D9.9
Marine subdomain FAIRness assessment report

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Deliverable abstract

This report, deliverable D9.9 - Marine subdomain FAIRness assessment report, is the result of Task 9.5 "Marine Research Infrastructures FAIR services" activities which involved all RIs within the Marine subdomain and tuning with WP5 (Community standards and catalogue of services) and WP7 (Common implementation and support). It compiles and analyses the annually successive versions of FAIR Implementation Profiles performed in 2019, 2020 and 2021.

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DELIVERY SLIP

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DOCUMENT AMENDMENT PROCEDURE

Amendments, comments and suggestions should be sent to the Project Manager at manager@envri-fair.eu.

GLOSSARY

A relevant project glossary is included in Appendix A. The latest version of the master list of the glossary is available at http://doi.org/10.5281/zenodo.4471374.

PROJECT SUMMARY

ENVRI-FAIR is the connection of the ESFRI Cluster of Environmental Research Infrastructures (ENVRI) to the European Open Science Cloud (EOSC). Participating research infrastructures (RI) of the environmental domain cover the subdomains Atmosphere, Marine, Solid Earth and Biodiversity / Ecosystems and thus the Earth system in its full complexity.

The overarching goal is that at the end of the proposed project, all participating RIs have built a set of FAIR data services which enhances the efficiency and productivity of researchers, supports innovation, enables data- and knowledge-based decisions and connects the ENVRI Cluster to the EOSC.

This goal is reached by: (1) well defined community policies and standards on all steps of the data life cycle, aligned with the wider European policies, as well as with international developments; (2) each participating RI will have sustainable, transparent and auditable data services, for each step of data life cycle, compliant to the FAIR principles. (3) the focus of the proposed work is put on the implementation of prototypes for testing pre-production services at each RI; the catalogue of prepared services is defined for each RI independently, depending on the maturity of the involved RIs; (4) the complete set of thematic data services and tools provided by the ENVRI cluster is exposed under the EOSC catalogue of services.

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1 Introduction

The ENVRI-FAIR project is engaging Research Infrastructures (RIs) in the environmental domain covering the subdomains Atmosphere, Marine, Solid Earth and Biodiversity / Ecosystems. The overarching goal of ENVRI-FAIR is that all participating research infrastructures (RIs) will improve their FAIRness and become ready for connection to the European Open Science Cloud (EOSC).
WP9 has a focus on the RIs in the Marine subdomain, which are represented in ENVRI-FAIR by Euro-Argo, EMSO, and the marine component of ICOS and LifeWatch, as RIs listed on the ESFRI roadmap, as well as SeaDataNet as European marine data management infrastructure. The overall aim of WP9 is to analyse the FAIRness of each of these RIs and to implement within each RI the necessary actions to improve its FAIRness. The latter is critical for the Marine subdomain as it will provide a coherent base for developing the integrated services systems required by a broad variety of research, regulatory and operational communities. Climate change and anthropogenic impacts are among the key issues that already affect and concern European and worldwide societies, but there are others that also have an enormous socio-economic impact (natural hazards, water quality, acidification). Therefore, "Essential Ocean Variables" (EOV) as identified by the Global Ocean Observing System (GOOS) will provide guidance to the WP9 activities for setting priorities at data type level.
Considering the ENVRI-FAIR challenge of multiple RIs and multiple subdomains, the agreed way forward is that the FAIR principles will be implemented within each RI to improve RI FAIRness at three levels: 1) to better serve its own users; 2) to facilitate the development of cross RI services at Marine subdomain level; and 3) to facilitate the development of cross subdomain services within ENVRI-FAIR. This implicates that in ENVRI-FAIR a bottom-up approach is followed, respecting the autonomy of RIs concerning requirements and solutions, however in close and regular interaction with WP5-WP7 which consider common standards, training, common implementation options at environmental domain level, as well as with WP8-WP11 which concern analysis and implementation activities in each of the subdomains.
This report, deliverable **D9.9 - Marine subdomain FAIRness assessment report** is the assessment of the level of FAIRness of the five Marine RIs with a focus on the definition of a well-defined set of digital objects and the definition of criteria to evaluate the level of FAIRness. The data steward of each community fills a questionnaire (FAIR Implementation Profile or FIP) to record the implementation choices about FAIR principles. Each year, Marine RIs complete a new FIP to catch up on the last updates concerning the FAIR implementation of their resources. The analysis of FAIRness is based on the implementation of FAIR enabling resources (FER) which determines if a criterion of FAIRness is fulfilled. This report is based on the FIP issues of the WP9 to evaluate the progression of the FAIR implementations through the years of each Marine RI.

2 RIs in the Marine subdomain

The Marine subdomain in ENVRI-FAIR is represented by Euro-ARGO, ICOS (Marine), EMSO, and LifeWatch (Marine) as RIs as listed on the ESFRI roadmap, and SeaDataNet as European marine data management infrastructure.

Euro-Argo - European Contribution to the international Argo Program
The objectives of the Euro-Argo ERIC are to optimise, sustain and improve the European contributions to Argo and to provide a world-class service to the research (ocean and climate) and operational oceanography (COPERNICUS Marine Service) communities. Euro-Argo also aims at preparing the new phase of Argo with an extension to deeper depths, biogeochemical parameters and observations of the polar regions. The Euro-Argo RI comprises a central facility and distributed national facilities. In May 2014, the EC awarded European legal status (ERIC) to the central facility. Euro-Argo aims at developing a capacity to procure, deploy and monitor one quarter of the global network (350 floats per year including the new phase of Argo to abyssal ocean, high latitudes, European marginal seas and biogeochemical parameters) and ensure that all the data can be processed and delivered to users (both in real-time and delayed-mode).
Coordinating institution: EURO-Argo ERIC, France;
Representing organisations in ENVRI-FAIR: Euro-Argo ERIC, IFREMER,NOC-BODC

EMSO - European Multidisciplinary Seafloor and Water Column Observatory
EMSO is a large-scale European ESFRI RI for strategically placed, deep sea observatories with the essential scientific objective of real-time, long-term monitoring of environmental processes related to the interaction between the geosphere, biosphere, and hydrosphere. It is a geographically distributed infrastructure composed of several deep-seafloor and water-column observatories, which is deployed at key sites in European waters, spanning from the Arctic, through the Atlantic and Mediterranean, to the Black Sea. Observatories are platforms equipped with multiple sensors, placed along the water column and on the seafloor. They constantly measure different biogeochemical and physical parameters that address natural hazards, climate change and marine ecosystems. EMSO offers data and services to a large and diverse group of users, from scientists and industries to institutions and policy makers. It provides relevant information for defining environmental policies based on scientific data. EMSO is a consortium of partners sharing a common strategic framework of scientific facilities (data, instruments, computing and storage capacity). EMSO ERIC has been established since January 2017.
Coordinating institution: EMSO ERIC, Italy;
Representing organisation in ENVRI-FAIR: EMSO ERIC

ICOS (Marine) – Integrated Carbon Observation System
ICOS provides consistent, long-term and high-quality observations required to understand the present state and predict future behaviour of the global carbon cycle and greenhouse gas emissions. The objectives of ICOS RI are to provide effective access to a single and coherent data set to facilitate research into multi-scale analysis of greenhouse gas emissions, sinks and the processes that determine them. ICOS provides essential information to research in order to understand regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. All this to inform policy makers and the general public on the state of the greenhouse gas budget of Earth's atmosphere as the main driver of climate change. ICOS RI tracks carbon fluxes in Europe and adjacent regions by observing the ecosystems, the atmosphere and the oceans through integrated national station networks, European central facilities and distributes the GHG data to the users via the ICOS Carbon Portal. ICOS ERIC was established in November 2015.
Coordinating institution: ICOS ERIC, Finland;
Representing organisations in ENVRI-FAIR: UHEL, FMI, ULUND, UVSQ, CMCC, UiB

LIFEWATCH (Marine) - European e-Science Infrastructure for Biodiversity and Ecosystem Research
LifeWatch operates e-Infrastructure for basic research on biodiversity and ecosystems, and supports research for the protection, management and sustainable use of biodiversity. The infrastructure includes facilities for data integration and interoperability; capabilities to create workflows of analytical and modelling tools; and a Service Centre providing special services for scientific and policy users, including training and research opportunities for young scientists. Its architecture supports access to and the integration of external resources such as data from associated infrastructures and distributed computational capacity from high performance clusters. User groups may create their own e-laboratories or e-services within the common architecture of the infrastructure. LifeWatch enables distributed large scale and collaborative systems research on biodiversity complexity. LifeWatch ERIC was established in May 2017. LifeWatch is represented in the Marine subdomain by VLIZ and its marine-focussed resources are considered here.
Coordinating institution: LifeWatch ERIC, Spain;
Representing organisation in ENVRI-FAIR: LifeWatch ERIC

SEADATANET - Pan-European Infrastructure for Ocean and Marine Data Management
SeaDataNet (SEADATANET) is a major operational infrastructure for managing, indexing and providing access to ocean and marine data sets and data products, acquired by European organisations from research cruises and other observational activities worldwide. It also promotes common standards and tools for the marine domain. Since the mid-1990s, SEADATANET has expanded and matured; at present, it provides federated discovery and access to more than 110 data centres for physics, chemistry, geology, bathymetry, and biology. It works closely with EuroGOOS, CMEMS, Euro-Argo, ICES, and EurOBIS a.o., is a major driver of EMODnet, and a principal initiator of the international Ocean Data Interoperability Platform (ODIP). SEADATANET is further developing its discovery, access, ingestion, publishing and visualisation services in the current SeaDataCloud project, working together with EUDAT and considering the EOSC challenge.
Coordinating institution: IFREMER, France;
Representing organisations in ENVRI-FAIR: MARIS, IFREMER, RBINS, OGS, CSIC, UKRI-BODC

3 Analysis of the RIs FAIRness evolution from 2019 to 2021

3.1 FAIR profiles definition

The FIPs issued from the GO-FAIR Foundation and ENVRI-FAIR joint activity are a representation of the implementation choices of different communities. They can be used to follow the evolution of FAIR data services and the convergence between communities.
These profiles are represented by 21 questions asked to the data steward of a community to assess the FAIRness of resources (see Table 1).

When a question is answered with an existing resource, or a resource that is in development, it is then considered as a FAIR-enabling resource (FER) which determines if a FAIR principle is met or not. Several FERs can meet the same FAIR principle.

Table 1: Questionnaire defining a FIP

FAIR principle	Question	FAIR enabling resource types	Your answers
F1-MD	What globally unique, persistent, resolvable identifiers do you use for metadata records?	Identifier type	e.g. PURL, DOI
F1-D	What globally unique, persistent, resolvable identifiers do you use for datasets?	Identifier type	
F2	Which metadata schemes do you use for findability?	Metadata scheme	
F3	What is the technology that links the persistent identifiers of your data to the metadata description?	Metadata-Data linking mechanism	
F4-MD	In which search engines are your metadata records indexed?	Search engines	
F4-D	In which search engines are your datasets indexed?	Search engines	
A1.1-MD	Which standardized communication protocol do you use for metadata records?	Communication protocol	
A1.1-D	Which standardized communication protocol do you use for datasets?	Communication protocol	
A1.2-MD	Which authentication & authorisation technique do you use for metadata records?	Authentication & authorisation technique	
A1.2-D	Which authentication & authorisation technique do you use for datasets?	Authentication & authorisation technique	
A2	Which metadata longevity plan do you use?	Metadata longevity plan	
I1-MD	Which knowledge representation languages (allowing machine interoperation) do you use for metadata records?	Knowledge representation language	
I1-D	Which knowledge representation languages (allowing machine interoperation) do you use for datasets?	Knowledge representation language	
I2-MD	Which structured vocabularies do you use to annotate your metadata records?	Structured vocabularies	
I2-D	Which structured vocabularies do you use to encode your datasets?	Structured vocabularies	
I3-MD	Which models, schema(s) do you use for metadata records?	Metadata schema	
I3-D	Which models, schema(s) do you use for datasets?	Data schema	
R1.1-MD	Which usage license do you use for metadata records?	Data usage license	
R1.1-D	Which usage license do you use for datasets?	Data usage license	
R1.2-MD	Which metadata schemas do you use for describing the provenance of your metadata records?	Provenance model	
R1.2-D	Which metadata schemas do you use for describing the provenance of your datasets?	Provenance model	

3.2 Method: how answers from Marine RIs were retrieved and processed

Each year, a FIP questionnaire has been completed by most of the Marine RIs using an online service setup by the WP5 and the GO-FAIR Foundation: https://fip-wizard.ds-wizard.org/dashboard.
This online service uses nanopublications technology (see Figure 1). Nanopublications are machine-readable assertions that can be minted (i.e. published) from the FIP wizard. The query language SPARQL was used to process this information: all published profiles had their nanopublications included in a SPARQL endpoint for latter processing. The SPARQL endpoint was made available during the workshop FIP for Purpose, in January and February 2022. During this workshop, the data stewards of each community had the opportunity to complete their FIPs.

Results were then fetched through this API. Make_matrix and make_matrix_nochoice routines executed a SPARQL query to retrieve all nanopublications made in ENVRI-FAIR, both for declared resources (FERs) and for questions that do not match a resource (i.e. unanswered questions).

In addition, results from the SPARQL query were cured: a few resource duplicates have been pruned (same resource URI declared multiple times in the same FIP question) and some inconsistencies have been fixed.

The results have been summarised similarly to the spreadsheet presented during the workshop. This new spreadsheet will be used as a reference.

```
@prefix this: <http://purl.org/np/RAnAWGdeI_1GGmDAqv-vZjby5XqbL2ZujNz1vgwK_6cRI> .
@prefix sub: <http://purl.org/np/RAnAWGdeI_1GGmDAqv-vZjby5XqbL2ZujNz1vgwK_6cRI#> .
@prefix np: <http://www.nanopub.org/nschema#> .
@prefix dct: <http://purl.org/dc/terms/> .
@prefix nt: <https://w3id.org/np/o/ntemplate/> .
@prefix npx: <http://purl.org/nanopub/x/> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix orcid: <https://orcid.org/> .
@prefix fip: <https://w3id.org/fair/fip/terms/> .
@prefix prov: <http://www.w3.org/ns/prov#> .
sub:Head {
 this: np:hasAssertion sub:assertion;
 np:hasProvenance sub:provenance;
 np:hasPublicationInfo sub:pubinfo;
 a np:Nanopublication .
}
sub:assertion {
 sub:DOI a fip:Available-FAIR-Enabling-Resource, fip:FAIR-Enabling-Resource, fip:Identifier-type, fip:Metadata-data-linking-mechanism;
 rdfs:comment "DOI is a persistent link to the digital object";
 rdfs:label "DOI|Digital Object Identifier";
 skos:exactMatch <https://www.doi.org> .
}
sub:provenance {
 sub:assertion prov:wasDerivedFrom <http://purl.org/np/RAiyPQd01Y1u-qo3HG3PDVgpHiIuNO9YngYlju1WTyzRI#DOI> .
}
sub:pubinfo {
 sub:sig npx:hasAlgorithm "RSA";
 npx:hasPublicKey
"MIGfMA0GCSqGSIb3DQEBAQUAA4GNADCBiQKBgQCtpcftn7kbe6toJbOTDQaCcCssEFSWqt6J4rZ02w+TfY7/eIOgJ
ZYOlpL6G3AzO2RNmVYWRPSlMiykaFuaRuBitvk1GKfGdprfZbvXwmeOxpqCTRBQX9EnFyQyd+Ra/ajfw/UsG8skeu1x
nUEpnQbpgbQYc/fvhJNN0UwEc77mOwIDAQAB";
 npx:hasSignature
"oCYyjGaTza+qRkKdrSVZFV6MQjXb2ebh+3tZl479ZsD2Idd7Rldmy749dfAAUfZVs4L/m8qAVALisrr+MgoFjGbDrpMjc
4Cdq1t0Gvu2RPVKJqH8nwv5tpdYSNfRpqQWeKmpgjg2ui1NCTbDONNhlBONShwoFCv0y9+7aVUoXe0=";
 npx:hasSignatureTarget this: .
 this: dct:created "2022-01-20T23:20:36.474+01:00"^^xsd:dateTime;
 dct:creator orcid:0000-0003-2195-3997;
 npx:introduces sub:DOI;
 npx:supersedes <http://purl.org/np/RAOvVwdp-A-uKhdEyLV2fhqHjZhOlGs788kSbfqg1FULk>;
 nt:wasCreatedFromProvenanceTemplate <http://purl.org/np/RAcTpoh5Ra0ssqmcpOgWdaZ_YiPE6demO6cpw-2RvSNs8>;
 nt:wasCreatedFromPubinfoTemplate
<http://purl.org/np/RAA2MfqdBCzmz9yVWjKLXNbyfBNcwsMmOqcNUxkk1maIM>,
<http://purl.org/np/RAjpBMlw3owYhJUBo3DtsuDlXsNAJ8cnGeWAutDVjuAuI>;
 nt:wasCreatedFromTemplate <http://purl.org/np/RAhptb1hUg1kQ6LRBLJfBHXVwYbU2Y4SwY9UJg2qkzvpI> .
}
```

Figure 1: Nanopublication minted from the Euro-Argo FIP 2021

3.3 Results overview

In order to provide a most complete overview of the FAIRness level, different metrics were used:

- the total number of FERs completed each year by each RI were computed (Table 2)
- common technologies used in FERs among the different RIs, their state of development (in development, operational, planned to be replaced) and the evolution of their number in time were summed up in a matrix, hereafter referred to as the convergence matrix and available in Appendix 2 and 3. Several information were extracted from this convergence matrix:
    - the number of FERs by state of development are summed up in Tables 3 and 4, which contains, in particular, the number of FIP questions without any operational resource associated yet
    - the number of common technologies by pairs of RIs are presented in Table 5. This view is referred to as heatmaps

The results detailed hereafter show the general progression of the resources FAIRness through the years.

3.3.1 Total number of FERs

Table 2 shows the total number of FERs completed each year by each RI. Back in 2019, marine institutes already had a relatively high number of FERs, highlighting an initial level of FAIRness. The increase of FERs through 2020 and 2021 shows a continuous development of the RIs concerning their resources. It is noteworthy that a high number of FERs does not guarantee the quality of the implementation of the technologies for each of them (e.g.: are all the publishable datasets, metadata made available through the resource? Is the ergonomics of the man-machine interface "good enough"? Are there any bugs in the downloading processes (is this robust)? Are the descriptions of the extracted data "sufficient enough" to process the data? etc.) . However, this metric is useful to monitor the resource development of the communities.

It is also noteworthy that the ICOS technologies (FERs) associated with FIP questions are common to all the subdomains they cover. FIP answers for EMSO are not available for years 2019 and 2020. Thus, the evolution of their FAIRness can not be assessed. Only their final status is available.

Table 2: number of available FERs per RI each year

	Argo GDAC	EMSO	LifeWatch Marine	SeaDataNet CDI	SeaDataNet Sextant	ICOS
2019	30	-	33	29	21	43
2020	30	-	39	38	21	67
2021	34	22	39	51	30	67

3.3.2 Common FERs and state of development: Convergence matrices

While the number of FERs provide an overview of the development tendencies of the communities, it does not show how they meet the FAIR principles. The convergence matrices from the spreadsheet enumerate the various technologies used in all completed FIPs, whether or not they are in use by RIs, and their state of development (in development, operational or operational but a replacement by a new technology is planned).

3.3.2.1 Number of FERs per state of development

All associated FERs do not have the same level of development. 3 states of development were defined:

- FER state 1 means resource in development
- FER state 2 means operational resource but a replacement is planned
- FER state 3 means resource is operational

The number of FERs per RI, per year and per state of development are summed up in Table 3. Most of FERs are in operational state and their number increased between 2019 and 2021: from an average 24.2

FERs per RI in 2019 (representing 77% of all FERs declared in 2019) to an average of 36.5 FERs per RI in 2021 (representing 90% of all FERs declared in 2021).
SeaDataNet_CDI and ICOS stand out with a high number of FERs (51 and 62) when compared to the average (36.2). Concerning SeaDataNet_CDI, they cover a wide variety of types of data, and thus must support a wide variety of standards (see details in Table 6 and Table 7). Concerning ICOS, the underlying reason seems to be more related to the usage of a user account system with all the requested authentication technologies, whereas the other RIs do not use such user accounts.

Some new FERs are in development: their number first increased in 2020 (from an average 6.4 to 9.4 FERs per RI) before decreasing in 2021 (to an average 3.8 FERs per RI). The development of new resources can be motivated by:

- the need of covering FIP left without any operational resource associated (also referred to as unanswered FIP question),
- the need of covering new user needs and requests (even if the FIP question has already an associated FER)
- the need arising from the development of new services in the Marine domain, as for instance the development of the ENVRI-Hub central gateway to RI services

The increase in the number of developments in 2020 was probably motivated and/or funded thanks to the ENVRI-Fair project. The number of resources still in development (FER state 1) gives an approximate margin of progress of how many resources could be added in the future.

The next section goes into more details to assess how many FIP questions are left unanswered, and how FERs are distributed within the FIP questions.

Table 3: Number of FERs per RI, per year and per state of development. Each FER state represents the following states:

	FER state	Argo GDAC	EMSO	LifeWatch Marine	SeaDataNet CDI	SeaDataNet Sextant	ICOS	Average
2019	1	8		10	3	2	9	6,4
	2	0		0	3	0	0	0,8
	3	22		23	23	19	34	24,2
2020	1	8		15	2	2	20	9,4
	2	0		1	2	0	0	1
	3	22		23	34	19	47	29
2021	1	2	0	14	0	2	5	3,8
	2	0	0	1	0	0	0	0,16
	3	32	22	24	51	28	62	36,5

1- FER in development: https://w3id.org/fair/fip/terms/declares-planned-use-of
2- operational FER, but planned replacement: https://w3id.org/fair/fip/terms/declares-planned-replacement-of
3- operational FER in use: https://w3id.org/fair/fip/terms/declares-current-use-of

3.3.2.2 Unanswered FIP questions

To reach the first step toward FAIRness, no FIP question should be left without any operational resource associated. To assess this, the number of FERs by state of development (operational or in development) and by FIP question were summed up in table 4. These data were also extracted from the convergence matrices (table 6 and 7 in the appendix) but with a higher level of detail than in Table 3.
Back in 2019, the marine domain already had a generally good coverage of the principles with very few FIP questions left without any associated operational resource: 3 left for ArgoGDAC, 5 for LifeWatch_Marine, 3 for SeadataNet_CDI, 5 for SeadataNet_Sextant and 4 for ICOS.

Through the years the number of operational resources increased and, in 2021, all RIs have improved their FAIRness coverage: ArgoGDAC and ICOS had no FIP questions left unanswered, EMSO only has 1 question left, LifeWatch_Marine has 4 left (out of 5 initially), SeadataNet_CDI has 1 left (out of 3) and SeadataNet_Sextant has 2 left (out of 5). This demonstrates a constant development of the Marine domain resources.
The FIP questions that are not associated to any operational FER, nor any in-development FER are the following:

- question A2: SeaDataNet_CDI, SeaDataNet_Sextant,LifeWatch_Marine and EMSO still **lack a longevity plan for metadata**.
- question F3: LifeWatch_Marine **remains without persistent identifiers linking data to metadata**
- question R1.1-MD: Lifewatch_Marine also **lacks a clear licensing about metadata records.**

FIP questions generally have several FERs associated. In 2019, the average number of operational FERs per FIP question and per RI was 1.3 and it increased to 1.7 in 2021. However, some FIP questions and RIs stand out with a higher number of FERs per FIP question. For instance, FIP A1.1-MD for SeaDataNet-CDI (resp. ICOS) has 8 (resp. 9) associated FERs. This means that communication protocols used for metadata records are multiple for those RIs. For ICOS, as mentioned in the previous section, this is probably because they use user accounts while other RIs do not.

Table 4: Number of FERs per FIP question, per RI, per operational or in development state for years 2019 and 2021.

The number in square brackets is the number of FER in development (FER state 1). The number without square brackets is the number of operational FERs (FER state 2 or FER state 3). "Unanswered FIP questions" correspond to the number of FIP questions without any operational resource associated.

	Number of operational FERs (FER state 3 or 2) [number of FERs in dev FER state 1]											
FIP question	Argo GDAC		EMSO		LifeWatch Marine		SeaDataNet CDI		SeaDataNet Sextant		ICOS	
	2019	2021	2019	2021	2019	2021	2019	2021	2019	2021	2019	2021
F1-MD	1 [2]	1 [2]	n/a	2	2	2	1	1	1	1	4	5
F1-D	1	1	n/a	1	1	1	1	1	1	1	3	3
F2	2	2	n/a	1	3 [1]	3 [3]	1	3	1	1	4	3
F3	1	1	n/a	1	0	**0**	1	1	1	1	1	1
F4-MD	1 [1]	6	n/a	1	1	1	2	6	1	3	2	4 [2]
F4-D	0 [2]	2	n/a	1	1	1	0	2	1	1	2	5 [1]
A1.1-MD	1	1	n/a	2	1	2	3 [1]	8	1	2	2 [2]	9 [1]
A1.1-D	1	1	n/a	2	0	**0** [1]	0	2	2	2	1	5
A1.2-MD	1	1	n/a	1	1	1	1	1	1	1	2	6
A1.2-D	1	1	n/a	1	2	2	1	2	1	1	2	5
A2	2	2	n/a	**0**	0	**0**	0	**0**	0	**0**	0 [1]	1
I1-MD	1	1	n/a	1	1	1 [1]	2	2	2	2	4	4
I1-D	2	2	n/a	1	1	1	2	2	0	2	2	2
I2-MD	0 [1]	1	n/a	1	3	3 [1]	2	2	3	2	1 [1]	1
I2-D	0 [1]	1	n/a	1	1	1	2	2	0	2	1 [1]	1
I3-MD	2	2	n/a	1	2 [1]	2 [1]	1	5	1	1	0 [1]	1
I3-D	1	1	n/a	1	1 [1]	1 [1]	2	3	1	2	1 [1]	2 [1]
R1.1-MD	1	1	n/a	1	0	**0**	1 [1]	1	1	1	1	1
R1.1-D	1	1	n/a	1	0 [6]	1 [5]	1 [1]	1	1	1	1	1
R1.2-MD	1	1	n/a	1	1 [1]	1 [1]	1	3	0 [1]	1 [1]	0 [1]	1
R1.2-D	1 [1]	2	n/a	1	1	1	1	3	0 [1]	**0** [1]	0 [1]	1
Unanswered FIP questions	3	**0**	n/a	**1**	5	**4**	3	**1**	5	**2**	4	**0**
Unanswered FIP questions without any development yet	0	**0**	n/a	**1**	4	**3**	3	**1**	3	**1**	0	**0**

3.3.2.3 Common resources

The convergence matrices highlight a common usage of the same technologies mostly in the Interoperability part (I1-MD, I1-D, I2-MD, I2-D), notably concerning the usage of Resource Description Framework Schema (RDFS) and the Nerc Vocabulary Services (NVS). It is then interesting to look at how common some technologies are across the Marine domain.

While the overall FAIRness of the Marine subdomain was already high in 2019, all RIs did not use the same standards to fulfil FAIR principles. The table 5 highlights the usage of the same technologies by different RIs. The increase in the number of FERs is correlated with an increasing convergence across the different communities, which in consequence increases the FAIRness not only per RI, but also across all of them.

Table 5: heatmaps of the common FERs of the Marine RIs

2019	SeaDataNet-CDI	lw-marine	ArgoGdac	EMSO	SeaDataNet-Sextant	ICOS
SeaDataNet-CDI		1	5		4	5
lw-marine	1		6		4	10
ArgoGdac	5	6			6	13
EMSO						
SeaDataNet-Sextant	4	4	6			10
ICOS	5	10	13		10	

2020	SeaDataNet-CDI	lw-marine	ArgoGdac	EMSO	SeaDataNet-Sextant	ICOS
SeaDataNet-CDI		4	7		6	10
lw-marine	4		7		6	13
ArgoGdac	7	7			6	16
EMSO						
SeaDataNet-Sextant	6	6	6			11
ICOS	10	13	16		11	

2021	SeaDataNet-CDI	lw-marine	ArgoGdac	EMSO	SeaDataNet-Sextant	ICOS
SeaDataNet-CDI		5	10	8	17	13
lw-marine	5		7	4	7	13
ArgoGdac	10	7		14	11	16
EMSO	8	4	14		8	10
SeaDataNet-Sextant	17	7	11	8		14
ICOS	13	13	16	10	14	

4 Conclusions and next steps

The analysis of FAIRness through FIPs started from the task 9.2 “Analysis and priorities to enhance RI data FAIRness”. It has been successfully conducted thanks to the FIP Workshop done during early 2022. This analysis assessed the increasing number of FERs and the improvement of the coverage of all FAIR principles over the years. The analysis also assessed the convergence towards the usage of the same standards among RIs. This convergence of resources among RIs is important as it participates in a better FAIRness of the overall subdomain. Indeed, it makes resources more reusable and interoperable since shared standards minimise the number of processes necessary to compare and use data from various sources.
The Marine subdomain demonstrated a great FAIRness individually with a growing overlap of FAIR-enabling resources technologies.

The ENVRI-FAIR project was a driving force into the improvement of this FAIRness. There is still work to do

- to complete the FAIRness: SeaDataNet, LifeWatch and EMSO need to fill the few remaining gaps in their coverage of the FAIR principles: **lack of a longevity plan for metadata (**SeaDataNet_CDI, SeaDataNet_Sextant,LifeWatch_Marine and EMSO**), lack of persistent identifiers linking data to metadata (**LifeWatch_Marine**) and lacks a clear licensing about metadata records (**Lifewatch_Marine**).**
- to sustain the services,
- and to adapt them to evolving user needs.

While the FIPs provide a general view on the implementation of different technologies for each RI, a FER does not reflect the quality of the implementation but rather its presence or absence. Thus, further work should also evaluate the quality of each resource implementation when it is relevant: stability (robustness), scalability (ability to adjust to increasing data volumes), correct usage of standards within the technology (e.g., ontologies in RDF), coverage over data and metadata, performance, ergonomics of Man Machine Interface (MMI).

To maintain FAIRness through the years, transversal questions should be considered such as, is there a quality plan implemented to ensure the maintenance and evolution of the resources? Is there a sustainability plan to ensure the availability of human and technical resources to maintain the services and the FAIRness of RIs? The status of these considerations and subsequent recommendations will be **addressed in the deliverable D9.10 *Marine subdomain white paper for sustainable data management*.**

It would also be interesting to refine the representation of convergence of used technologies to include more criteria of comparison, giving additional information to the communities on the current state of share. Such criteria could involve the expansion of a more in-depth questionnaire asking for implementation details about the concerned resources (i.e., does all resources of the community make use of that technology? To which purpose this technology is used (with more details ?). This refinement, while complex to formalise, would allow a more detailed view leading to spot potential room for improvement of the implementations or issues. This ultimately gives material for decisions to potentially switch for a different technology or add a new one. It is also worth noting that while FIPs provide a way to see what developments should be done, each RI also has their own roadmaps to satisfy more specific users. This can lead to prioritising some developments over others. FIPs are also a means to provide counsel for the choice of a new technology to use.

5 Appendix 1: Links to FIP questionnaires

Euro-Argo
- 2019: https://fip-wizard.ds-wizard.org/projects/7b143e27-4b1c-444e-be4a-fa8d0839981f
- 2020: https://fip-wizard.ds-wizard.org/projects/d43b2df5-7ac3-4ab8-b4af-ad1969c1500f
- 2021: https://fip-wizard.ds-wizard.org/projects/7fa2089d-d511-4ed1-ae9a-8e8b3c210977

LifeWatch-Marine
- 2019: https://fip-wizard.ds-wizard.org/projects/a3b50610-dcf7-457d-bde9-8664b36c42d7
- 2020: https://fip-wizard.ds-wizard.org/projects/bbfb4318-3cad-4f80-ba2f-af87a20f3d3b
- 2021: https://fip-wizard.ds-wizard.org/projects/77fa913c-00b4-4be5-8512-1128914af0d5

Seadatanet-CDI
- 2019: https://fip-wizard.ds-wizard.org/projects/d3d8ee5f-b85d-4a3e-89d3-4e61649084b0
- 2020: https://fip-wizard.ds-wizard.org/projects/402316f4-34cf-4cb1-b0a8-68247d21a4eb
- 2021: https://fip-wizard.ds-wizard.org/projects/4d83c004-8154-439a-8b76-6b0a3179efc9

Seadatanet-Sextant
- 2019: https://fip-wizard.ds-wizard.org/projects/9e4cc2f2-7829-4b13-916a-dcb48fdf460e
- 2020: https://fip-wizard.ds-wizard.org/projects/820eef79-2459-468f-a780-b09745184da0
- 2021: https://fip-wizard.ds-wizard.org/projects/c8bce49b-6aab-41b1-8613-721097f8a1fe

EMSO
- 2021: https://fip-wizard.ds-wizard.org/projects/4887b64f-5149-45a3-8897-9d6be202180f

ICOS
- 2019: https://fip-wizard.ds-wizard.org/projects/4ab6b540-83a4-4ae2-b783-e31e7be45331
- 2020: https://fip-wizard.ds-wizard.org/projects/4a26b5a8-70bc-4b07-a4d4-045d01b7a989
- 2021: https://fip-wizard.ds-wizard.org/projects/1c21320e-c154-4324-b760-2c44f77b8a2b

6 Appendix 2: Detailed FERs technologies per RI in 2019

2019		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
F1-MD	DOI | Digital Object Identifier		3	3		3	3
F1-MD	Handle System			1			3
F1-MD	ePIC | Persistent Identifier Consortium for eResearch			1			3
F1-MD	URI		3				3
F1-MD	SDN_CDI_PID	3					
F1-D	DOI | Digital Object Identifier			3		3	3
F1-D	Handle System						3
F1-D	ePIC | Persistent Identifier Consortium for eResearch						3
F1-D	B2HANDLE	3					
F1-D	URI		3				
F2	NetCDF CF-1.7			3			
F2	schema.org-dataset		1	3			
F2	DataCite Metadata Scheme		3				3
F2	ISO 19115 | Geographic information - Metadata		3			3	3
F2	ISO 19139 | Geographic information - Metadata - XML schema implementation						3
F2	GeoDCAT-AP						3
F2	SDN2_CDI_ISO19139	3					
F2	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
F3	DataCite | DataCite Ontology			3			
F3	LOD | Linked Open Data						3
F3	SDN_CDI_PID_LUI	3					
F3	DOI | Digital Object Identifier					3	
F3	No Choice		0				
F4-MD	Google Dataset Search			3			
F4-MD	Euro-ARGO Data Selection			1			
F4-MD	B2FIND						3
F4-MD	ICOS Carbon Portal | Integrated Carbon Observation System Data Portal						3
F4-MD	GEOSS Portal | Global Earth Observation System of Systems Portal	3					
F4-MD	SDN-CDI-Search | SeaDataNet CDI search user interface	3					
F4-MD	SDN-Sextant | SeaDataNet Sextant search engines					3	
F4-MD	Google Search		3				
F4-D	Google Dataset Search			1			
F4-D	Euro-ARGO Data Selection			1			
F4-D	re3data | Registry of Research Data Repositories						3

2019		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
F4-D	ICOS Carbon Portal | Integrated Carbon Observation System Data Portal						3
F4-D	SDN-Sextant | SeaDataNet Sextant search engines					3	
F4-D	Google Search		3				
F4-D	No Choice	0					
A1.1-MD	HTTPS | Hypertext Transfer Protocol Secure			3			3
A1.1-MD	OPeNDAP | Open-source Project for a Network Data Access Protocol						1
A1.1-MD	REST | Representational state transfer		3				3
A1.1-MD	OAI-PMH	3					1
A1.1-MD	OGC CS | Open Geospatial Consortium Catalogue Services 3.0	3					
A1.1-MD	ORCID | Open Researcher and Contributor ID	3					
A1.1-MD	SPARQL endpoint	1					
A1.1-MD	CSW | Catalog Service for the Web					3	
A1.1-D	HTTPS | Hypertext Transfer Protocol Secure			3			3
A1.1-D	ERDDAP					3	
A1.1-D	No Choice	0	0				
A1.2-MD	Open Data		3	3		3	3
A1.2-MD	OAuth | Open Authorization						3
A1.2-MD	SDN-MID-Service | SeaDataNet Marine ID AAA service	3					
A1.2-D	Open Data		3	3			3
A1.2-D	OAuth | Open Authorization						3
A1.2-D	SDN-MID-Service | SeaDataNet Marine ID AAA service	3				3	
A1.2-D	InnovAuth		3				
A2	Argo Metadata Longevity Plan			3			
A2	Argo Metadata Preservation Policy			3			
A2	The ICOS Preservation Policy						1
A2	No Choice	0	0			0	
I1-MD	RDFS | Resource Description Framework Schema	2		3		3	3
I1-MD	OWL | Web Ontology Language						3
I1-MD	JSON-LD | JavaScript Object Notation for Linking Data						3
I1-MD	XMLS | eXtensible Markup Language Schema	3				3	3
I1-MD	JSON Schema | JavaScript Object Notation Schema		3				
I1-D	RDFS | Resource Description Framework Schema			3			3
I1-D	NetCDF | Network Common Data Form	3		3			3
I1-D	ODV_ASCII | Ocean Data View ASCII format for marine datasets	3					
I1-D	DwC-A | Darwin Core Archive		3				
I1-D	No Choice					0	

2019		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
I2-MD	NVS | NERC Vocabulary Service	3		1		3	
I2-MD	ICOS Ontology | Integrated Carbon Observation System Ontology						1
I2-MD	DwC-A | Darwin Core Archive						3
I2-MD	SDM MD | SeaDataNet metadata directories	3					
I2-MD	GEMET | General Multilingual Environmental Thesaurus					3	
I2-MD	INSPIRE registry					3	
I2-MD	Marine Regions georeferences		3				
I2-MD	WoRMS | World Register of Marine Species		3				
I2-MD	Aquatic Sciences and Fisheries Thesaurus		3				
I2-D	NVS | NERC Vocabulary Service	3		1			
I2-D	ICOS Ontology | Integrated Carbon Observation System Ontology						1
I2-D	DwC-A | Darwin Core Archive		3				3
I2-D	SDM MD | SeaDataNet metadata directories	3					
I2-D	No Choice					0	
I3-MD	DataCite Metadata Scheme		3	3			
I3-MD	schema.org-dataset			3			
I3-MD	ICOS Ontology | Integrated Carbon Observation System Ontology						1
I3-MD	SDN2_CDI_ISO19139	3					
I3-MD	ISO 19139 | Geographic information - Metadata - XML schema implementation					3	
I3-MD	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
I3-MD	DCAT | Data Catalog Vocabulary Version 3		1				
I3-D	DataCite Metadata Scheme			3			
I3-D	NetCDF CF-1.7					3	3
I3-D	ICOS Ontology | Integrated Carbon Observation System Ontology						1
I3-D	ODV_ASCII | Ocean Data View ASCII format for marine datasets	3					
I3-D	NetCDF_CF_SDN | NETCDF CF format SeaDataNet Profile	3					
I3-D	DwC-A | Darwin Core Archive		3				
I3-D	ERDDAP		1				
R1.1-MD	CC BY 4.0 | Attribution 4.0 International			3			
R1.1-MD	CC0 1.0 | CC0 1.0 Universal Public Domain Dedication					3	3
R1.1-MD	SDN DP | SeadataNet Data Policy and User License	1					
R1.1-MD	SDN DA L 1.0 | SeaDataNet Data Access License 1.0	2					

2019		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
R1.1-MD	No Choice		0				
R1.1-D	CC BY 4.0 | Attribution 4.0 International	1	1	3			3
R1.1-D	SDN DA L 1.0 | SeaDataNet Data Access License 1.0	2					
R1.1-D	SDN DP | SeadataNet Data Policy and User License					3	
R1.1-D	CC0 1.0 | CC0 1.0 Universal Public Domain Dedication		1				
R1.1-D	CC BY SA 4.0 | Attribution-ShareAlike 4.0 International		1				
R1.1-D	CC BY-ND 4.0 | Attribution-NoDerivatives 4.0 International		1				
R1.1-D	CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International		1				
R1.1-D	CC BY-NC-SA 4.0 | Attribution-NonCommercial-ShareAlike 4.0 International		1				
R1.2-MD	NetCDF CF-1.7			3			
R1.2-MD	PROV-O | W3C PROV Ontology		1			1	1
R1.2-MD	ISO 19139 | Geographic information - Metadata - XML schema implementation	3					
R1.2-MD	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
R1.2-D	PROV-O | W3C PROV Ontology			1		1	1
R1.2-D	NetCDF CF-1.7			3			
R1.2-D	ISO 19139 | Geographic information - Metadata - XML schema implementation	3					
R1.2-D	DwC-A | Darwin Core Archive		3				

Table 6: Convergence matrix for 2019 with FER state of development indication
0 - no choice
1 - planned, in development
2 - operational, planned for replacement
3 - operational, in use

7 Appendix 3: Detailed FERs technologies per RI in 2021

2021		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
F1-MD	DOI | Digital Object Identifier		3	3	3	3	3
F1-MD	Handle System			1			3
F1-MD	ePIC | Persistent Identifier Consortium for eResearch			1			3
F1-MD	ORCID						3
F1-MD	URI		3				3
F1-MD	SDN_CDI_PID	3					
F1-D	DOI | Digital Object Identifier			3		3	3
F1-D	PURL | Persistent Uniform Resource Locator				3		
F1-D	Handle System						3
F1-D	ePIC | Persistent Identifier Consortium for eResearch						3
F1-D	B2HANDLE	3					
F1-D	URI		3				
F2	NetCDF CF-1.7			3			
F2	schema.org-dataset		1	3			3
F2	OceanSITES Data Format				3		
F2	DataCite Metadata Scheme		3				3
F2	DCAT-AP | Data Catalog Vocabulary Application Profile for Data Portals in Europe		1				3
F2	ISO 19115 | Geographic information - Metadata	3	3			3	
F2	OGC SensorML | Open Geospatial Consortium Sensor Model Language	3					
F2	SDN2_CDI_ISO19139	3					
F2	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
F2	INSOIRE-EF		1				
F3	DataCite | DataCite Ontology			3	3		
F3	LOD | Linked Open Data						3
F3	SDN_CDI_PID_LUI	3					
F3	DOI | Digital Object Identifier					3	
F3	No Choice		0				
F4-MD	Google Dataset Search	3		3	3		3
F4-MD	Euro-ARGO Data Selection			3			
F4-MD	Argo GDAC | Argo float data and metadata from Global Data Assembly Centre			3			
F4-MD	Argo floats metadata dashboard			3			
F4-MD	Argo floats ERDDAP server			3			
F4-MD	Argo Opensearch API			3			
F4-MD	B2FIND	3					3

2021		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
F4-MD	Dimensions						3
F4-MD	WIGOS | WMO Integrated Global Observing System						1
F4-MD	ICOS Carbon Portal | Integrated Carbon Observation System Data Portal						3
F4-MD	OpenAIRE						1
F4-MD	GEOSS Portal | Global Earth Observation System of Systems Portal	3					
F4-MD	SDN-CDI-Search | SeaDataNet CDI search user interface	3					
F4-MD	SPARQL endpoint	3				3	
F4-MD	Google Search	3	3				
F4-MD	SDN-Sextant | SeaDataNet Sextant search engines					3	
F4-MD	SPARQL (open) endpoint					3	
F4-D	Google Dataset Search	3		3	3		3
F4-D	Euro-ARGO Data Selection			3			
F4-D	re3data | Registry of Research Data Repositories						3
F4-D	Dimensions						3
F4-D	ERDDAP						3
F4-D	WIGOS | WMO Integrated Global Observing System						1
F4-D	ICOS Carbon Portal | Integrated Carbon Observation System Data Portal						3
F4-D	GEOSS Portal | Global Earth Observation System of Systems Portal	3					
F4-D	SDN-Sextant | SeaDataNet Sextant search engines					3	
F4-D	Google Search		3				
A1.1-MD	HTTPS | Hypertext Transfer Protocol Secure			3	3		3
A1.1-MD	ERDDAP				3		3
A1.1-MD	CSW | Catalog Service for the Web					3	3
A1.1-MD	OPeNDAP | Open-source Project for a Network Data Access Protocol						3
A1.1-MD	WMS | Web Map Service	3					3
A1.1-MD	SPARQL endpoint	3				3	3
A1.1-MD	SPARQL (open) endpoint	3					3
A1.1-MD	REST | Representational state transfer		3				3
A1.1-MD	Python programming library ICOSCP						3
A1.1-MD	OAI-PMH	3	3				1
A1.1-MD	OGC CS | Open Geospatial Consortium Catalogue Services 3.0	3					
A1.1-MD	ORCID | Open Researcher and Contributor ID	3					
A1.1-MD	OpenSearch	3					
A1.1-MD	WFS | Web Feature Service	3					

2021		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
A1.1-D	HTTPS | Hypertext Transfer Protocol Secure	3		3	3	3	3
A1.1-D	ERDDAP		1		3	3	3
A1.1-D	CSW | Catalog Service for the Web						3
A1.1-D	OPeNDAP | Open-source Project for a Network Data Access Protocol						3
A1.1-D	WCS | Web Coverage Service						3
A1.1-D	HTTP | Hypertext Transfer Protocol	3					
A1.2-MD	Open Data		3	3		3	3
A1.2-MD	EGI Checkin				3		
A1.2-MD	ICOS local account						3
A1.2-MD	OAuth | Open Authorization						3
A1.2-MD	eduGAIN Interfederation Service						3
A1.2-MD	ORCID						3
A1.2-MD	SAML2 | Security Assertion Markup Language 2.0						3
A1.2-MD	SDN-MID-Service | SeaDataNet Marine ID AAA service	3					
A1.2-D	Open Data		3	3			3
A1.2-D	EGI Checkin				3		
A1.2-D	eduGAIN Interfederation Service						3
A1.2-D	ICOS local account						3
A1.2-D	SAML2 | Security Assertion Markup Language 2.0						3
A1.2-D	ORCID						3
A1.2-D	SDN-MID-Service | SeaDataNet Marine ID AAA service	3				3	
A1.2-D	SAML1.1 | Security Assertion Markup Language 1.1	3					
A1.2-D	InnovAuth		3				
A2	Argo Metadata Preservation Policy			3			
A2	Argo Metadata Longevity Plan			3			
A2	The ICOS Preservation Policy						3
A2	No Choice	0	0		0	0	
I1-MD	RDFS | Resource Description Framework Schema	3		3	3	3	3
I1-MD	OWL | Web Ontology Language						3
I1-MD	JSON-LD | JavaScript Object Notation for Linking Data		1				3
I1-MD	XMLS | eXtensible Markup Language Schema	3				3	3
I1-MD	JSON Schema | JavaScript Object Notation Schema		2				
I1-D	RDFS | Resource Description Framework Schema			3	3		3
I1-D	NetCDF | Network Common Data Form	3		3		3	3
I1-D	ODV_ASCII | Ocean Data View ASCII format for marine datasets	3				3	
I1-D	DwC-A | Darwin Core Archive		3				
I2-MD	NVS | NERC Vocabulary Service	3	1	3	3	3	

2021		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
I2-MD	ICOS Ontology | Integrated Carbon Observation System Ontology						3
I2-MD	SDM MD | SeaDataNet metadata directories	3					
I2-MD	GEMET | General Multilingual Environmental Thesaurus					3	
I2-MD	Marine Regions georeferences		3				
I2-MD	WoRMS | World Register of Marine Species		3				
I2-MD	Aquatic Sciences and Fisheries Thesaurus		3				
I2-D	NVS | NERC Vocabulary Service	3		3	3	3	
I2-D	ICOS Ontology | Integrated Carbon Observation System Ontology						3
I2-D	SDM MD | SeaDataNet metadata directories	3				3	
I2-D	DwC-A | Darwin Core Archive		3				
I3-MD	DataCite Metadata Scheme		3	3			
I3-MD	schema.org-dataset	3		3			
I3-MD	OceanSITES Data Format				3		
I3-MD	ICOS Ontology | Integrated Carbon Observation System Ontology						3
I3-MD	ISO 19115 | Geographic information - Metadata	3					
I3-MD	DCAT-AP | Data Catalog Vocabulary Application Profile for Data Portals in Europe	3					
I3-MD	OGC SensorML | Open Geospatial Consortium Sensor Model Language	3					
I3-MD	SDN2_CDI_ISO19139	3					
I3-MD	ISO 19139 | Geographic information - Metadata - XML schema implementation					3	
I3-MD	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
I3-MD	DCAT | Data Catalog Vocabulary Version 3		1				
I3-D	DataCite Metadata Scheme			3			
I3-D	OceanSITES Data Format				3		
I3-D	NetCDF CF-1.7	3				3	3
I3-D	ICOS Ontology | Integrated Carbon Observation System Ontology						3
I3-D	WMO Core Profile | World Meteorological Organization Core Metadata Profile						1
I3-D	ODV_ASCII | Ocean Data View ASCII format for marine datasets	3				3	
I3-D	NetCDF_CF_SDN | NETCDF CF format SeaDataNet Profile	3					
I3-D	DwC-A | Darwin Core Archive		3				
I3-D	ERDDAP		1				

2021		Research Infrastructure (RI)					
FIP	Resource technology	SeaData Net-CDI	lw-marine	ArgoG DAC	EMSO	SeaData Net-Sextant	ICOS
R1.1-MD	CC BY 4.0 | Attribution 4.0 International	3		3	3	3	
R1.1-MD	CC0 1.0 | CC0 1.0 Universal Public Domain Dedication						3
R1.1-MD	No Choice		0				
R1.1-D	CC BY 4.0 | Attribution 4.0 International	3	1	3	3	3	3
R1.1-D	CC0 1.0 | CC0 1.0 Universal Public Domain Dedication		3				
R1.1-D	CC BY SA 4.0 | Attribution-ShareAlike 4.0 International		1				
R1.1-D	CC BY-ND 4.0 | Attribution-NoDerivatives 4.0 International		1				
R1.1-D	CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International		1				
R1.1-D	CC BY-NC-SA 4.0 | Attribution-NonCommercial-ShareAlike 4.0 International		1				
R1.2-MD	NetCDF CF-1.7			3	3		
R1.2-MD	PROV-O | W3C PROV Ontology		1			1	3
R1.2-MD	ISO 19139 | Geographic information - Metadata - XML schema implementation	3					
R1.2-MD	ISO 19115 | Geographic information - Metadata	3				3	
R1.2-MD	OGC SensorML | Open Geospatial Consortium Sensor Model Language	3					
R1.2-MD	EML GBIF Profile Metadata | Ecological Metadata Language Global Biodiversity Information Facility Profile Metadata		3				
R1.2-D	NetCDF CF-1.7			3	3		
R1.2-D	PROV-O | W3C PROV Ontology			3		1	3
R1.2-D	ISO 19139 | Geographic information - Metadata - XML schema implementation	3					
R1.2-D	OGC SensorML | Open Geospatial Consortium Sensor Model Language	3					
R1.2-D	ISO 19115 | Geographic information - Metadata	3					
R1.2-D	DwC-A | Darwin Core Archive		3				

Table 7: Convergence matrix for 2021 with FER state of development indication
0 - no choice
1 - planned, in development
2 - operational, planned for replacement
3 - operational, in use

9 Appendix 4: Glossary

CDI	Common Data Index (metadata format and data access system by SeaDataNet)
CMEMS	Copernicus Marine Environment Monitoring Service
COPERNICUS	A major earth observation programme run by European Commission and European Space Agency
EMODNET	European Marine Observation and Data Network
EMSO	European Multidisciplinary Seafloor and water column Observatory
ENVRI	1) An environmental RI cluster FP7 project 2) Environment research infrastructures (in ESFRI level or upcoming) as a community
EOSC	European Open Science Cloud
EOV	Essential Ocean Variable(s)
ERIC	European Research Infrastructure Consortium (legal entity type)
ESFRI	European Strategy Forum on Research Infrastructures
FAIR	Findable Accessible Interoperable Reusable
FER	FAIR-enabling resource
FIP	FAIR Implementation Profile
GDAC	Global Data Assembly Center
GOFAIR	An international programme on FAIR implementation
ICOS	Integrated Carbon Observation System
LW	LifeWatch
NVS	NERC Vocabulary Services
OBIS	Ocean Biogeographic Information System
ODIP	Ocean Data Interoperability Platform
ORCID	Open Researcher and Contributor ID
PROV-O	Web Ontology Language encoding of the PROV Data Mode
RDF	Resource Description Framework
RI	Research Infrastructure
SEADATANET	SeaDataNet pan-European infrastructure for marine data management
SPARQL	SPARQL Protocol And RDF Query Language