNESCO including ODIS and OBIS in addition to EMODnet as the European data gateway, through the use of schema.org based JSON-LD. We now provide an operational authoring pathway via Google Sheets → CSV → JSON-LD with validations and examples, plus clearer guidance on repository pathways and protocol DOIs.

Contents

1. Introduction

D1.1[3] outlined the high level strategic direction and idealized approach for the capture, description and publication of knowledge artifacts generated from the Horizon Europe funded MARCO-BOLO project. The overall aim is to achieve FAIR, linked-open (meta)data for MARCO-BOLO by using schema.org JSON-LD, established community vocabularies, and persistent identifiers, with harvesting through ODIS to facilitate the widest possible discoverability and interoperability. D1.2 reports how this approach has been tested and operationalised across the consortium, focusing on a user-friendly metadata authoring pathway and concrete repository routes.

2. Principles and Alignment

The principles established in Deliverable D1.1 remain the foundation of MARCO-BOLO's data and information management strategy, and D1.2 reaffirms these commitments while providing additional context and practical guidance. At the heart of this approach is the principle of **"publish once, use many times"**, which seeks to minimise duplication of effort and maximise the value of every data asset generated within the project. This principle ensures that once data and metadata are curated to an agreed standard, they can be seamlessly integrated into multiple systems, reused across disciplines, and linked to downstream products without repeated manual intervention. Central to this approach is in leveraging established, open long-term repositories to ensure high data availability and security.

To achieve this, MARCO-BOLO prioritises **web-scale interoperability**: the ability for diverse systems and platforms across the internet to seamlessly exchange and interpret data. This is accomplished by adopting schema.org (Guha et al., 2016) , with **JSON-LD** (Kellogg et al., 2020), as the core metadata representation. JSON-LD is widely recognised for its ability to embed structured, machine-readable information directly into web resources, enabling automated discovery and integration by search engines, aggregators, and knowledge graphs. By leveraging this format, MARCO-BOLO ensures that its outputs are not only **FAIR**—Findable, Accessible, Interoperable, and Reusable (Wilkinson et al., 2016)—but also aligned with the broader vision of a linked open data ecosystem. Persistent identifiers (PIDs) underpin this strategy, providing globally unique, resolvable references for datasets, protocols, software, and other entities. These identifiers guarantee that MARCO-BOLO resources remain citable and traceable long after the project concludes, supporting transparency, reproducibility, and long-term stewardship.

In addition to FAIR, MARCO-BOLO acknowledges the importance of **CARE** (Collective Benefit, Authority to Control, Responsibility, and Ethics) (Carroll et al., 2020) and **TRUST** principles (Lin et al., 2020), particularly when dealing with sensitive or community-owned data. These frameworks complement FAIR by embedding ethical considerations and governance responsibilities into data

[3]Lear, D., Exter, K., Tagliolato, P., Provoost, P., & Barry, R. (2025). Joint Data and Information Management Plan (Deliverable No. D1.1). MARCO-BOLO Project, Marine Biodiversity Association. https://marcobolo-project.eu/wp-content/uploads/2025/10/MARCO-BOLO_D1.1_29.05.2025.pdf

management practices, ensuring that openness does not come at the expense of equity or accountability.

The project also embraces the **Five-Star Open Data model (Figure 1)**, which provides a clear progression path for improving data openness and interoperability (Berners-Lee, T. 2006). At the entry level, data should be available on the web in any format; at the highest level, data should be linked to other datasets, creating a rich, interconnected web of knowledge. MARCO-BOLO's use of JSON-LD and linked identifiers aims to advance its outputs towards the upper tiers of this model, enabling cross-domain integration and advanced analytics.

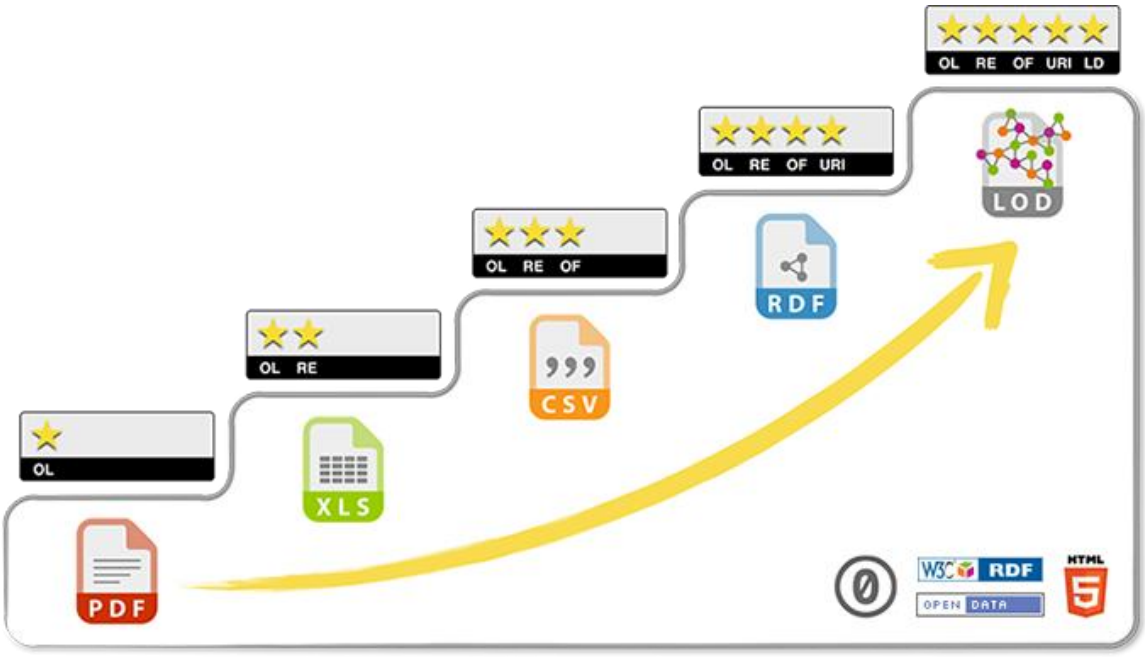

Figure 1: The Five-Star Open Data model. Illustration of five progressive levels of open data publication: ★ (One star): Data available on the web under an open license in any format (e.g., PDF document). ★★ (Two stars): Data available as machine-readable structured data (e.g., Excel spreadsheet). ★★★ (Three stars): Data available in non-proprietary, open format (e.g., CSV file). ★★★★ (Four stars): Data uses open standards from W3C, with URIs to identify entities, enabling direct referencing (e.g., RDF format). ★★★★★ (Five stars): Data is linked to other datasets to provide context, creating a web of interconnected data. Each level builds upon the previous, with higher stars indicating greater openness, interoperability, and reusability. Adapted from Berners-Lee (2006, 2010), https://5stardata.info/en/. Image is in the public domain.

Finally, MARCO-BOLO continues to align its work with global observation frameworks, particularly the **Essential Ocean Variables (EOVs)** (Miloslavich et al. 2018) defined by the Global Ocean Observing System (GOOS) and the **Essential Biodiversity Variables (EBVs)** (Jetz et al., 2019),

promoted by The Group on Earth Observations Biodiversity Observation Network (GEO BON). These frameworks provide a common language for describing and comparing observations across scales and disciplines. However, while EOV specifications are clearly defined, relatively mature and widely adopted, EBV definitions remain in flux, with ongoing discussions about metrics, resolution, and implementation. In light of this, D1.2 recommends a pragmatic approach: record the general EBV class name where applicable, without attempting to impose unstable or incomplete specifications, while fully adopting the more stable GOOS BioEco EOV standards wherever possible. This approach ensures that MARCO-BOLO metadata remains interoperable and forward-compatible, while avoiding unnecessary complexity or premature standardisation.

3. Work Package Support

Since the outset of MARCO-BOLO, Work Package 1 (WP1) has acted as the backbone for data and information management across the consortium, ensuring that technical work packages (WP2–WP5) can focus on their scientific objectives while meeting interoperability and FAIR compliance requirements. This support has been multi-faceted, combining strategic guidance, practical tools, and hands-on engagement.

3.1 Development of Authoring Tools and Templates

WP1 designed and iteratively improved a Google Sheets-based metadata authoring workflow (Figure 2), and this now serves as the primary interface for capturing structured metadata across all WPs. This tool simplifies the complexity of schema.org JSON-LD by providing user-friendly tabs for Actions, Datasets, People, Places, Documents, and Protocols. For WP2–WP5, this means that researchers can record essential details—such as sampling events, analytical steps, and derived outputs—without needing prior expertise in semantic web technologies. WP1 also embedded validation rules, dropdowns, and foreign-key checks to reduce errors and ensure consistency across entries.

3.2 Repository Pathway Guidance and Compliance

Each data-generating WP produces distinct types of outputs, from raw eDNA sequences (WP2) to biodiversity occurrences (WP3), autonomous system observations (WP4), and complex model outputs (WP5). WP1 aims to provide clear, domain-specific publishing routes: ENA for sequence data, OBIS/EMODnet Biology for species occurrences, and Zenodo or MarineInfo for software, workflows, and supporting documentation. This guidance was reinforced through the planned development of decision trees and quick-reference sheets, enabling WPs to navigate repository requirements confidently and avoid delays in data deposition.

3.3 Protocol Standardisation and DOI Assignment

Recognising the importance of reproducibility, WP1 worked closely with WP2 and WP4 to ensure that laboratory and analytical protocols are documented and published in trusted repositories such as Ocean Best Practices System (OBPS)., protocols.io, or Zenodo. WP1 will facilitate DOI minting for these protocols, enabling direct linkages to datasets and Actions in the metadata graph. This approach not only satisfies FAIR principles but also strengthens the scientific credibility of MARCO-BOLO outputs.

3.4 Hands-On Training and Data Clinics

WP1 organised regular “data surgeries” and one-to-one clinics to address practical challenges faced by WPs. For WP2, this included troubleshooting ENA submissions, clarifying checklist requirements, and resolving issues related to multiplexed sequencing libraries. For WP3 and WP4, WP1 provided guidance on geospatial metadata and sensor descriptions, ensuring alignment with Darwin Core and ODIS thematic profiles. WP5 benefited from advice on cataloguing aggregated datasets and representing provenance for complex modelling workflows. These sessions were instrumental in building confidence and capacity across the consortium.

3.5 Persistent Identifier Strategy and Governance

To guarantee long-term accessibility, WP1 introduced a W3ID-based identifier scheme for MARCO-BOLO entities. Each WP will be allocated a numeric range for opaque IDs, enabling independent assignment while maintaining global uniqueness. WP1 is also preparing routing configurations for w3id.org, ensuring that these identifiers will resolve to current landing pages even after project completion. This strategy is critical for sustaining interoperability with ODIS and other linked-data infrastructures.

3.6 Automation and Integration Support

Beyond manual guidance, WP1 developed scripts to automate key tasks, such as generating README files from Sheets metadata and compiling JSON-LD for harvesting by ODIS. These tools reduce administrative burden on WPs and ensure that outputs remain synchronised across repositories and documentation layers.

Through these combined efforts, WP1 has transformed data management from a compliance obligation into an integrated, value-adding component of MARCO-BOLO's scientific workflow. By embedding best practices and providing tailored support, WP1 has enabled WP2–WP5 to deliver high-quality, interoperable outputs that will stand the test of time.

4. Methods — Authoring & Publishing

We have operationalised an Action-centric authoring model implemented in Google Sheets v3, compiled to JSON-LD and readied for ODIS harvesting.

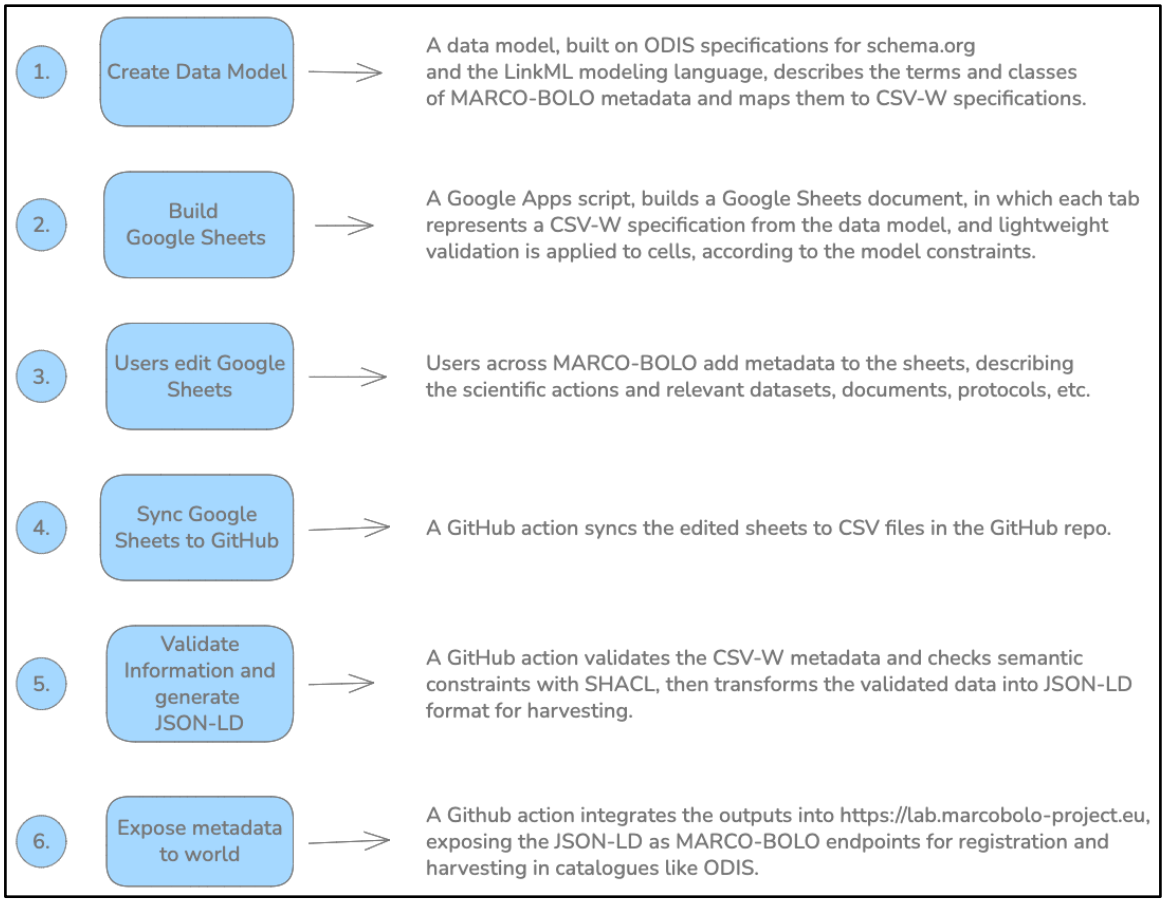

Figure 2: *Illustration of the workflow for the CSV-to-JSON-LD metadata tool. Beginning at step 1, a data model is built using the LinkML modeling language (LinkML Contributors, 2024) and CSV-W specifications (Tennison et al., 2015)). Google Apps scripts and GitHub actions drive data flow and validation, including semantic constraints with SHACL (Knublauch et al. 2017), resulting in valid JSON-LD for ingestion into data catalogues like ODIS.*

This approach has been tested with a small subset of task leads from the technical work packages, as task leads are the closest to the data generation and therefore best placed to describe it. Additionally a number of online meetings have been held to discuss the underlying concept and how it maps to the manner in which tasks have been delivered. A number of examples have been documented.

4.1 Authoring model and Sheets workflow

Contributors describe coherent “Actions” (e.g., Field sampling → Lab analysis → QC/processing → Publication), each linking inputs/outputs, who/where/when, and protocols/software. Information is entered into Sheets tabs (Action, Dataset, Person, Place, Document, HowTo) with validations for keys and foreign keys. The compiler generates conformant schema.org JSON-LD.

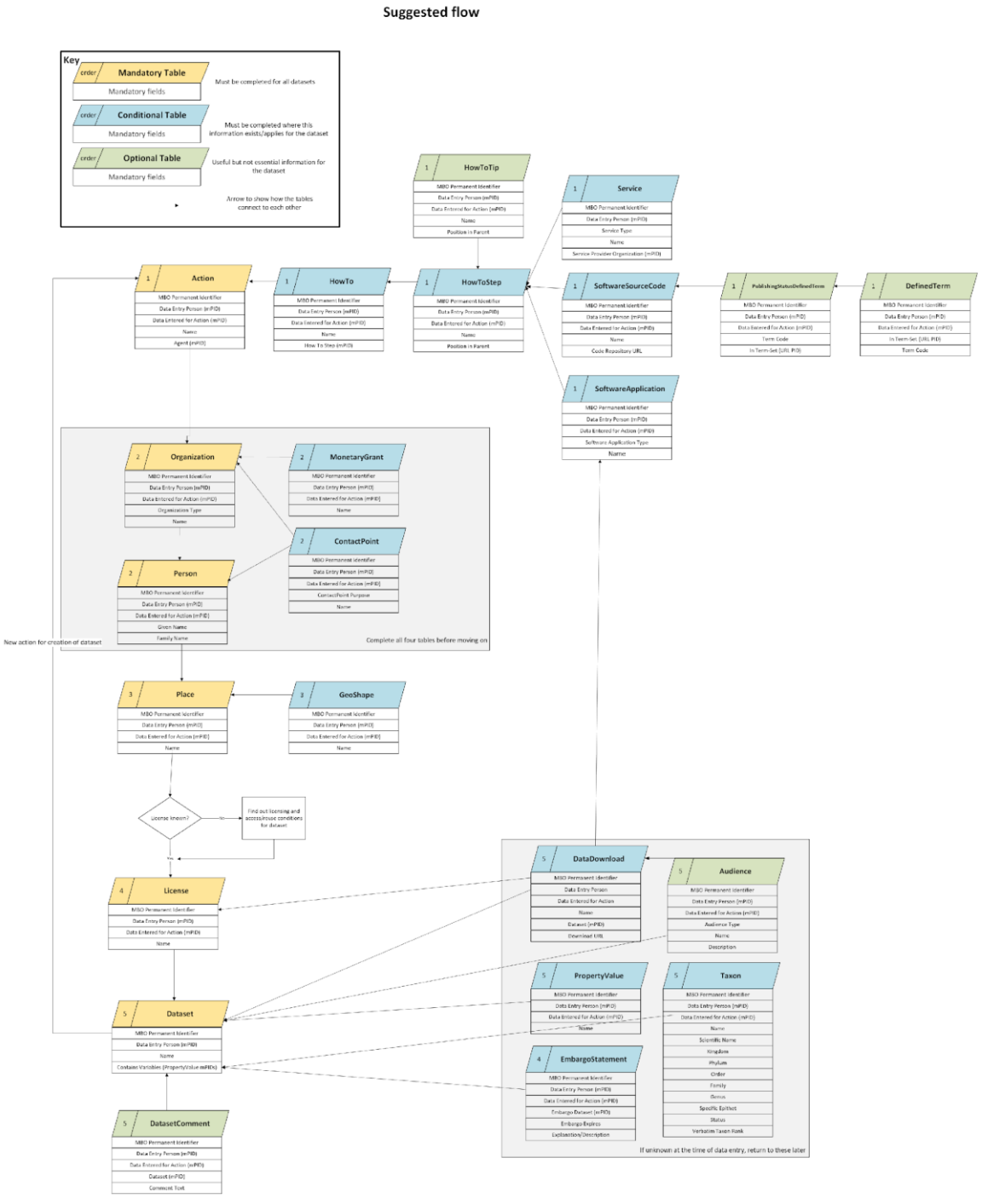

Figure 3— The workflow progresses from methodology documentation (top: Actions) through contributor information (People & Organizations group), geographic context (Place group), to data outputs (Dataset & Document group) with technical specifications (Dataset Details group). Required fields (yellow) ensure baseline metadata, while optional (green) and conditional (blue) fields support capturing the comprehensive process.

4.2 Publishing decision trees

Recognizing the scope of MARCO-BOLO will include a variety of primary and secondary data the workflow directs:

- New data: publish in a domain-appropriate FAIR repository; record DOI/URL and license in Sheets; prefer CC-BY/CC0.
- Reused published data: reference source DOI/URL; record transformation Actions; publish derived outputs with their own metadata.
- Unpublished inputs: either arrange publication by the owner or document constraints and provenance; proceed with derived outputs where permissible.

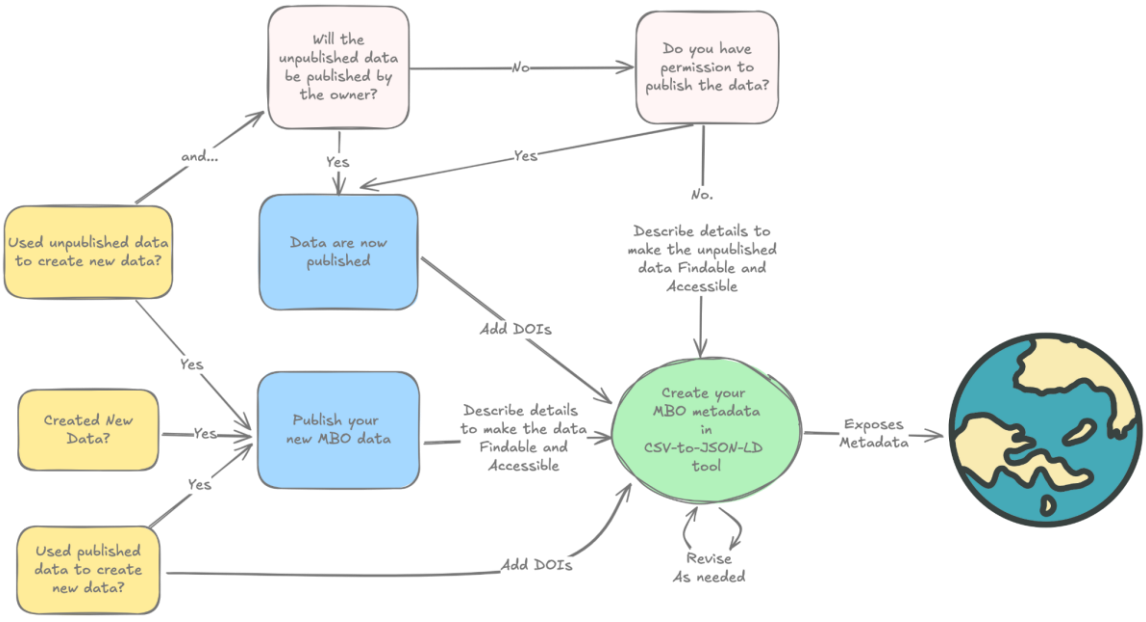

Fig. 4: The decision tree guides researchers through creating MBO metadata based on data provenance: for newly created data, unpublished data used with permission, or published data reuse. All paths converge at metadata creation in the CSV-to-JSON-LD tool, followed by DOI assignment and exposure through the catalog.

4.3 eDNA specifics (WP2)

For sequence data, structure samples/experiments to reflect replicates and multi-marker workflows. Where full multiplex archives are scientifically important, archive in Dryad and cross-link to ENA demultiplexed runs. Derived results should be mapped to OBIS via Darwin Core (DwC) using the IPT application.

4.4 Licensing & embargo

Default to CC-BY or CC0. Where licensing is not yet known, allow a temporary “undefined” value until resolved. For embargoed data, publish full metadata early and use “restricted” license with clear access conditions and publication date.

5. Identifier Strategy & Persistence

Persistent identifiers (PIDs) are fundamental to the FAIR principles, ensuring that every entity described in MARCO-BOLO metadata—datasets, actions, protocols, software, and even people—can be unambiguously referenced and resolved over time. Where possible and available MARCO-BOLO commits to utilising and preserving existing PIDs as used and provided by the data generating Work Packages.

While DOIs and ORCIDs serve well for publications and individuals, MARCO-BOLO requires a mechanism for project-specific entities that may not qualify for those existing PID systems. In these circumstances we proposed to utilise W3IDs.

W3ID is a community-based permanent identifier service endorsed by the W3C Permanent Identifier Community Group. It provides a stable, HTTPS-based namespace (https://w3id.org/) that can redirect to any current location of your resource. The key advantage is longevity. As such even after MARCO-BOLO funding ends or in the case of any hosting infrastructure changes, W3IDs will continue to resolve because the redirect rules are maintained in a public GitHub repository under community governance.

Why W3IDs for MARCO-BOLO?

- **Opaque, stable IDs:** MARCO-BOLO proposed the use of zero-padded slugs (e.g., mbo_0000001) under https://w3id.org/marco-bolo/. These IDs are semantically neutral, so they remain valid even if resource names or internal structures change.
- **Delegated ranges:** Each Work Package receives a numeric range (e.g., WP2: mbo_0002000–mbo_0004999), enabling independent assignment without central bottlenecks.
- **Machine-readable linking:** W3IDs become the @id in schema.org JSON-LD records, which ODIS harvests. This guarantees that MARCO-BOLO outputs are discoverable and interoperable in global linked-data graphs.
- **Future-proof routing:** Redirects are managed via .htaccess rules in the W3ID GitHub repo. If MARCO-BOLO's catalog moves, only the target URL changes—never the identifier.

Then utilisation of W3IDs ensures that users of MARCO-BOLO resources can confidently cite their use, with reassurance of the persistent nature of the identifier. W3IDs additionally facilitate automated interoperability with a machine actionable end-point, aligning with the FAIR principles and existing beyond the lifespan of MARCO-BOLO funding.

6. External Alignment with Regional and Global Infrastructures

The MARCO-BOLO approach to data and metadata publishing is deliberately designed to integrate seamlessly with established global infrastructures, ensuring that project outputs are not only FAIR but also discoverable and reusable at scale. To achieve this, all JSON-LD records produced within the

project conform to the patterns and thematic profiles defined by the **Ocean Data and Information System (ODIS)**. This alignment is critical because it enables the **Ocean InfoHub (OIH)** to harvest MARCO-BOLO metadata directly, index it within its federated knowledge graph, and expose it to a wide range of downstream consumers. By adhering to these structured patterns, MARCO-BOLO ensures that its outputs—datasets, protocols, software, and related documentation—are interoperable with other UN Ocean Decade initiatives and can be linked across the global ocean data ecosystem and beyond traditional thematic boundaries.

For primary data types, MARCO-BOLO follows a domain-appropriate repository strategy. **The European Nucleotide Archive (ENA)** remains the authoritative route for the deposition of raw sequence data, including environmental DNA (eDNA) reads and associated metadata. This ensures compliance with international standards for molecular data and guarantees long-term preservation in a trusted archive. For biodiversity occurrence data derived from these sequences, MARCO-BOLO leverages **OBIS (Ocean Biodiversity Information System)** and **EMODnet Biology**, both of which provide robust infrastructures for publishing species occurrence records in Darwin Core Archive format.

Beyond these core pathways, MARCO-BOLO recognises the need to preserve and share a wide range of ancillary assets, including software tools, analytical workflows, protocols, and supporting documentation. For these resources, the project recommends the use of **Zenodo**, **MarineInfo**, or **IMIS** (Integrated Marine Information System). These repositories provide persistent identifiers (DOIs), rich metadata support, and long-term accessibility, ensuring that every component of the MARCO-BOLO knowledge base remains citable and reusable. By adopting this multi-repository strategy, MARCO-BOLO not only adheres to the recommendations of the UN Ocean Decade Data and Information Strategy but also sets a benchmark for best practice in marine biodiversity data management.

7. Risks & Mitigations

Risk 1: Time Compression Ahead of Month-36 Review

The most pressing challenge is the limited time remaining before the Month-36 review, which coincides with multiple deliverable deadlines across the consortium. This compression of timelines increases the risk that metadata authoring and repository submissions will be rushed or incomplete. To mitigate this, WP1 has introduced a structured support model that includes regular "data clinics" and the appointment of dedicated WP-level liaisons These individuals act as focal points for metadata tasks within their respective work packages, ensuring that progress continues even when scientific teams are under pressure. WP1 also advocates for a **minimum viable record** approach: capture essential metadata fields first, then iterate to enrich records over time. This staged strategy reduces bottlenecks and ensures that core compliance requirements are met before the review.

Risk 2: Complexity of ENA Submissions for eDNA Data

Submitting environmental DNA (eDNA) data to the European Nucleotide Archive (ENA) is inherently complex, involving multiple object types (Study, Sample, Experiment, Run) and strict adherence to checklist requirements. The risk is compounded by variations in sequencing strategies, such as multiplexed libraries and multi-marker workflows. Additionally, WP1 supports a pragmatic **dual-archiving approach**: demultiplexed reads are deposited in ENA for compliance, while full multiplex archives can be stored in Dryad and cross-linked in metadata. This flexibility ensures scientific completeness without compromising repository standards to checklist requirements to provide all the discovery, description, and provenance metadata.

Risk 3: Identifier Governance and W3ID Implementation

Persistent identifiers are critical for interoperability, yet their governance introduces complexity. Without a clear scheme, there is a risk of inconsistent or duplicate IDs, undermining the integrity of the metadata graph. WP1 mitigates this by proposing a formal **W3ID-based identifier strategy**, including numeric ranges allocated per work package and automated assignment during metadata compilation. WP1 will also conduct resolution tests before the end of the project to validate the redirect infrastructure.

Risk 4: Licensing Variability and Uncertainty

Data licensing remains a potential source of inconsistency, particularly when contributors are uncertain about institutional policies or embargo requirements. This can delay publication or result in incomplete metadata. WP1 addresses this by establishing **default open licenses (CC-BY or CC0)** for all MARCO-BOLO outputs, while allowing temporary placeholders such as "undefined" when decisions are pending. For embargoed datasets, WP1 provides clear guidance: publish full metadata immediately, apply a "restricted" license tag, and specify access conditions and expected release dates. This approach balances openness with legitimate constraints.

Risk 5: Inconsistent Granularity in Action Descriptions

The Action-based metadata model is central to MARCO-BOLO, but its flexibility can lead to uneven granularity across work packages. Some contributors may over-split workflows into excessive detail,

while others may provide overly broad descriptions. This inconsistency hampers provenance tracking and machine readability. WP1 mitigates this by supplying **worked examples** for common workflows (e.g., eDNA sampling, autonomous system deployments, modelling pipelines) and reinforcing the principle of **"tell the reproducible story"**: keep Actions focused on major scientific steps, while pushing fine-grained procedural details into the HowTo tab or linked protocol documents. This ensures clarity without sacrificing completeness.

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MARCO-BOLO

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