BIODIVERSITY BUILDING BLOCKS FOR POLICY

D3.3 FAIR data products and interoperability with the Essential Biodiversity Variables Data Portal

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Key-Takeaways

- The Biodiversity Building Blocks for Policy (B3) project advances FAIRness (the principle that data should be Findable, Accessible, Interoperable and Reproducible) in biodiversity science and evidence-based policy by addressing a full spectrum of data, software, training materials, and geospatial outputs.

- Open and accessible geospatial outputs are central to B3's FAIR strategy. To this end, B3 collaborates with the Essential Biodiversity Variables (EBV) Data Portal and EBVCube format to openly share all geospatial results, supporting transparency and accessibility.

- The EBV Data Portal provides a user-friendly platform that enables users to search, explore, visualise, and download biodiversity datasets, thereby facilitating discovery, access, and reuse by the community.

- The EBVCube format harmonises geospatial biodiversity datasets into multidimensional structures, enhancing both accessibility and interoperability for a broad spectrum of users and applications.

- Taxonomic information of EBVCubes is now available both via an API and in the metadata file (JSON), making this information easier to access and use.

- B3's approach ensures that data, methods, and outputs remain traceable, reproducible, while facilitating the integration of biodiversity information across environmental disciplines. It aligns with the objectives of the European Green Deal Data Space, which aims to harness the potential of data to drive Europe's digital and green transitions.

- By adhering to international standards, leveraging persistent identifiers, and promoting open sharing, B3 paves the way for the development of robust data spaces. This approach reduces barriers to collaboration and maximises the reusability of biodiversity assets for research, policy, and innovation.

Executive Summary

The Biodiversity Building Blocks for Policy (B3) project aims to enhance the impact and broaden the use of biodiversity information to inform policy making through the provision of clear, informative and reproducible biodiversity analyses. A key aspect of B3 is its commitment to the FAIR principles—Findable, Accessible, Interoperable and Reproducible—which serve as the cornerstone for interoperability and scalability which is key for the Green Deal Data Space.

In this deliverable, we focused on enhancing FAIRness of B3 geospatial outputs. To this end, B3 collaborates with the EBV Data Portal and EBVCube to openly share all geospatial results, supporting transparency and accessibility. In order to increase interoperability between occurrence cubes and the EBVCube format, a geospatial format for biodiversity, new taxonomic fields have been added to the metadata. These can also be accessed via the API.

To further assess the project's strengths and identify areas for improvement, a FAIR Awareness Survey was conducted among B3 partners. Results from this survey will be considered for enhancing B3 future development and data sharing practices. Finally, this report explores how the B3 approach fosters broader interoperability across research domains, particularly with the Earth science community, and how its outcomes contribute to shaping the Green Deal Data Space.

Non-Technical Summary

The Biodiversity Building Blocks for Policy (B3) project aims to make biodiversity data more useful in shaping better environmental policies. It achieves this by producing clear, reliable and easy-to-understand analyses of biodiversity trends and patterns. Much of B3's work is based on the FAIR principles, which stand for findable, accessible, interoperable, and reusable. These principles ensure that data can be easily found, shared and used by a wide range of people and systems. This is particularly important for creating a shared digital space for environmental information across Europe.

This report focuses on how B3 improves the discoverability, sharing, and use of geographical results. To achieve this, B3 collaborates closely with tools such as the EBV Data Portal and EBVCube, which facilitate the open availability and accessibility of spatio-temporal data from diverse biodiversity sources. Additionally, new information linked to scientific names of species have been added. This information can be accessed via an online interface, facilitating connection with other systems.

To understand how well B3 is performing and where improvements can be made, we asked project partners about their experiences with FAIR data practices. Their feedback will help us to continue improving the way in which B3 shares data and supports collaboration.

Finally, this report explores how B3's approach could enhance collaboration with researchers and experts in other fields. We hope that our findings will contribute to broader European efforts to create shared spaces for environmental data, supporting better decision-making for a sustainable future.

List of Abbreviations

ACDD	Attribute Convention for Data Discovery
AD4GD	All Data for Green Deal
API	Application Programming Interface
B3	Biodiversity Building Blocks for Policy
BON	Biodiversity Observation Networks
CBD	Convention on Biological Diversity
CF	Climate and Forecast Metadata Conventions
CSV	Comma Separated Values
DOI	Digital Object Identifier
EBV	Essential Biodiversity Variables
EBVCube	Essential Biodiversity Variables Cube Format
EBV Data Portal	GEO BON Essential Biodiversity Variables Data Portal
EEA	European Environment Agency
EML	Ecological Metadata Language
ETC BE	European Topic Centre on Biodiversity and Ecosystems
EU	European Union
FAIR	Findable, Accessible, Interoperable and Reproducible
FAIRiCUBE	F.A.I.R. Information Cube
IAS	Invasive Alien Species
iDiv	German Centre for Integrative Biodiversity Research
GBIF	Global Biodiversity Information Facility
GEO BON	Group of Earth Observation Biodiversity Observation Network
NetCDF	Network Common Data Form
OGC	Open Geospatial Consortium
SQL	Structured Query Language
USAGE	Urban Data Spaces for Green Deal
XML	Extensible Markup Language

1 Introduction

Applying FAIR principles (Findable, Accessible, Interoperable, Reusable) to biodiversity data and derived products ensures that they remain findable, accessible, interoperable, and reusable for research, conservation, and policymaking (Wilkinson et al. 2016; Groom et al. 2019). Embedding FAIR practices enhances data integration, scientific reproducibility, and long-term preservation of biodiversity knowledge, which are recognized as fundamental to advancing both research and societal outcomes (Lannom et al. 2020; Barker et al. 2022).

This commitment to FAIR principles forms a cornerstone of the Biodiversity Building Block for Policy (B3) project, which aims to accelerate the mobilisation of biodiversity data and increase the flow of science-based evidence to stakeholders. To achieve this, B3 has prioritized making all project developments, software, analytical pipelines, and results freely accessible (see Section 4).

One of the project's initial products, led by the Global Biodiversity Information Facility (GBIF), was the development of occurrence cubes produced via the GBIF API[1], or alternatively through reproducible R and Python wrappers (Blissett et al. 2025). In general, occurrence cubes aggregate primary biodiversity data (i.e., species observations) by spatial, temporal and/or taxonomic dimensions, as well as any other criteria specified in a Structured Query Language (SQL)-based query. In March 2025, a user-friendly web interface was launched, substantially lowering the barrier for users without programming experience to generate species occurrence datasets. Each cube, similar to GBIF's traditional download service, is assigned a Digital Object Identifier (DOI), strengthening the findability, traceability, and reproducibility of the datasets. Furthermore, the original SQL query used to generate each cube is included in the DOI, ensuring full transparency of the data extraction process.

Previous project deliverables have covered the findability, reproducibility, and traceability of occurrence cubes. The present deliverable further advances this effort by focusing on increasing the FAIRness of geospatial biodiversity outcomes—specifically, model-based or predictive outputs derived from primary data. In support of this objective, B3 collaborates with the Essential Biodiversity Variables (EBV) Data Portal of the Group on Earth Observations Biodiversity Observation Network (GEO BON), hereafter referred to as the EBV Data Portal.

At the core of the EBV Data Portal is the EBV framework, originally proposed by Pereira et al. (2013) and developed through subsequent implementations (e.g., Kissling et al. 2018; Jetz et al. 2019; Pereira et al. 2024). The EBV framework provides a structure for harmonising biodiversity data, enabling effective monitoring across multiple spatial and temporal scales. Importantly, EBVs are (i) sensitive to ecological change, (ii) they can be scaled across different temporal and spatial resolutions, and (iii) EBVs also cover multiple domains of biological diversity. In this sense, the framework encompasses six EBV classes and 21 EBV names. The EBV classes are genetic composition, species traits, species populations, community composition, ecosystem functioning and ecosystem structure. Particularly, for B3, the focus is on the species-level EBVs, which are directly aligned with the species occurrence cubes.

[1] https://doi.org/10.5281/zenodo.14973380

Figure 1 presents the stages involved in transforming primary observations into actionable biodiversity indicators through the EBV framework. Initially, observations are aggregated and harmonised into a gridded cube incorporating dimensions of time, space, and entity (with taxonomic details that are embedded in the entity dimension). These harmonised datasets, accompanied by rich metadata, support a variety of analytical tasks, including gap-filling, uncertainty estimation, predictive modelling, and the generation of policy-relevant indicators. Provenance is rigorously tracked throughout this process to ensure full transparency and reproducibility of all results.

To facilitate the biodiversity data use cycle and operationalise EBVs, the German Centre for Integrative Biodiversity Research (iDiv), in partnership with GEO BON, has developed an integrated suite of tools to support the EBV data ecosystem. Among recent advancements, the EBV team has developed a robust infrastructure for creating (ebvcube R package, Quoss et al. 2022) and publishing spatio-temporal results of biodiversity data analysis (Pereira et al. 2024). Data publication is carried out via the EBV Data Portal[2], which offers open access and standardised sharing of multidimensional biodiversity datasets, thus underpinning the FAIR principles central to both B3 and the development of upcoming data spaces.

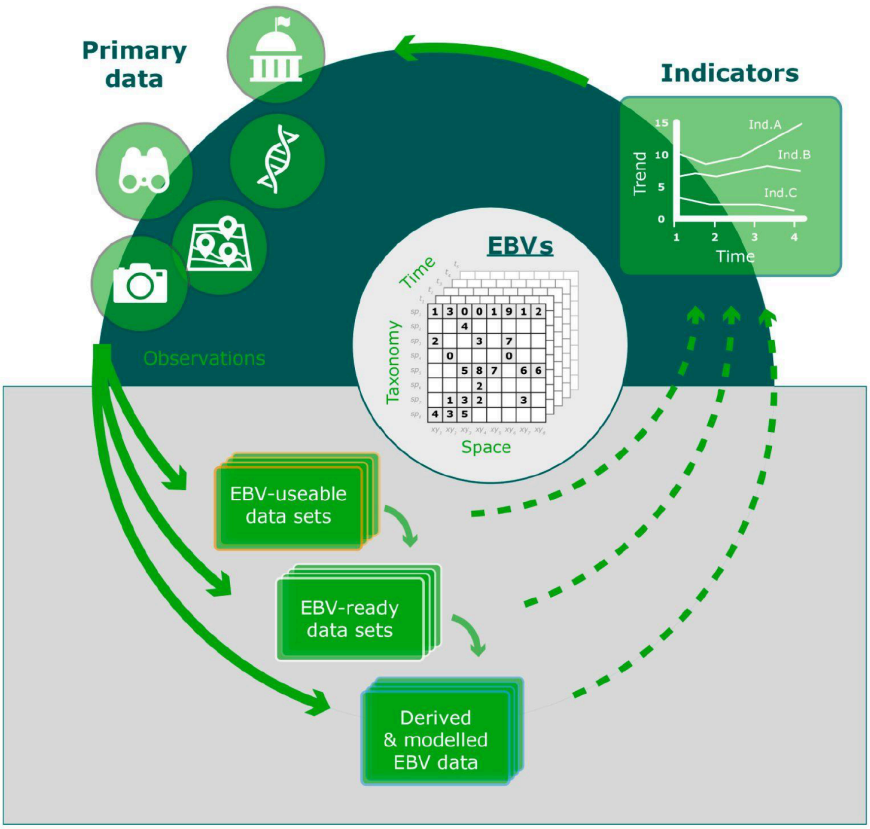


Figure 1: Schematic representation of the biodiversity data use cycle. Primary observations are used to calculate policy indicators. Analytical steps indicate the creation of

[2] https://portal.geobon.org/

intermediate EBVCubes until the final indicators are calculated (from B3 Grant agreement, adapted from Kissling et al. 2018).

As part of Milestone 10 – Interoperability Strategy, a prototype was developed to facilitate the open data mobilisation of occurrence cubes from GBIF to the EBV Data Portal (see Section 3). During this implementation, we identified key aspects that need to be considered to increase interoperability, particularly concerning the taxonomic information.

This document focuses on the EBV Portal and the EBVCube format, which is scheduled to start a ratification process as a geospatial standard for biodiversity data at the Living Data Conference in October 2025. The EBVCube format adheres to the Climate and Forecast Conventions (CF, version 1.8[3]), the Attribute Convention for Data Discovery (ACDD, version 1.3[4]), and is based on the Network Common Data format (netCDF). Section 2 provides a detailed overview of the new implementations to enhance interoperability between species occurrence cubes and the EBV infrastructure. These efforts also reinforce alignment with the FAIR principles, ensuring the resulting data products are both accessible and reusable.

To further assess B3's strengths and identify areas for improvement, a FAIR Awareness Survey was conducted among B3 partners (see Section 5). Results from this survey will be considered for supporting B3 future development and data sharing practices. Finally, this report explores how the B3 approach fosters broader interoperability across research domains, particularly with the Earth science community, and how its outcomes contribute to shaping the Green Deal Data Space.

2 Increasing Interoperability Between the Essential Biodiversity Variables Data Ecosystem and Species Occurrence Cubes Products

The EBV Data Portal is part of B3 FAIR strategy to openly share all geospatial results from the project. It is hosted at the German Centre for Integrative Biodiversity Research (iDiv) and is a pivotal part of the GEO BON development tools. The core component of the portal is the published datasets that are formatted into a hierarchical structure of the netCDF (see Section 2.1). This is done through the ebvcube R package that produces a multidimensional array in netCDF format with embedded metadata that follows the CF standard, ACDD and the EBV terms (see Section 2.2). The dataset format is called the EBVCube format. The overarching goal of the EBV Data Portal and the EBVCube format is harmonising geospatial biodiversity datasets, making them more accessible and interoperable.

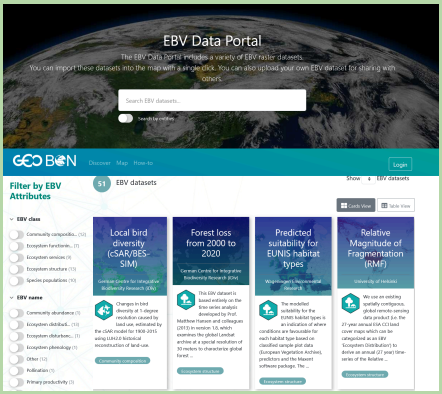
The EBV Data Portal and the ebvcube R package are closely linked, but the R package can also be used as a standalone tool. The portal can be used to easily explore and download datasets, and ultimately publish them. On the other hand, the ebvcube R package, supports the creation of the entire EBVCube format, including defining the file structure, mapping the data into a 4D array, and embedding metadata. During the publication phase at the EBV Data Portal,

[3] https://cfconventions.org/Data/cf-conventions/cf-conventions-1.8/cf-conventions.html
[4] https://wiki.esipfed.org/Attribute_Convention_for_Data_Discovery_1-3

the portal allows the entry of metadata via a web interface (Figure A1-A2) and the uploading of data cubes either as EBVCubes or as individual GEOTIFFs.

Implementing both the EBV Data Portal and the ebvcube R package facilitates the development of automated workflows and gives users full control over the workflow up to data submission. Before publication and DOI assignment in the portal, the EBV team performs a detailed metadata review. Table 1 provides a summary of the main steps for creating and publishing an EBVCube dataset.

Table 1: Main components and steps conducted to create and publish an EBVCube.

Main components	Steps using the ebvcube R Package	Steps at the EBV Data Portal
		
Dataset	Creation of the EBVCube using ebvcube R package functions (i.e., netCDF).	• Upload dataset in the EBVCube format (i.e., netCDF). • Alternatively, upload GEOTIFFs for further postprocessing by the EBV team.
Metadata	Embed metadata using JSON file downloaded from the portal, or to the package functions.	• Fill in metadata through webinterface. • Download metadata as a JSON file.
Dataset Publication	The R package is not part of the data set publication process.	• Complete the submission of the dataset and metadata. • The metadata will be revised later. Once approved, the dataset will be published and the DOI assigned.

In order to improve interoperability between the species occurrence cubes by B3, and the EBV Data Portal, it was identified as a priority to improve the taxonomic features which are stored in the entity dimension. In particular, to implement machine-readable access to the portal, and to add additional tools for better taxonomic search and visualisation in the front-end (see Section 2.3). Detailed information about the EBV Data Portal, the EBVCube format and the main changes implemented in the EBV ecosystem are explained in the following sections.

2.1 GEO BON Essential Biodiversity Variables Data Portal (EBV Data Portal)

The EBV Data Portal is a user-friendly interface that allows any user to search, explore, download and visualise biodiversity datasets. An authentication process is only required for publishing data and this is done through a free GEO BON member account[5] that anyone can register for.

The portal provides a wide range of geospatial datasets and models on EBVs, from a single time span to time series or models under different scenarios (e.g., social, climate), with spatial scales ranging from local to regional and global coverage. Some examples are information on global ecosystem changes from remote sensing and spatio-temporal species distribution models under future climate or socio-economic scenarios.

The main features of the portal are described below.

2.1.1 Enhancing FAIR Principles Through the EBV Data Portal

The EBV Data Portal is oriented on the FAIR principles and aims at improving data findability, accessibility, interoperability and reproducibility. The front-end development addresses data findability and accessibility, and it is continuously improved to provide a better user experience and easier machine access. Key features are described below and illustrated in Figure 2:

- Search and filter functionality on the landing page
- DOI and versioning
- Download options:
    - Datasets as netCDF
    - Metadata according to ACCD Standard (JSON) and as the Ecological Metadata Language (EML) standard (XML- Extensible Markup Language)
- Entities list (e.g., taxonomy, list, EUNIS habitats) as Comma Separated Values (CSV)
- Licence specification (i.e., Creative Commons licences)

These features will apply to B3 geospatial products published at the EBV Data Portal, and will increase open and FAIR datasets.

[5] https://members.geobon.org/register/index

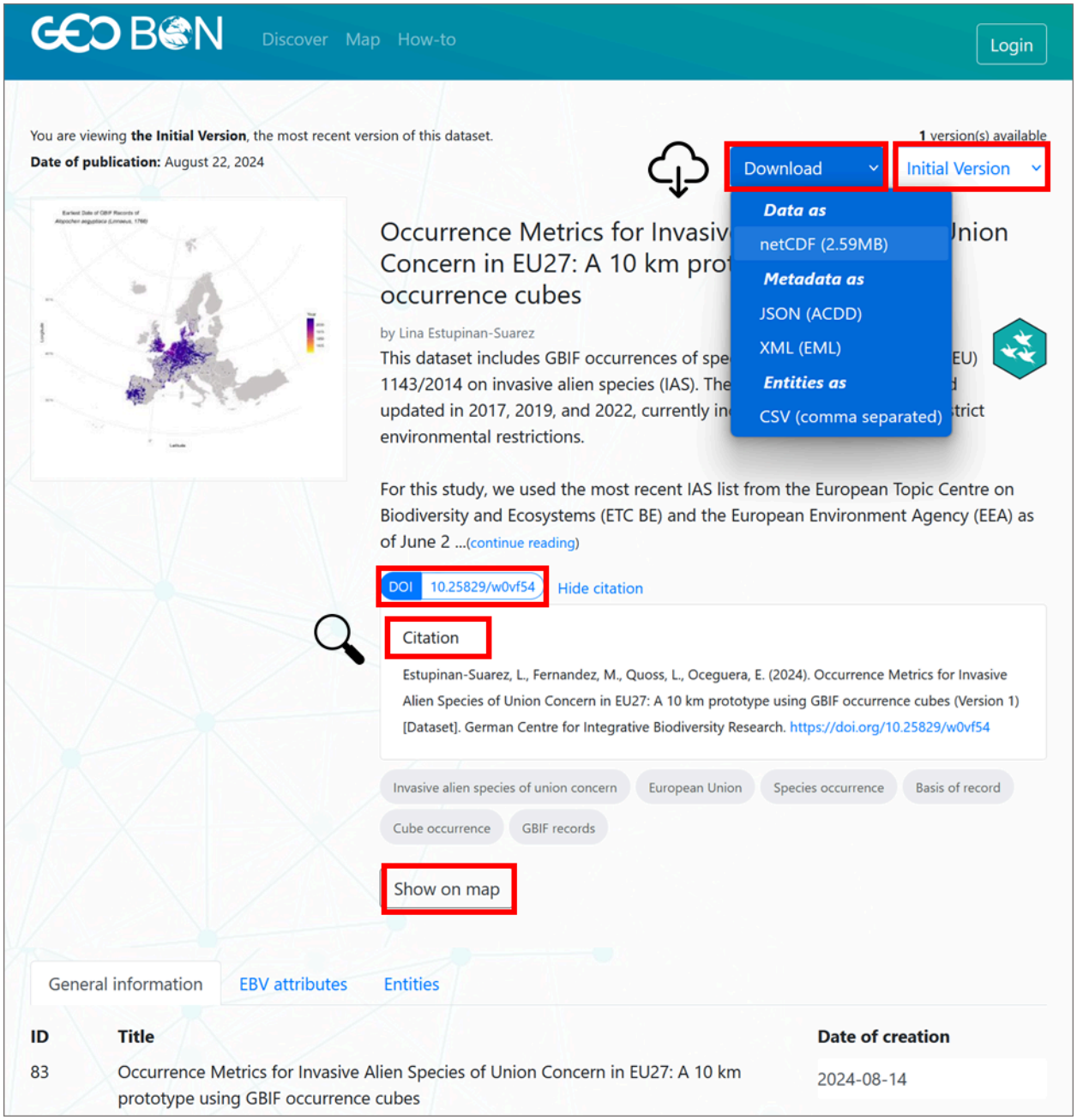


Figure 2: Screenshot of the Occurrence Metrics for Invasive Alien Species of union concern. Red boxes point out the interface options for visualising 'Show on map', downloading data and metadata, citation, DOI, and version of the dataset.

2.1.2 Improving the Front-end for Exploring Taxonomic Information

In order to increase the visibility and findability of datasets containing taxonomy, the front end has been enhanced with new features. In addition to the search bar on the landing page, a radio button for 'Searching by entities' (i.e., species, habitat type, ecosystem type, etc.) has been added. This makes it possible, for example, to search for available datasets containing certain

species based on their scientific names. A screenshot of the new EBV Data Portal landing page is shown in Figure 3.

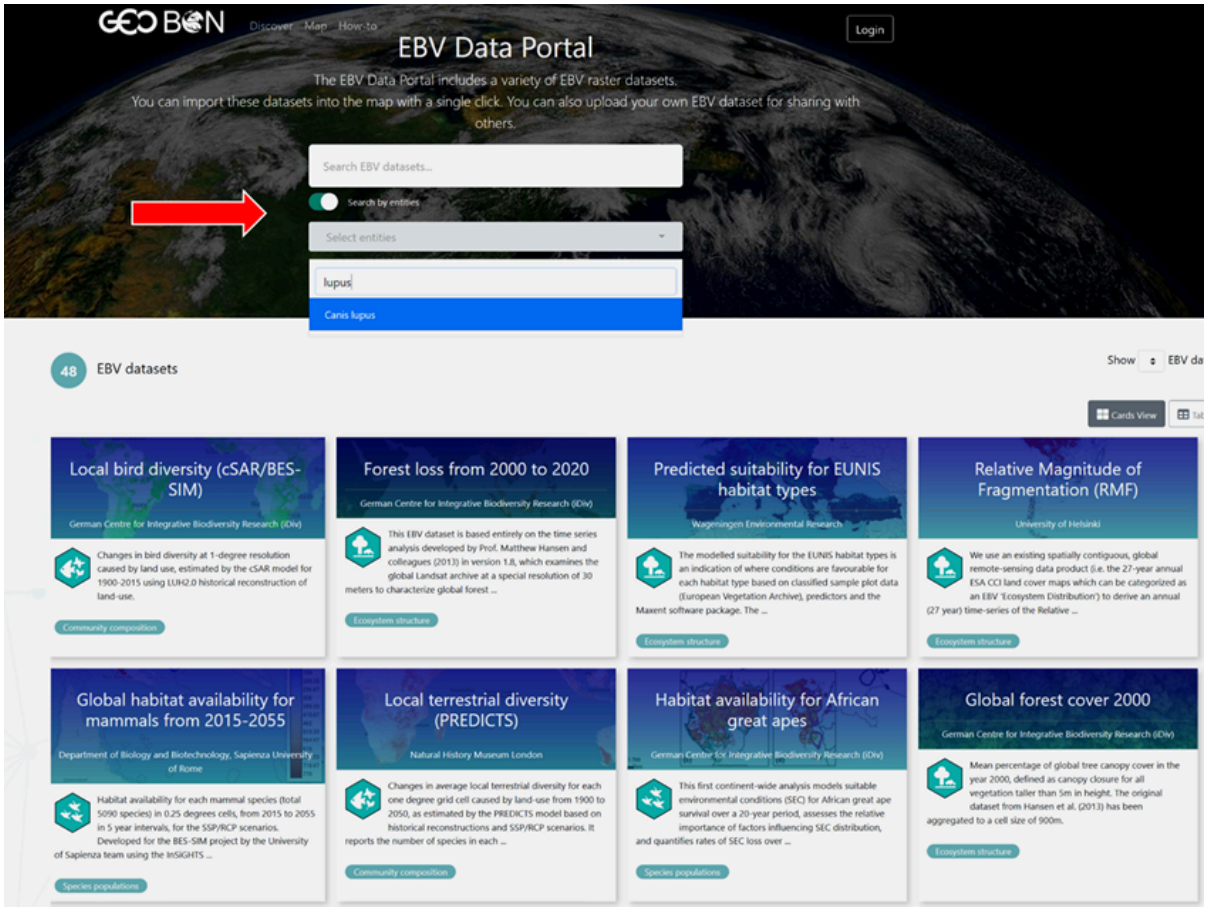


Figure 3: Screenshot of the EBV Data Portal landing page. The arrow points to the new search bar for entities.

In addition, when visualizing the datasets, a new tab has been incorporated to display the taxonomy information in a tabular format which is embedded in the entity dimension. In Figure 4, it is shown how the entity information, including taxonomy, can be downloaded as CSV. At the bottom of Figure 4, the taxonomy tab ('Entities') that uses the Darwin Core terms is highlighted.

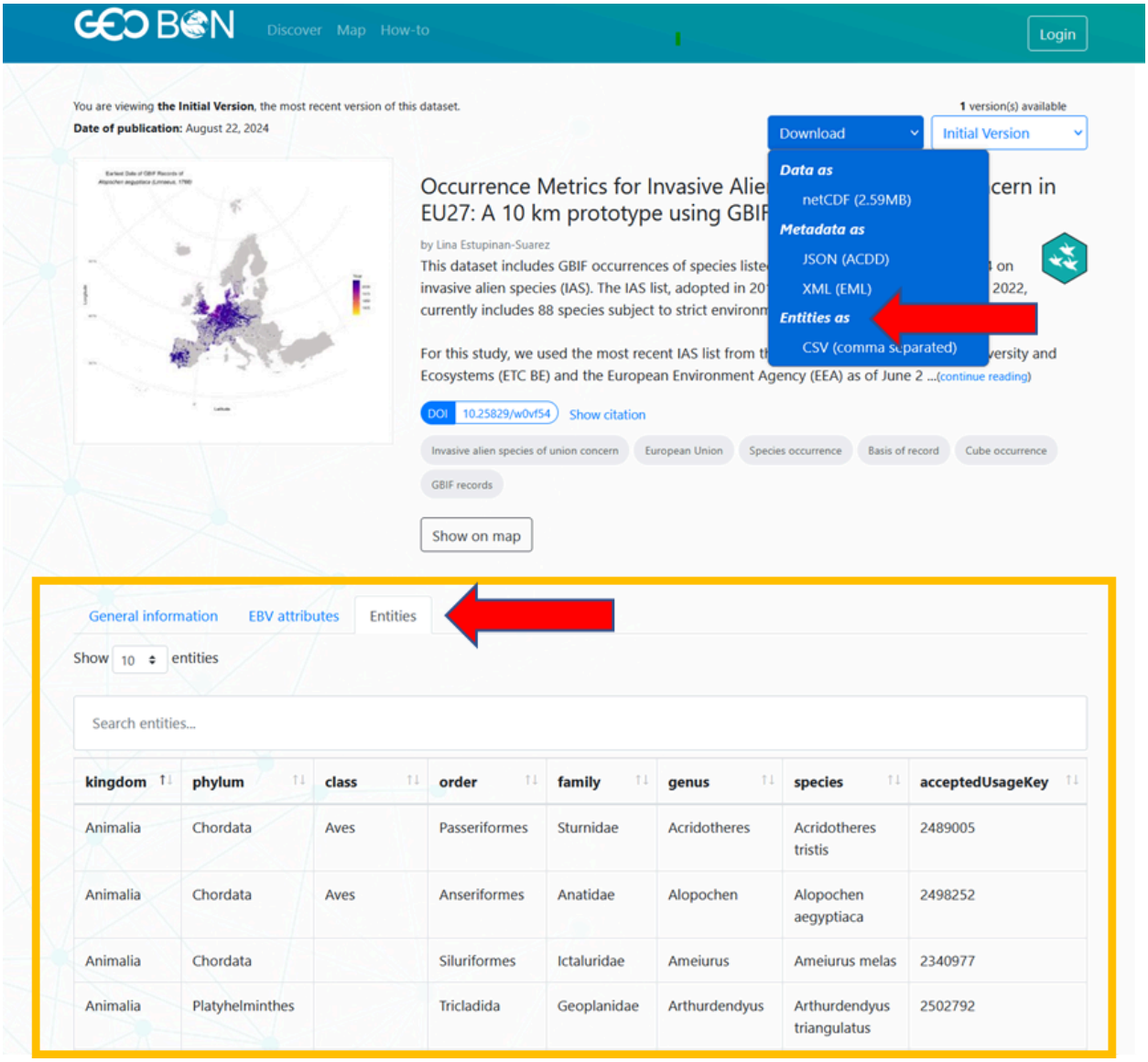
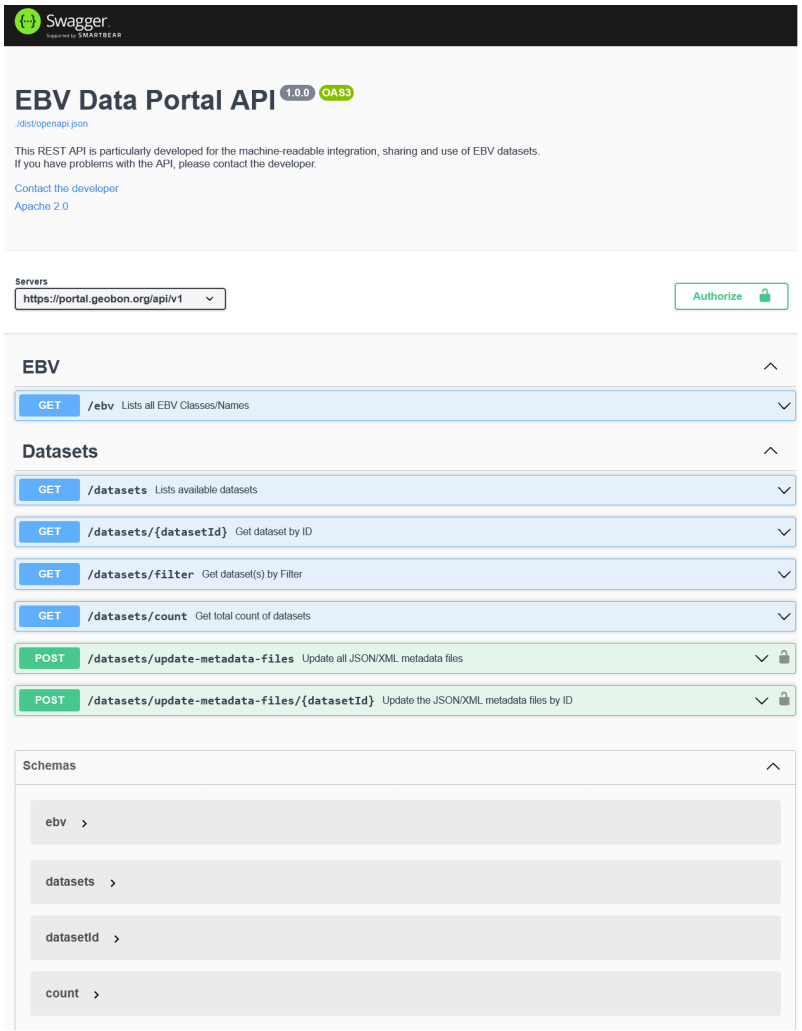


Figure 4: Screenshot of a dataset detail page on the EBV Data Portal. The yellow box indicates the new 'Entities' tab that displays taxonomic information. The arrows point to the 'Entities' tab and download link (URL example: https://portal.geobon.org/ebv-detail?id=83).

2.1.3 API Access to Taxonomic Information

Datasets can be accessed and downloaded using their DOIs via the JSON-based API. The API is documented and can be tested interactively through the integrated Swagger UI (https://portal.geobon.org/api/swagger-ui/). In the new implementation, each dataset's taxonomic information, such as scientific names or habitat classifications, is included directly in the JSON response, making it easy to retrieve and process (Figure 5).

a.



b.

Figure 5: Screenshots of (a) the Swagger UI https://portal.geobon.org/api/swagger-ui/ and (b) the JSON response of the API including the scientific name of species ('ebv_entity_names') https://portal.geobon.org/api/v1/datasets/83.

2.2 The Essential Biodiversity Variables Cube Format (EBVCube)

The EBVCube format is a multidimensional array based on the netCDF format. It has three pillars. One pillar is an established hierarchical structure of the netCDF, the second pillar is comprehensive metadata terms that complies with different standards, and the third pillar is the 4D cube (array) that holds the data[6]. Importantly, the netCDF supports the creation, access, and sharing of array-oriented scientific data. As a key feature, netCDF allows embedding data and metadata in the same file, so that they are both bound and the format becomes self-describing[7]. Importantly, the netCDF format has been widely used and maintained over decades by the remote sensing community to store gridded time-series of diverse geospatial variables for the last decades[8]. The defined hierarchical structure of the netCDF together with rich metadata are the foundation of the EBVCube format.

A brief introduction to this topic is given in the next sections, and references are included to investigate the details in more depth.

2.2.1 EBVCube: Hierarchical Structure and Components of the netCDF Implementation

The structure of the EBVCube can be classified in two major categories (Quoss et al. in prep.):

- **Hierarchy**: In this category we refer to the levels also called components and refer as groups in the netCDF terminology. These define the nested hierarchical structure of the EBVCube and are the *root* (head hierarchy level)*, scenario(s)* and *metric(s)* (Figure 6)*.* While the *root* and *metrics* are mandatory hierarchy levels, the *scenario* level is optional and depends exclusively on the dataset.
- **Data Cube**: This is a four-dimensional cube with the following dimensions: *latitude, longitude, time* and *entity(ies).* As expected, it corresponds to spatio-temporal datasets, in a gridded format with geographic information. In the netCDF terminology, these data cubes are referred to as *variables*.

Detailed information on the netCDF structure and components is available in the GitHub repository[9].

2.2.2 EBVCube Metadata

Rich metadata is a pivotal element of the EBVCube format. Having this as a ground, the EBVCube metadata is built-on the CF (version 1.8), the ACDD (version 1.3), and the netCDF Convention. Complementary, biodiversity terms have been included following the EBVs framework (Pereira et al. 2013). Figure 7 illustrates the four metadata conventions that have been implemented and provides a few examples of the metadata attributes.

[6] https://portal.geobon.org/downloads/pdf/how_to_ebv-portal.pdf
[7] https://www.unidata.ucar.edu/software/netcdf/
[8] https://www.unidata.ucar.edu/software/netcdf/usage.html
[9] https://github.com/EBVcube/EBVCube-format

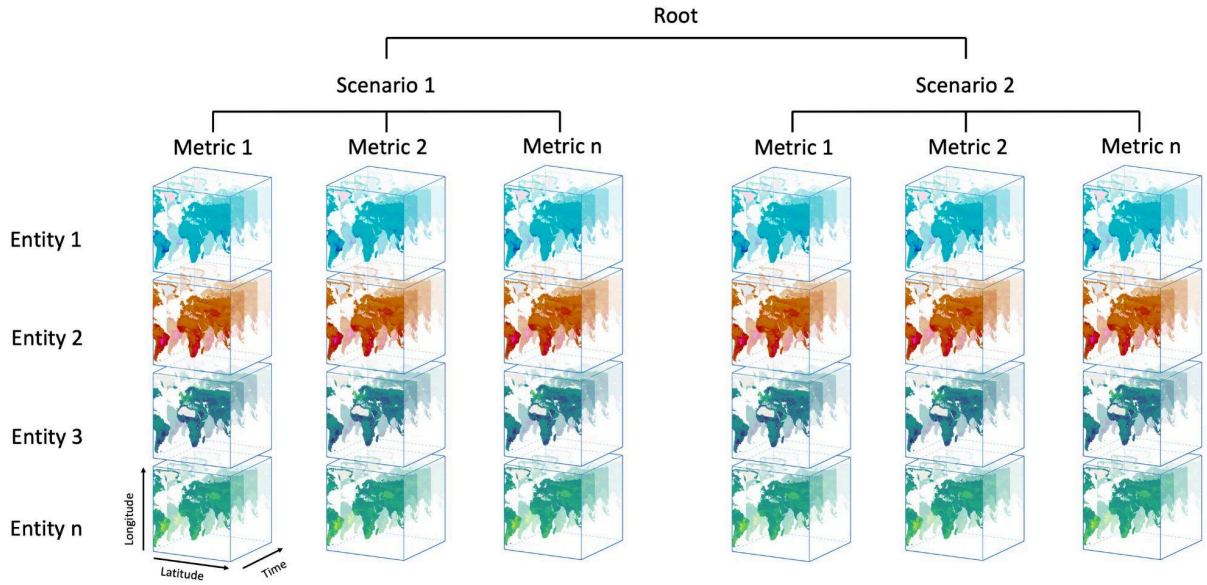


Figure 6: Components of the EBVCube format. Hierarchical structure: Root, Scenarios and Metrics. Cube dimensions: latitude, longitude, time, entity(ies) (Source: Christian Langer 2024).

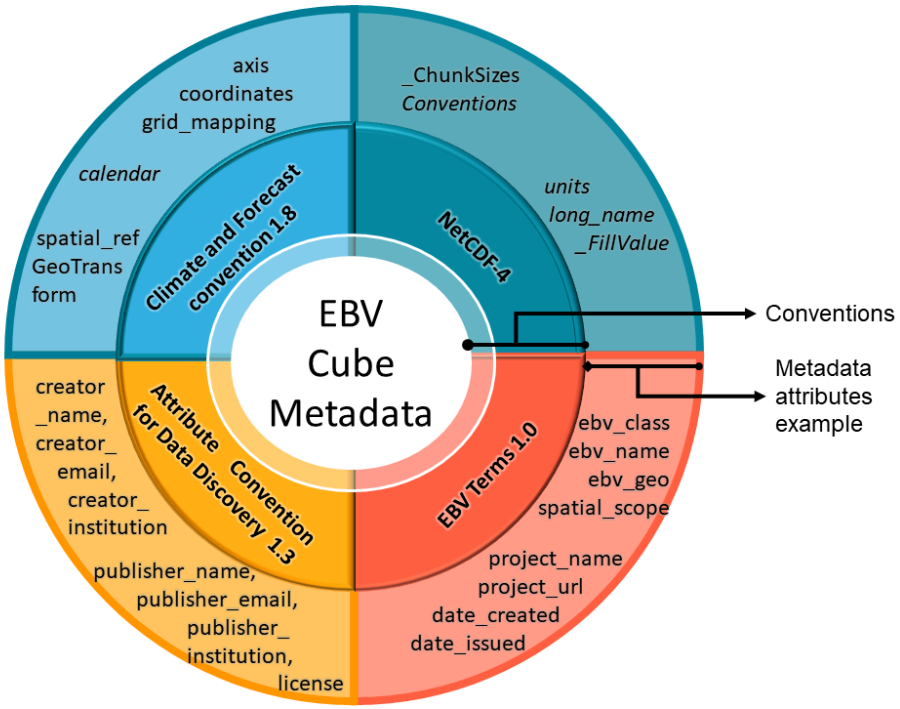


Figure 7: Schematic of the metadata conventions and the EBVCube terms.A few attributes and examples of variables are provided. Words in italic indicate more than one convention.

A summary table of the attribute category, its position in the netCDF structure, and the corresponding conventions is provided below (Table 2). A detailed description of all attributes

and metadata attributes can be found at the GitHub repository[10]. Note that, in the netCDF convention, latitude, longitude and time are called coordinate variables. These coordinate variables have a set of corresponding metadata attributes, e.g., 'axis', which describe them.

Table 2: Summary of the EBVCube metadata attribute. Data retrieved from GitHub repository on 17 April 2025. ACCD: Attribute Convention for Data Discovery. Black: The attribute is found in more than one convention. CF: Climate and Forecast Conventions. EBV Terms. GDAL. netCDF convention.

EBVCube structure	NetCDF component	Attributes category	Attribute names list (color code indicates the convention)
Hierarchy	Root	**Global attributes**	id, naming_authority, title, date_created, date_issued, date_modified, date_metadata_modified, product_version, summary, references, source, project_name project_url, creator_name, creator_email, creator_institution, contributor_name, licence, publisher_name, publisher_email, publisher_institution, ebv_class, ebv_name, ebv_scenario_classification_name, ebv_scenario_classification_version, ebv_scenario_classification_url, ebv_geospatial_scope, ebv_geospatial_description, geospatial_lat_resolution, geospatial_lon_resolution, geospatial_lat_units, geospatial_lon_units, geospatial_bounds_crs, geospatial_bounds, time_coverage_resolution, time_coverage_start, time_coverage_end, ebv_domain, comment, Conventions, keywords, ebv_vocabulary, ebv_cube_dimensions, history
	Scenario /Metric	**Scenario and metric attributes**	standard_name, long_name, units, standard_name, long_name
Data Cube	ebv_cube	**Data cube attributes**	grid_mapping, long_name, coordinates, units, coverage_content_type, _FillValue, _ChunkSizes
	crs	**Coordinate reference system attributes**	grid_mapping_name, spatial_ref, GeoTransform, long_name

[10] https://github.com/EBVcube/EBVCube-format?tab=readme-ov-file

EBVCube structure	NetCDF component		Attributes category	Attribute names list (color code indicates the convention)
	Dimensions	lon lat	**Latitude and longitude attributes**	axis, units, standard_name, long_name, units, long_name
		time	**Temporal attributes**	axis, calendar, units, long_name, _ChunkSizes
		entity	**Entity attributes**	ebv_entity_type, ebv_entity_scope, ebv_entity_classification_name, ebv_entity_classification_url, units, long_name

2.3 Enhancing Metadata for Species Taxonomy

New metadata have been added to the EBVCube format and the EBV Data Portal API to enhance the provenance of taxonomic information. This information builds on the 'entity' dimension. Particularly, in the EBVCube, taxonomic information is stored as two new variables and incorporated into the netCDF structure. These are 'entity_taxonomy_levels' and 'entity_taxonomy_table'. The 'entity_taxonomy_levels' is a two-dimensional array that holds the names of the different taxonomic levels (e.g., 'species', 'genus', 'family', 'order', 'class', 'phylum' and 'kingdom'), in accordance with the Darwin Core vocabulary (see below for more details). The 'entity_taxonomy_table' is a three-dimensional array that holds the taxonomy values (e.g., taxonomic information of each species, classification system of EUNIS habitats). In addition, the taxonomy species key is added as taxonomic level in the 'entity_taxonomy_levels'' and the corresponding information in the 'entity_taxonomy_table'. The 'taxonomy_key' variable is optional and is only added if taxonomic keys are provided by the user. The three new taxonomic variables are bound to the entity dimension. Note that all new terms have been included in the API and the metadata file (JSON, XML) (Table 3).

Table 3: Summary of the new taxonomy attributes. Data retrieved from GitHub repository on 17 April 2025.

Infrastructure component	Stored as:	Names
API and Metadata (JSON, XML)	New metadata attributes	ebv_entity_names entity_taxonomy_levels entity_taxonomy_table
NetCDF	New variable bound to the entity dimension	entity_taxonomy_levels entity_taxonomy_table

New implementations are documented in the How-To[11], that is a user-friendly document and covers exclusively the attributes given by the user. Technical details are provided in GitHub.

[11] https://portal.geobon.org/downloads/pdf/how_to_ebv-portal.pdf

Furthermore, additional changes at the EBV Data Portal were made to increase interoperability. The main changes are:

- To promote machine readability via the API.
- Implementation of Darwin Core vocabulary[12] to describe different levels of species taxonomy.
- A template (CSV) to provide species taxonomy terms according to Darwin Core when creating the EBVCube.

The corresponding Darwin Core terms that have been implemented for species taxonomy are kingdom, phylum, class, order, family, genus. These can also be extended to other taxonomic classification fields (e.g., subfamily, subgenus).

2.4 Summary of FAIR Features in the EBV Ecosystem

The EBV Data Ecosystem is centred around the EBV Data Portal and the EBVCube format. As outlined in previous sections, both tools are being continuously improved to enhance FAIR compliance. In particular, in close collaboration with B3, new features have been developed to improve the provenance of taxonomic information which are summarised in Table 4.

It is worth noting that there is an additional EBV GIS tool called the EBVCubeVisualizer which is a QGIS plugin that facilitates the exploration of EBVCube data using geographical information systems. This is explained in detail in the corresponding GitHub repository[13]. Additionally, another useful resource for opening and exploring EBVCubes is Panoply, a NASA platform for visualising georeferenced gridded data that clearly displays the hierarchy of netCDFs[14].

Table 4: Summary of FAIR features in the EBV Data Portal and the EBVCube format. Blue text indicates new developments to improve interoperability with B3 geospatial products.

FINDABLE	ACCESSIBLE	INTEROPERABLE	REUSABLE
All datasets have a DOI and corresponding version. Search bar at the landing page. New search bar for browsing entities (e.g., scientific name).	Data and metadata download option without login. Open formats: - CSV - JSON - XML - netCDF A new tab has been added to display 'entities', which hold the taxonomy.	API Standards: - ACCD/CF (JSON) - EML (XML) - Darwin Core Darwin Core vocabulary used for taxonomy. List of entity names and keys (e.g., scientific names) included in the API.	Rich metadata: Compliance to ACCD, CF, and netCDF. Publishers must assign a licence to datasets: Creative Commons is encouraged. Extensive documentation.

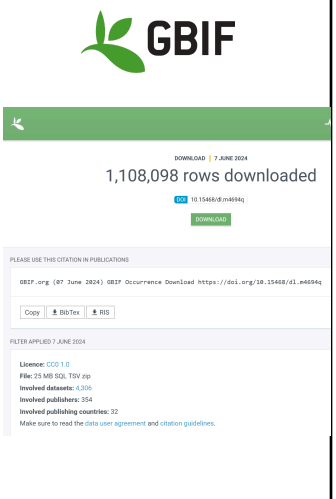
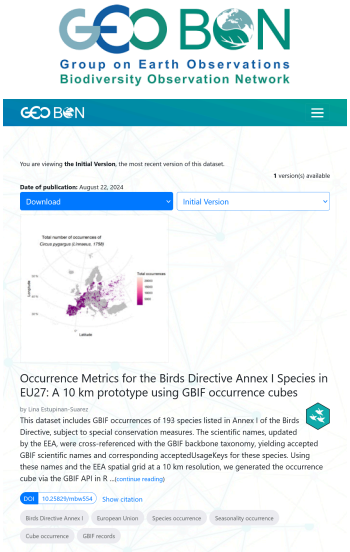
[12] https://dwc.tdwg.org/list/
[13] https://github.com/EBVcube/EBVCubeVisualizer
[14] https://www.earthdata.nasa.gov/data/tools/panoply

3 Data Mobilisation Workflow

To improve the transparency and reproducibility of B3 workflows, we developed a data mobilisation prototype in Milestone 11 - Interoperability strategy. Specifically, we selected two species lists from the European Union (EU) biodiversity legislation i.e., (i) the Birds Directive (Annex I), and (ii) the Invasive Alien Species (IAS) of Union concern. These lists were translated into a tabular format previously in Task 1.5[15]. For each legislation, we normalized the taxonomy (species names) against the GBIF backbone, and created an occurrence cube through the API using the R wrapper. Afterwards, we calculated basic spatial metrics per species, such as the total number of occurrences, the earliest month and the latest month with occurrences in all years, among others. The geospatial results were provided using the European Environment Agency (EEA) 10 km grid, and published as EBV Cubes.

To ensure open access to our code, we published the repository on GitHub. All notebooks are available in R Markdown, HTML and PDF formats (Table 5). Furthermore, data inputs and outputs are available on open data portals with DOIs. This data mobilisation has enabled us to demonstrate the data flow of occurrence cubes for species relevant to policy on the EBV Data Portal, while enhancing the FAIR principles. Further documentation and a detailed explanation are available in the Milestone 10 deliverable (Estupinan-Suarez et al. 2024).

Table 5: Example of data mobilisation from the Interoperability Strategy Document (Milestone 10) (From Estupinan-Suarez et al. 2024)**.**

	INPUT DATA	DATA ANALYSES	OUTPUT DATA
Open format	SQL, CSV	R script/ R markdown	NetCDF
Screenshot web platforms			
DOI Data mobilisation:	GBIF DOI: 10.15468/dl.m4694q	• GitHub: https://github.com/E	GEO BON DOI: 10.25829/mbw554

[15] https://doi.org/10.5281/zenodo.15674038

	INPUT DATA	DATA ANALYSES	OUTPUT DATA
Annex I of the Birds Directive		BVcube/B-Cubed_data_mobilisation • Zanodo DOI: 10.5281/zenodo.13798783	
DOI Data mobilisation: Invasive Alien Species of Union Concern	GBIF DOI: 10.15468/dl.gxk3vh	• GitHub: https://github.com/EBVcube/B-Cubed_data_mobilisation • Zenodo DOI: 10.5281/zenodo.13798783	GEO BON DOI: 10.25829/w0vf54

4 Consolidating the B3 FAIR Approach

The B3 project has developed several products focused on increasing FAIRness in their released products and analytical outcomes. A central element is the Data Management Plan (D1.3), which offers all partners clear guidance on implementing the four pillars of FAIR across the project's workflows and outputs. In addition, all tasks in Work Package 3 have a strong development and implementation on FAIR principles such as FAIR data mobilisation (Milestone 10), portability and reusability of Software (D3.1), open and standardised sharing of training resources (D3.2) for capacity building and increase reproducibility, and finally enhancing findability, accessibility and interoperability of the project geospatial results (D3.3). Key elements and references of the deliverables are presented in Table 6.

Furthermore, the B3 Policy Brief by Sica et al. (2024) expands on the application of FAIR data and emphasises the need of FAIR-aligned workflows and indicators for robust, science-based policy development. In summary, B3 covers the implementation of the FAIR principle with a diverse range of deliverables and products, from data and software to training and policy. For a more comprehensive view, please refer to the relevant documents and provided resources.

Table 6: B3 products aimed at increasing FAIRness. F: Findable. A: Accessible. I: Interoperable. R: Reusable. NA: Not Apply.

Name	Git Hub	[Format] [DOI/Link]	Description
D1.3 Data Management Plan (DMP, v2)	NA	• [PDF] [Link] https://b-cubed.eu/library	The DMP offers guidelines on each FAIR component to increase B3 products usability. The document has been updated to cover recommendations by EU project reviewers.

Milestone 10. Interoperability strategy document	Yes	• [PDF][Link] https://b-cubed.eu/library?type=0&Filter%5Bsort%5D=year+desc&search=M10 • [GitHub] https://github.com/EBVcube/B-Cubed_data_mobilisation	It showcases the data mobilization from species occurrence at GBIF to GEOBON EBV Data Portal.
D3.1 Software requirements and quality assessment	Yes	• [HTML] https://docs.b-cubed.eu/guides/software-development/ • [GitHub] https://github.com/b-cubed-eu/documentation/	The purpose of this guide is to ensure that the software developed in B3 meets the desired standards of quality, openness, portability and reusability. It offers high-level specifications for software and computational tools.
D3.2 Documentation and tutorials	Yes	• [HTML] https://docs.b-cubed.eu/guides/occurrence-cube/ • [GitHub] https://github.com/b-cubed-eu/documentation/	This task has covered extensively clear examples and detailed information to create occurrence cubes and conduct further analysis increasing reproducibility.
D3.3 FAIR data products and interoperability	NA	• [PDF][Link] TBD	This corresponds to the present deliverable, which describes how to increase the FAIRness of geospatial biodiversity datasets.
Policy Brief: Effective biodiversity monitoring requires FAIR data and FAIR models for FAIR indicators (Findable, Accessible, Interoperable, and Reusable)	NA	• [PDF][DOI] https://doi.org/10.5281/zenodo.13912947	This policy brief explores the urgent need to apply a FAIR approach to all components required for calculating indicators, including data, workflows and indicators.

5 FAIR Awareness Survey

We conducted a FAIR Awareness Survey based on Akerman et al.'s (2021) questionnaire, which comprises ten yes/no questions (yes indicates awareness and answering no would indicate no awareness) and a glossary. Of the 10 questions asked, four were about reusability

(4 questions), followed by accessibility (2 questions), findability (3 questions), and lastly, interoperability (1 question). Figure 8 shows the questions asked and summarises the results. A total of 25 researchers involved in B3 participated in the FAIR Awareness Survey. Approximately 80% of participants responded "Yes" to all questions, indicating a generally high level of awareness of FAIR practices. The question with the lowest awareness was the statement (question 5 on the figure): “Are you aware that metadata should remain available over time, even if the data(set) is no longer accessible?”—with only 52% responding affirmatively. This was followed by question 8 “Are you aware that metadata describing your data(set) should follow the specifications of a community-endorsed standard?” with 80% awareness, and then by question 7 “Are you aware that provenance information about the collection and/or generation of data should be included in the metadata?” with 88% awareness.

Overall, these results indicate a generally high level of FAIR awareness among B3 researchers, which is promising for both ongoing and future data management practices. Nevertheless, the comparatively lower awareness regarding metadata standards and long-term availability highlights the need for continued support to ensure consistent application of metadata practices across all partners.

Figure 8: Results of the FAIR Awareness Survey conducted among B3 partners based on the questionnaire by Akerman et al. (2021).

6 Final Remarks and Perspectives

6.1 Contribution of B3 FAIR approach to Shaping the Green Deal Data Space

The development and implementation of data spaces are closely tied to the application of FAIR principles, which are central to this deliverable. In short, data spaces are distributed ecosystems that integrate heterogeneous data sources and enable secure, trustworthy data exchange among participants, while preserving data sovereignty (Farrell et al. 2033). Key cross-cutting elements of data spaces include data governance (e.g., contract negotiation and legal agreements), open and transparent governance models, processing mechanisms (such as metadata brokers and catalogs), and principles of reproducibility and replicability through standardised metadata. Ultimately, the core objective of data spaces is to connect data producers, consumers, and services across organizational boundaries, facilitating the exchange and execution of digital assets such as datasets and applications (Bacco et al. 2024).

In particular, the Green Deal Data Space seeks to harness the value of data for a digital transformation and green transition in Europe (DG ENV 2022). In the context of biodiversity, data are rapidly increasing in both volume and diversity, driven by emerging technologies and methods such as camera traps, bioacoustics, environmental DNA, citizen science initiatives, and novel algorithms that accelerate data processing and analytics. This growth presents significant challenges in ensuring provenance, accessibility, and interoperability, so that these data can be made ready-to-use by various communities. In addition, it is important to consider not only primary data, but also the processing steps and resulting outputs.

Within B3, we address a broad spectrum of biodiversity data analytics stages, ranging from primary observations to EBVs and derived policy indicators. Primary observations typically consist of species occurrence records accessed through GBIF, and aggregated efficiently using the new occurrence cube functionality. GBIF maintains transparent agreements with data providers based on standardised licensing frameworks and attribution practices. It also assigns DOIs to datasets, ensuring unique identification and persistent access when datasets are cited in publications.

B3 maintains an open-access project repository hosted on GitHub[16], where all workflows, software, and processing scripts are freely available to the community. Regarding B3's geospatial products, the transformation of analytical results into a harmonised, multidimensional data structure (i.e., the EBVCube format), and their subsequent publication on the EBV Data Portal targets to effectively complete the data lifecycle. This process aims at enhancing cross-domain interoperability and promotes the seamless integration and reuse of biodiversity information, which is also essential for the development of data spaces.

Furthermore, in a joint policy brief developed by B3 and its sibling projects—AD4GD (All Data for Green Deal), FAIRiCUBE (F.A.I.R. Information Cube), and USAGE (Urban Data Spaces for Green Deal)—a common set of recommendations was proposed to address key challenges related to semantic interoperability and the adoption of shared standards in environmental and biodiversity data spaces (Schleidt et al. 2025). These projects collectively focus on enhancing

[16] https://github.com/b-cubed-eu/

the FAIRness of diverse datasets, supporting that data from multiple domains are findable, accessible, interoperable, and reusable in alignment with the FAIR principles. Each project has implemented relevant data standards; examples include OGC (Open Geospatial Consortium) protocols, ACCD, and CF conventions, catalogs among others (Martirano 2024, EOX IT Services and Schiller 2025). Additionally, the policy brief examined topics such as semantic consistency, machine-readability, and transparency across platforms and user communities. A shared perspective emerged, positioning FAIR implementation as a critical step toward overcoming data fragmentation, facilitating integration and exchange, and supporting the creation of a coherent European Green Deal Data Space capable of underpinning science-based policy, innovation, and public engagement in response to environmental challenges.

Finally, B3's end-to-end approach contributes to making every stage of data generation, processing, and dissemination transparent, well-documented, and governed by standardised metadata and persistent identifiers. This enhances reproducibility, as consistent workflows and metadata enable independent verification and replication of analyses. Although an entire compliance of FAIR principles is hardly accomplished, we believe that with B3 approach and further FAIR practices, biodiversity data users and providers can more readily participate in emerging data spaces. In fact, data space users would be able to track the provenance of data and understand the origins and transformations of datasets and indicators. Ultimately, we expect that a robust FAIR approach will enable biodiversity analyses to be scaled up and more effectively integrated with interconnected domains such as climate, agriculture, forestry, health, and pollution.

6.2 Connecting Species Occurrence Cubes with the Earth Science and Remote Sensing Communities

The integration of biodiversity and climate science is becoming increasingly urgent in order to understand the dual crisis of biodiversity loss on a warming planet. To increase the use of species cubes in fields such as Earth science and remote sensing, providing an unprojected grid was identified as a priority. Specifically, we focused on the EPSG 4326 coordinate system with the 1984 World Geodetic System, commonly used in GPS and known as WGS84. This coordinate system is used worldwide and applied to bioclimatic variable products such as WorldClim[17] and CHELSA[18]. Below is an example query to produce an occurrence cube for Belgium within a 30-minutes grid and using unprojected coordinates.

```
SELECT
  FLOOR(decimalLatitude) AS degreesLatitude,
  FLOOR((ABS(decimalLatitude) * 60) % 60) AS minutesLatitude,
  FLOOR((ABS(decimalLatitude) * 3600) % 60) AS secondsLatitude,

  FLOOR(decimalLongitude) AS degreesLongitude,
  FLOOR((ABS(decimalLongitude) * 60) % 60) AS minutesLongitude,
```

[17] https://www.worldclim.org/
[18] https://chelsa-climate.org/

```
  FLOOR((ABS(decimalLongitude) * 3600) % 60) AS
secondsLongitude
FROM
  occurrence
WHERE
  countryCode = 'BE'
```

In addition, to facilitate the conversion of occurrence cubes to grids with an Extended Quarter-Degree Grid Cells coordinate system, which is used in some national implementations, GBIF has prepared grids with different spatial resolutions that users can download. These grids are available at https://download.gbif.org/grids/EQDGC/.

6.3 BON-in-a-Box: A Pipeline Engine by GEO BON for Sharing Biodiversity Workflows

One of the next steps toward making biodiversity workflows operational across multiple users and systems is the implementation of shared, collaborative cloud infrastructures. One example is the compliance of the Clearing-House Mechanism of the Convention on Biological Diversity (CBD), or in other words the national reporting to the CBD objectives. In this sense, GEO BON has developed BON-in-a-Box, an open-source, community-driven platform that supports the automation and standardization of biodiversity data workflows by converting raw data into EBVs and indicators (Griffith et al. 2024). At the core of the platform is the Pipeline Engine, which enables modular, customizable, and user-friendly workflows that can incorporate diverse programming languages, data types, and execution environments, including local or cloud-based options[19]. These flexible workflows are particularly useful for institutions with varying technical capacities and data sensitivities, supporting transparent and reusable processes aligned with global biodiversity monitoring needs.

Developed in line with FAIR principles, BON-in-a-Box fosters openness, interoperability, and reproducibility by enabling community members to contribute to and adapt workflows for various taxa, regions, and reporting frameworks[20]. It enables national agencies, NGOs, and other stakeholders to design customised workflows that meet specific data and reporting requirements, including obligations under the Kunming-Montréal Global Biodiversity Framework. The platform facilitates national biodiversity assessments, supports cross-institutional collaboration, and lowers technical barriers to effective monitoring and decision-making (Griffith et al. 2024). The available pipelines fall into three main categories: (i) Pipelines for reporting, which focus on the calculation of EBVs and indicators aligned with the CBD framework and subject to peer review; (ii) General biodiversity monitoring workflows, applicable across scales and monitoring objectives; and (iii) Sampling prioritisation pipelines, which help build national Biodiversity Observation Networks (BONs) by identifying sampling areas based on criteria such as environmental gradients, species presence (e.g., threatened species), or site accessibility. These sampling pipelines provide a structured approach to expanding national and regional monitoring programmes.

[19] https://boninabox.geobon.org/pipeline-engine
[20] https://geo-bon.github.io/bon-in-a-box-pipeline-engine/pipeline_standards.html

Although indicators used for national reporting are beyond B3's scope, it is worth noting that new tools such as BON-in-a-Box are actively being developed and represent promising avenues for enhancing the implementation of FAIR principles in biodiversity science and policy.

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9 Annex

Figure A1: Screenshot of the EBV Data Portal web interface for updating the metadata. Tab 1 - General Information.

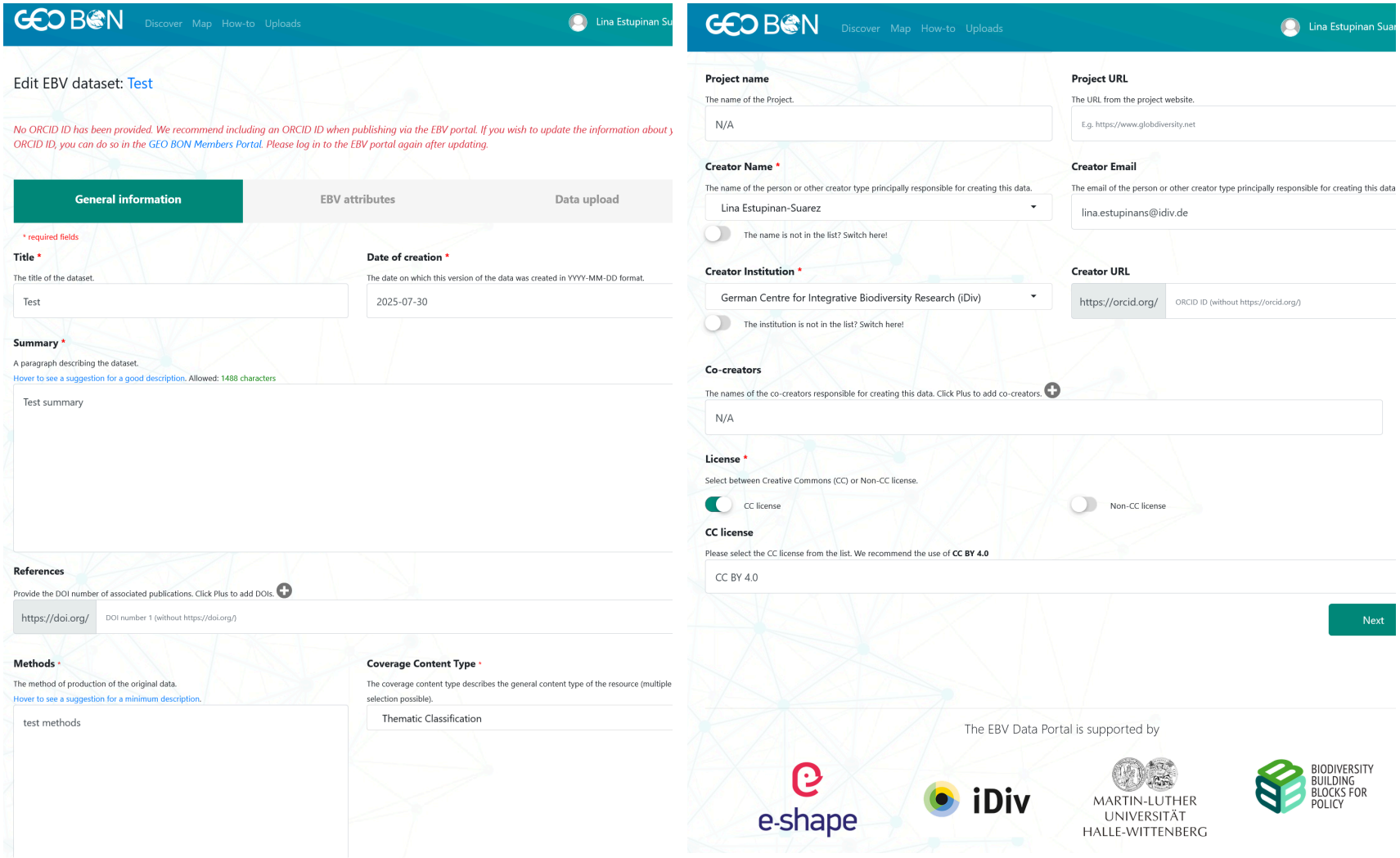
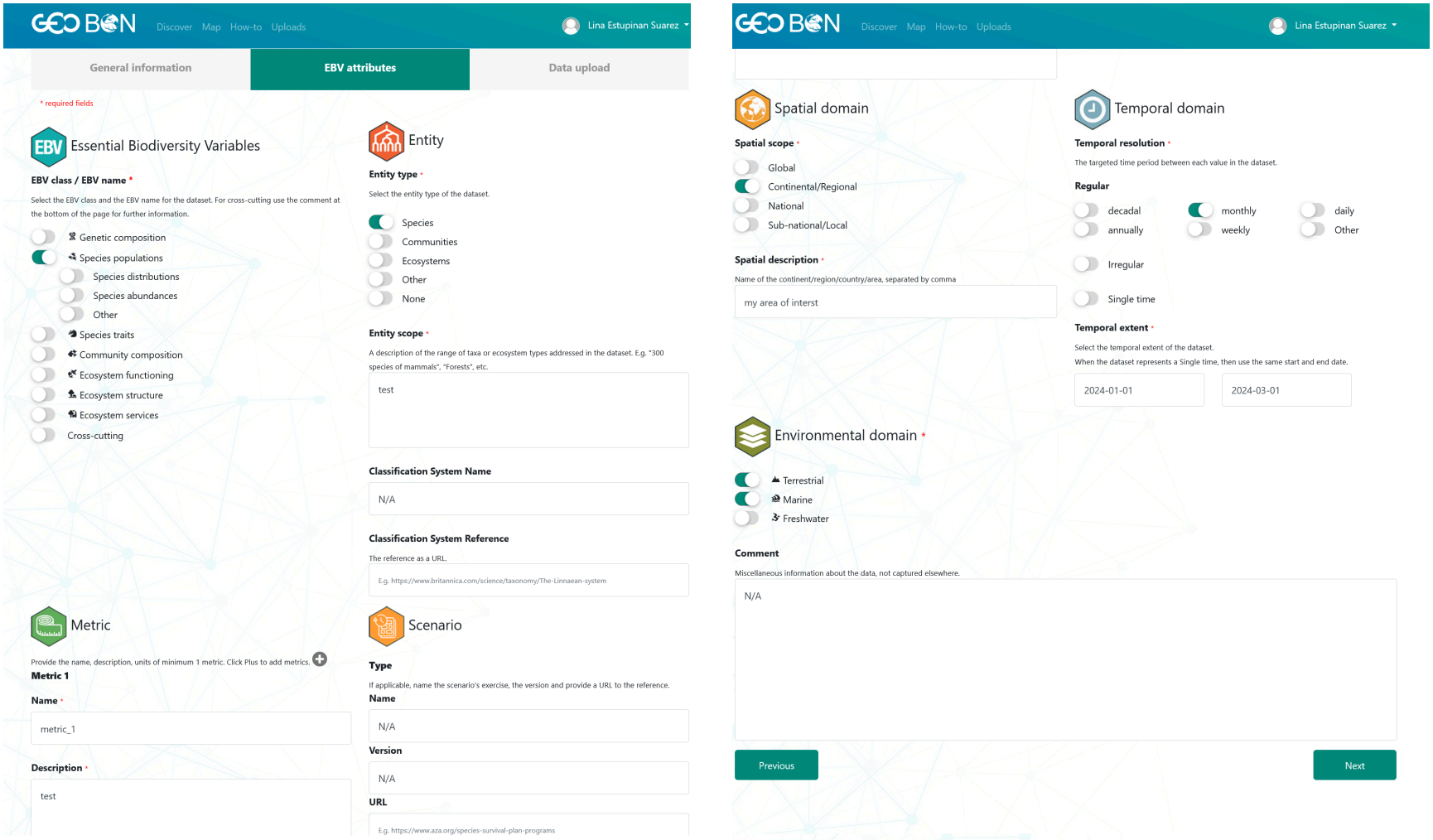


Figure A2: Screenshot of the EBV Data Portal web interface for updating the metadata. Tab 2 - EBV attributes.



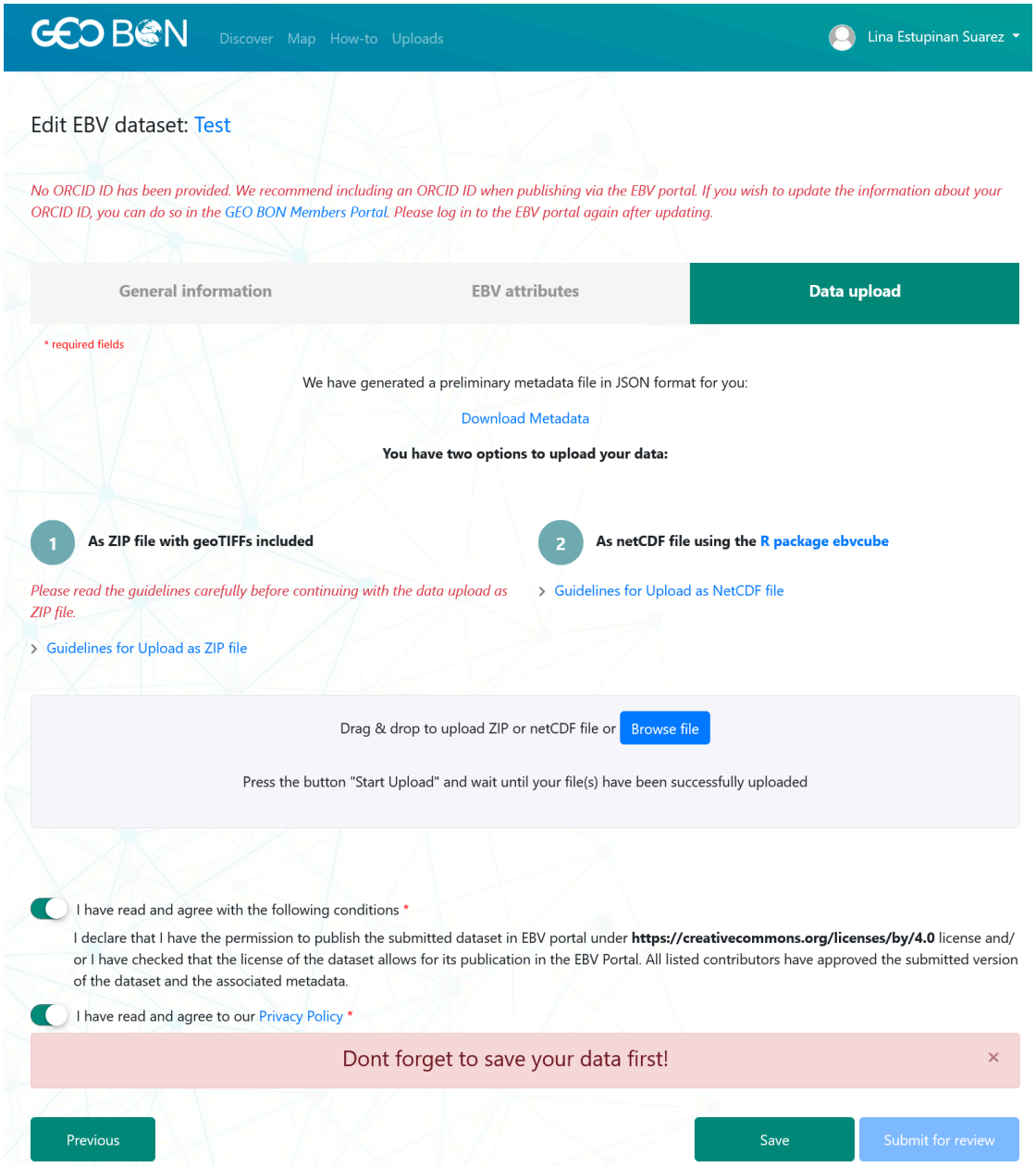


Figure A3: Screenshot of the EBV Data Portal web interface for data upload (Tab 3).