D.3.2. Report on testing workflows generating biodiversity and environmental variables and uptake of new data into WFD, MFSD, and EV systems
Version draft 2

Date of delivery: 11.11.2025

Author(s) name(s): Muresan Mihaela, …..

Affiliation: NIRD GeoEcoMar

MARK IF PUBLIC / SENSITIVE / CLASSIFIED

Funded by the European Union

UK Research and Innovation

Document Information

Grant Agreement	101082021
Project Acronym	MARCO-BOLO
Project Title	MARine COastal BiOdiversity Long-term Observations

Deliverable Number	D3.2
Work Package Number	WP3
Deliverable Title	D.3.2. Report on testing workflows generating biodiversity and environmental variables and uptake of new data into WFD, MFSD, and EV systems
Lead Beneficiary	Muresan Mihaela, GeoEcoMar
Author(s)	Muresan Mihaela, WP3 team (CNR, Hereon, SGN, UB, USE, APS)
Due Date	30.11.2025 (month 48)
Submission Date	11.11.2025
Dissemination Level	PU[1]
Type of Deliverable	Report[2]

Version N.N	11.11.2025, Muresan Mihaela
Version N+1.+1	DD.MM.YYYY, Muresan Mihaela
Version N+2.N+2	DD.MM.YYYY, Author

[1] Dissemination level: **PU:** Public, information as referred to in European Commission Decision 2015/844

[2] Type of deliverable **R: Document,** Report,
Data Management Plan

Executive Summary

This study evaluates the capacity of a number of existing monitoring programs in four European river - estuary -coastal systems (**Elbe - North Sea, Danube - Black Sea, Po – Adriatic Sea, and Guadalquivir - Atlantic Ocean**) to support **Essential Biodiversity Variables (EBVs) and, where available, Essential Ocean Variables (EOVs)**. We analyzed more than 100 monitoring datasets across freshwater, transitional, and marine domains, assessing their readiness to generate EBVs based on spatial and temporal representativeness, taxonomic coverage, data accessibility, and methodological approach.

Across all case studies, monitoring systems already provide strong foundations for EBVs related to species abundance, community composition, and ecosystem functioning. These EBVs are supported by long-term marine programs (ICES, CMEMS, LTER) and established WFD/MSFD policy. However, other EBVs, particularly trait diversity, ecosystem structure, and river-sea connectivity, are poorly represented or fragmented, especially in estuaries and wetlands.

Marine data are generally more standardized, interoperable, and openly accessible, enabling easier integration into regional and global data infrastructures (EMODnet, ICES, CMEMS, BONs). Freshwater and estuarine data, although abundant, are often stored in restricted databases, limiting reuse and slowing EBV/EOV translation. The dominant barrier is data accessibility, not lack of data.

All sites show high policy alignment (WFD, MSFD, Natura 2000), ensuring long-term monitoring continuity. To become EBV/EOV-ready, the systems need improved FAIR access to biological datasets, harmonized metadata and taxonomy, and better integration across freshwater- estuary - sea continuum.

Overall, the monitoring capacity exists, but stronger interoperability is needed so that national monitoring smoothly flows into regional and global biodiversity observation systems.

Contents

1. Objectives

This study aims to evaluate the readiness of existing monitoring systems across **four representative European case-studies covering the river - estuary - coastal continuum** to deliver EBVs/EOVs, and to identify the improvements needed to enable their use in integrated biodiversity and ecosystem assessments. Thus, the **main objectives** are:

- Assessing the capacity of existing monitoring programs (WFD, MSFD, Habitats Directive) to support EBVs and EOVs by analyzing dataset availability, spatial and temporal representativeness, methodological consistency, and accessibility across freshwater, transitional, and marine domains in all the four case-studies.
- Identifying gaps that prevent data reuse and upscaling to regional/global biodiversity and ecosystem-state indicators according to international frameworks such as GEO BON and GOOS.
- Assessing the level of data integration and interoperability that enables the flow of monitoring data, from national data producers to regional/EU data hubs (EMODnet, ICES, EEA, CMEMS) and ultimately to global biodiversity and ocean observation systems.

2. Background

EBVs and EOVs are global frameworks developed by GEO BON and GOOS (Affinito et al., 2024, Lumbierres et al., 2024), respectively, to track biodiversity and ecosystem change in a comparable and standardized way. Although the EBV framework defines **84 EBVs** grouped **into six classes** (Pereira et al., 2013, Langer et al., 2022, Lumbierres et al., 2025), **none are yet fully operational globally**. Only a small subset, mainly **species distribution, species abundance, and increasingly phenology, ecosystem structure and functioning**, are considered near-operational, because global data pipelines already exist (GBIF, OBIS, Copernicus, CMEMS) (Kissling et al., 2018; GEO BON, 2023). These EBVs benefit from standardized monitoring and automated data flows from national to global repositories. Other EBVs, particularly **trait diversity, genetic composition, and ecosystem connectivity**, remain in early development due to fragmented monitoring and lack of interoperability across countries (Kissling et al., 2018). National monitoring programs such as the WFD, MSFD, and Habitats Directive already collect most of the raw measurements (species, habitats, environmental conditions) **(Fig.1).** EBVs/EOVs provide the structure to harmonize these observations and enable data flow from national schemes to regional and global systems (e.g., EMODnet, ICES, CMEMS), turning monitoring data into comparable and scalable indicators of ecosystem change (Hardisty et al., 2019**,** Gonzalez et al., 2023). **GEO BON is currently upgrading BON-in-a-Box platform into a monitoring knowledge hub that**

enables users at all scales to report, share, and benefit from biodiversity monitoring activities (GEO BON Strategic Plan 2023–2026).

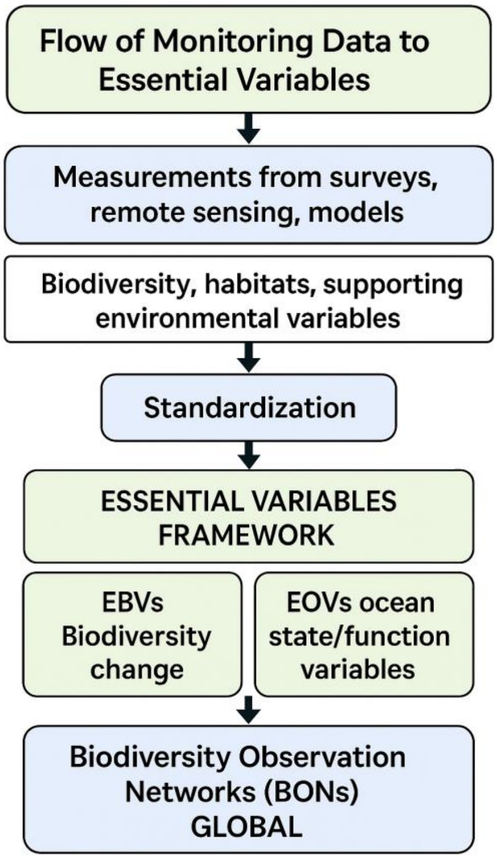


Fig. 1 Monitoring to Essential Variables: A Data Flow Framework

3. Methodology

Datasets from all the four case studies (Elbe - North Sea, Po - Adriatic Sea, Danube - Black Sea, Guadalquivir River - Atlantic Sea) covering the land-river-sea continuum, were provided by each partner (CNR, Hereon, SGN, USE, APS) and also compiled from online official sources, including national monitoring data, regional datahubs (EURObis, CMESM, EMODNet), and datasets published in different repositories (e.g. Zenodo). The potential of each dataset to contribute to EBVs was assessed using the GEOBON - GOOS suitability criteria: (i) spatial representativeness (coverage across ecological gradients), (ii) temporal resolution and consistency (frequency and longevity of measurements), (iii) data accessibility and standardization (FAIR principles), (iv) ecological relevance (direct linkage to EBV classes), and (v) integration with environmental drivers (coupling with physico-chemical EOVs). Each criterion was scored on a 1 – 5 scale, where 5 represents full compliance with the standard (systematic, long-term, open, and integrated monitoring), then an EBV readiness score was subsequently derived. This hierarchical scoring allowed cross-domain comparison and identification of data gaps along the river - sea continuum in each case study, following the GEO BON biodiversity observation network framework and the GOOS biological EOV principles.

4. CASE STUDIES

Elbe River basin - North Sea

The Elbe River basin (~148,000 km², of which ~97,000 km² lie in Germany) originates in the Krkonoše Mountains in the Czech Republic and flows northwest through central Germany into the North Sea (Shupe et al., 2021, IKSE, 2022). It hosts a wide diversity of habitats along its longitudinal gradient, including alpine headwaters, lowland floodplains, riparian forests, oxbows, and estuarine tidal flats (IKSE, 2022). The Elbe Estuary between Hamburg and Cuxhaven forms a highly dynamic and ecologically valuable transitional zone, characterized by tidal mudflats, brackish channels, and salt marshes (Stapf *et al.*, 2023). It supports numerous migratory and diadromous species, including European eel (*Anguilla anguilla*), Atlantic salmon (*Salmo salar*), estuarine birds and diverse benthic communities (BfN, 2020; Natura 2000 Elbe estuary IMP). The German Bight (Elbe's mouth discharge into the North Sea) is a productive coastal shelf system strongly influenced by riverine nutrient inputs from the Elbe and other major rivers (Capuzzo *et al*., 2018; Burson et al., 2016, OSPAR, 2023). It contains ecologically relevant habitats such as sandbanks, mussel beds, and seagrass meadows (*Zostera marina*) (Krause-Jensen *et al*., 2021; Reusch *et al*., 2018).

Po River basin - Adriatic Sea

The Po River basin (~70,000 km²) stretches from alpine headwaters in the Cottian Alps to lowland floodplains, encompassing diverse habitats: rivers, oxbows, riparian forests, and wetlands and a rich biodiversity (Nogherotto *et al*., 2022). In turn, the Po Delta is an area of wetlands and lagoons, which play the role of an ecological buffer zone linking river and sea. It is a biodiversity hotspot, designated Ramsar and Natura 2000, hosting >370 bird species, amphibians, reptiles, and migratory fish (RAMSAR, Natura 2000 Network - Po Delta). It provides nursery habitats supporting Adriatic fisheries, while acting as a critical node of connectivity (river - sea, river - floodplain, nutrient/sediment flux). Yet, it is vulnerable to nutrient enrichment (eutrophication), habitat loss (drainage), salinization, and sea-level rise (Balzarolo *et al*, 2010). The Northern Adriatic (~100,000 km²) is among the most productive seas of the Mediterranean, fueled by Po nutrient inflows (RAC/SPA, 2010, CMEMS, LTER). Key habitats include seagrass meadows (*Posidonia oceanica*), coralligenous reefs, and sandy shelf ecosystems. Riverine connectivity shapes productivity, but eutrophication and hypoxia are recurrent risks.

Danube basin - Black Sea

The Danube River Basin is Europe's second largest catchment (~801,000 km²), draining 19 countries and flowing from the Alps and Carpathians to the Danube Delta and into the northwestern Black Sea *(ICPDR, 2015, 2021)*. The Danube Delta, shared by Romania and Ukraine, is Europe's largest wetland (~4,152 km²), designated as a Ramsar site and UNESCO Biosphere Reserve, with extensive reed beds, lakes, and channels (Ramsar Secretariat, 2023; UNESCO, 2023). It acts as a key ecotone between river and sea, supporting >300 bird species and functioning as a nursery and migration corridor for fish, including sturgeons (Zaitsev & Mamaev, 1997). The Danube provides habitats for over 100 fish species, diverse macroinvertebrate assemblages, and riparian wetland biodiversity (ICPDR, 2021). The Delta also acts as a nutrient and sediment filter, yet the Danube remains the dominant source of nitrogen and phosphorus inputs to the Black Sea, historically driving eutrophication and seasonal hypoxia (Giosan *et al.,* 2012; Panin & Jipa, 2002*)*. The northwestern Black Sea shelf (~60,000 km²) is one of the basin's most productive marine areas, strongly shaped by Danube freshwater and nutrient inflows (Neumann et al., 2025), hosting rich plankton, benthic communities, and seagrass beds, although many habitats have been degraded.

Guadalquivir Basin - Atlantic Ocean

The Guadalquivir River, located in southern Spain, is one of the Iberian Peninsula's major rivers, draining a large basin before (cca. 58,000 km²) flowing into the Atlantic Ocean through the Gulf of Cádiz (CHG, 2022; Sánchez *et al*., 2020). Its lower course and estuary form a dynamic transitional water system, where freshwater mixes with marine waters under strong tidal influence and marked salinity gradients (Ruiz *et al.,* 2015). This estuarine mosaic, including the surroundings of Doñana National Park, sustains highly productive ecosystems and supports rich biological communities, including benthic invertebrates, estuarine and migratory fish, and more than 300 bird species using the area as a feeding, wintering, or stopover site (Martín *et al*., 2021; Montes *et al.,* 1998; Ramsar Secretariat, 2023). At the ocean front, the Guadalquivir plume delivers nutrients and suspended sediments to the coastal shelf of the Gulf of Cádiz, influencing primary productivity and modulating local ecological processes (Navarro & Ruiz, 2013; Ruiz *et al*., 2015).

5. Results and Discussion

5.1. ELBE – NORTH SEA

5.1.1. Datasets and EVs suitability

The Elbe - North Sea system is one of the most data - rich river - sea continuum in Europe, with monitoring traditions extending back more than six decades covering the freshwater Elbe catchment, its tidal estuary, and the German Bight of the North Sea (**Fig. 1, Table 1**).

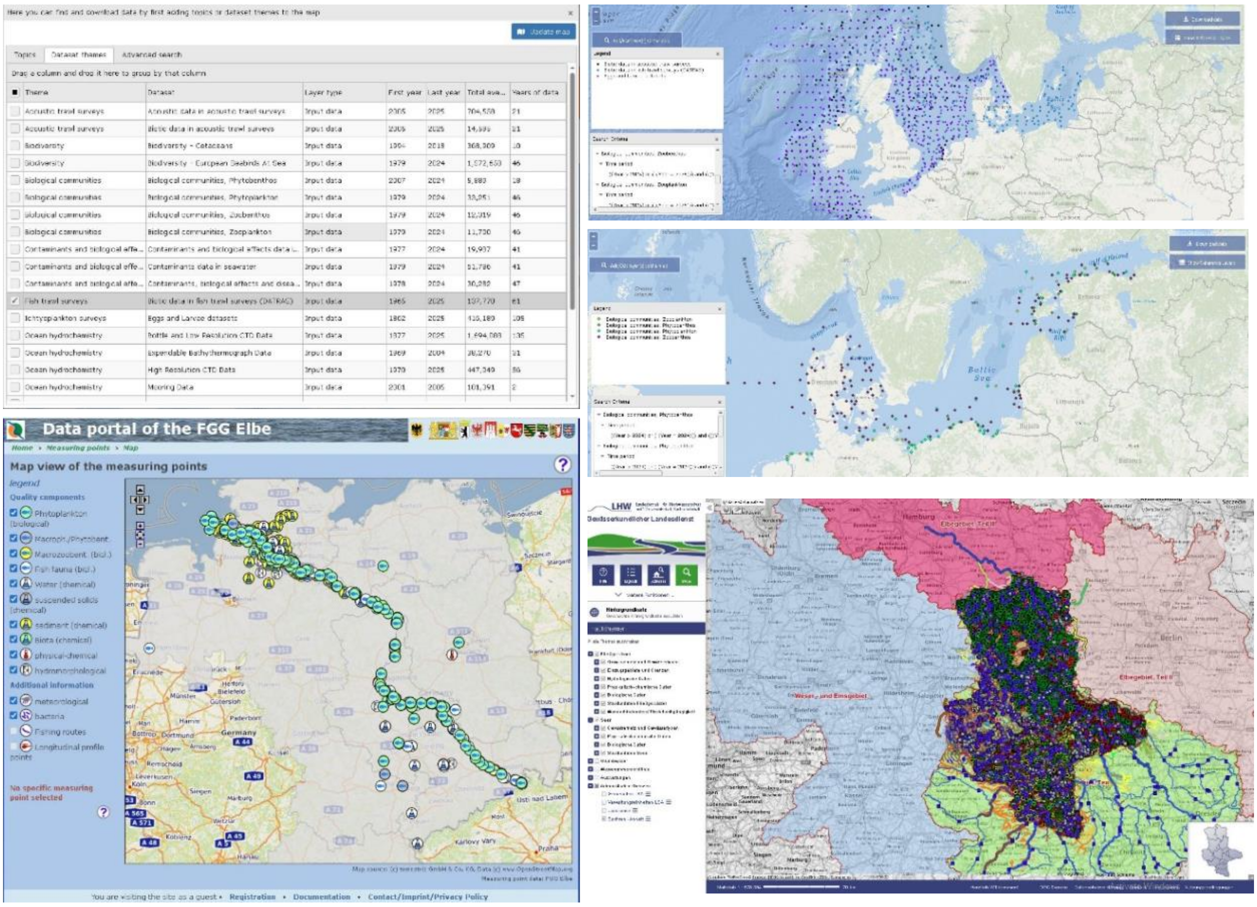


Fig. 1. Integrated monitoring network supporting EBV/EOV observations across the Elbe–North Sea river – estuary - coast continuum

Table 1. Catalog of datasets used in the Elbe–North Sea EBV/EOV assessment including domain (freshwater, transitional, marine), alignment with Essential Biodiversity Variables (EBVs) and Essential Ocean Variables (EOVs), spatial and temporal coverage, data accessibility (FAIRness), and methodological notes. The table also reports dataset suitability for EBV/EOV operationalization and traceability of data sources.

Dataset / Source	Domain	EBV Class Alignment	EOV Alignment	Spatial Coverage	Temporal Coverage	Records (approx.)	Access	Notes on Taxonomy / Methodology	Suitability	Spatial coverage source
MUDAB – Phytoplankton	Marine & estuarine (North/Baltic; Elbe estuary)	Species abundance; Community composition	Phyto biomass/diversity; Oxygen; Nutrients	80,434 stations (subset)	1975-2024	Subset of 1,489,308	Restricted portal access	Species-level in many cases; WoRMS harmonization needed	High	https://www.mudab.de/ https://geoportal.bafg.de/mudab/index.html#Recherche
MUDAB – Macrozoobenthos	Marine benthos (German Bight, Wadden, estuaries)	Species abundance; Community composition; Trait diversity Ecosystem structure	Seafloor integrity (macrofauna biomass)	Coastal benthic stations	1990s-2024	Tens of thousands	Restricted portal access	Good species resolution; some genus-only; WoRMS compliance	Partial	https://www.mudab.de/
MUDAB – Zooplankton	Estuarine & marine	Species abundance; Community composition	Zooplankton biomass/ diversity	Selected stations	1990s-2024	Thousands–tens of thousands	Restricted portal access	Mixed taxonomic levels; harmonization needed	Partial	https://www.mudab.de/
MUDAB – Chlorophyll-a	Estuarine & marine	Proxy for community abundance & productivity	Phytoplankton biomass EOV	Broad coverage	1986-2025	Subset of 9,769,227	Restricted portal access	Methods vary; harmonization required	High	https://www.mudab.de/
MUDAB – Marine mammals	Marine	Species occurrence/abundance (limited)	—	Few stations	2021	739	Restricted portal access	Sparse; presence-only	Weak	https://www.mudab.de/

BfN Species distributions of marine mammals (purpoises)	Marine (German offshore areas)	Species Population		German offshore areas, based on a 10x10 km grid (EU-GRID)	2001-2018 (seasonal/ 3-year aggregate)	BfN 3-year raster datasets, BfN acoustic, ship/aerial annual monitoring campaigns, INSPIRE datasets,	Portal at the moment not accessible	The estimates differ in methodology, area and period	Partial	https://www.bfn.de/daten-und-fakten/kartenanwendung-populationsentwicklung-von-schweinswalen-im-3-jahresraster?utm
MDI -NI Purpose sightings	Marine (coastal waters of Lower Saxony)	Species Population		12-nm-zone from Borkum to Cuxhaven	Spring 2008, 2010	Two aerial surveys/2008	Partially (based on conditions)	line-transect method	Partial	https://mdi.niedersachsen.de/HeronKaDI/JAVA_SCRIPT/37_Portal/
MDI -NI Grey Seals monitoring	Lower Saxony Wadden Sea National Park	Species Population/ distribution	—	Saxony Wadden Sea National Park	2006-2011	FFH monitoring program (survey flights in winter and spring)	Partially (based on conditions)	Aerial transects	High	https://mdi.niedersachsen.de/HeronKaDI/JAVA_SCRIPT/37_Portal/
MDI -NI 'Seal Managemen t Plan'&TMAP	Lower Saxony Wadden Sea	Species Population/ distribution	—	Lower Saxony Wadden Sea	1991 - 2021	Annually summer months		Aerial surveys	High	https://mdi.niedersachsen.de/HeronKaDI/JAVA_SCRIPT/37_Portal/
MDI-SH - Marine mammals (GeoServer)	Marine (German Bight)	Species distributions; abundance (patchy)	—	German Bight (strandings/ sightings)	2000s-present	100s-1,000s	Open	Uneven coverage	Partial	MDI-SH GeoPortal https://geodienste.hamburg.de/

MUDAB – Sediment chemistry	Marine & estuarine	Context (pressures, not direct EBV)	Contaminants, supporting variables	Sediment stations	1984-2024	438,571	Restricted portal access	Environmental context, not biodiversity	Partial	https://www.mudab.de/
ICES DATRAS – Fish trawl surveys	Marine shelf (North Sea)	Species abundance; Community composition; Traits	—	North Sea trawl grid (ICES NS-IBTS, multi-country grid)	1965-2025	137,770 events	Open (ICES)	Fully standardized WoRMS aligned	High	https://datras.ices.dk/
ICES – Phytoplankton	Marine & estuarine	Species abundance; Community composition; Phenology, Ecosystem structure and function	Phyto biomass/diversity	Baltic Sea, North Sea, NE Atlantic	1979-2024	33,251 events	Open (ICES)	Long series, standardized	High	https://www.ices.dk/data/data-portals/Pages/Biological.aspx
ICES – Zooplankton	Marine & estuarine	Species abundance; Community composition	Zooplankton biomass/diversity	Baltic Sea, North Sea, NE Atlantic	1979-2024	11,700 events	Open (ICES)	Smaller coverage	Partial	https://www.ices.dk/data/data-portals/Pages/Biological.aspx
ICES – Zoobenthos	Marine benthos	Species abundance; Community composition; Trait diversity, Ecosystem function &structure	Seafloor integrity	Baltic Sea & North Sea monitoring	1979-2024	12,319 events	Open (ICES)	Good species resolution	High	https://www.ices.dk/data/data-portals/Pages/Biological.aspx

ICES – Phytobenthos	Coastal marine	Species abundance; Community composition	Habitat/coverage (primary producers)	Baltic & North Sea coastal waters	2007-2024	5,889 events	Open (ICES)	Shorter time series	Partial	https://www.ices.dk/data/data-portals/Pages/Biological.aspx
Helgoland Roads LTER – Microplankton &Phytoplankton	Marine (German Bight)	Species abundance; Community composition; Phenology	Microplankton composition	Single station (Helgoland Roads, German Bight)	1962-present	~100k entries	Open	High WoRMS compliance	High	https://marine-data.de/data?qf=genericType/data&q=Helgoland+Roads+LTER&offset=0 https://marine-data.de/data?qf=genericType/data&q=phytoplankton&offset=0 https://doi.pangaea.de/10.1594/PANGAEA.736644
Helgoland Roads LTER phytoplankton	Marine (German Bight)	Species abundance; Community composition; Phenology	Phytoplankton & microzooplankton composition	every weekday at the station "Kabeltonne" (54°11.3’N, 7°54.0’E)	1962-present	144 datasets	login required	High WoRMS compliance	Moderate	https://doi.pangaea.de/10.1594/PANGAEA.960407 (dataset in review)
TMAP - Wadden Sea Birds (CWSS)	Coastal	Species abundance (counts), distributions	—	Trilateral Wadden Sea flyway sites (DE, DK, NL)	1980s-present	100k+	By request (CWSS)	Standardized census	High	https://www.waddensea-secretariat.org/

BfNsightings of seabirds	Marine	Species abundance (counts), distributions		German EEZ, North & Baltic Seas	2004 - 2020		open data via WFS/WMS	Taxonomic resolution generic (need species-level for EBV species)	High	https://metadaten.bfn.de/BfN-MetaCat/?lang=de#/search?sortAttribute=title_sort&filter=%7B%22keyword_facet%22%3A%5B%22Open%20Data%22%5D%7D&term=&core=
EMODnet Biology - German Bight	Marine	Species occurrences (phyto, benthos, fish) Ecosystem structure	Context for EBVs	German Bight region (southern North Sea)	2000s-present	1000k+	Open (EMODnet)	Taxonomy harmonized to WoRMS	High	https://www.emodnet-biology.eu/
CMEMS Biogeochemistry -North Sea	Marine	Productivity, phenology Ecosystem structure & function	Phytoplankton biomass/diversity, oxygen, nutrients	Basin-scale North Sea gridded fields	1990s-present	Millions (gridded)	Open (CMEMS)	Model outputs; validated	High	CMEMS https://marine.copernicus.eu/
FGG - Phytoplankton (WFD BQE)	Freshwater	Community abundance; Community composition	—	German freshwater stations (Elbe basin)	2000s-present	Thousands	Portal summaries	WFD compliant	High	FGG Portal https://www.fgg-elbe.de/
FGG - Macrophytes / Phytobenthos (WFD BQE)	Freshwater	Species abundance & distributions, Ecosystem structure & function	—	German freshwater stations (Elbe basin)	2000-present	Hundreds	Portal summaries	Low frequency	Partial	FGG Portal https://www.fgg-elbe.de/

FGG - Macrozoobenthos (WFD BQE)	Freshwater	Community abundance; Diversity; Traits Ecosystem structure & function	—	German freshwater stations (Elbe basin)	2000s-present	Thousands	Portal summaries	Multimetric indices	High	FGG Portal https://www.fgg-elbe.de/
FGG - Fish fauna (WFD BQE)	Freshwater & Transitional	Species abundance; Community composition; (proxy) Connectivity	—	German freshwater & transitional stations (Elbe basin)	2000s-present	Thousands	Portal summaries	EFI+ style	High	FGG Portal https://www.fgg-elbe.de/
FGG - Hydromorphology	Freshwater	Connectivity / Free River flow	River discharge/sediment	Elbe basin rivers (Germany)	Project-based	Sparse	Portal summaries	Barrier inventory	Weak–Partial	FGG Portal https://www.fgg-elbe.de/
Rieger & Redelstein 2025 - Elbe Phytoplankton	Transitional (Elbe)	Species abundance; Community composition; Phenology Ecosystem structure & function	Phyto biomass/diversity	Middle & lower Elbe River	2006-2023	266,792	Open	Utermöhl; biovolume	High	DOI 10.1594/PANGAEA.980525
GLD Sachsen-Anhalt – Hydrology	Freshwater	Connectivity context (flows/levels)	River discharge	Saxony-Anhalt river network (Elbe basin)	1990s-present	Many stations, daily/hourly	Open portal	Driver/context for EBVs	High for context	GLD portal https://gld.sachsen-anhalt.de/

The Elbe–North Sea monitoring system includes marine, transitional, and freshwater datasets (**29** assessed in the current study), with marine data dominating the inventory (app.70%) (**Table 1**, **Figs. 2 & 3**). Marine datasets provide robust coverage of **Species Abundance, Community Composition, Ecosystem Functioning,** and **Phenology**, while the transitional, and freshwater datasets contribute more selectively, especially to **Connectivity**, benefiting from freshwater hydrology data, WFD hydromorphology, and fish indices (GLD Sachsen-Anhalt, FGG). However, barriers inventory and migration corridors are not yet systematically linked to biological responses. Representation of **Trait Diversity** and **Ecosystem Structure** is moderate in all datasets, somewhat stronger in marine and freshwater benthic datasets (macrozoobenthos, phytobenthos). However**, Ecosystem structure**, supported mainly by the marine datasets (57%) such as benthic surveys (ICES/MUDAB) and phytobenthos monitoring, remains patchier and shorter in duration compared to pelagic variables. **Ecosystem functioning** is well represented, through chlorophyll-*a* (MUDAB), CMEMS productivity and nutrient data, and validated Earth observation records, directly supporting eutrophication and productivity EBVs/EOVs. **Traits** can be derived for fish (size spectra) and benthic assemblages, but cross-taxon functional trait datasets are scarce. As mentioned, **Species Abundance** and **Community Composition** are the most comprehensively supported EBVs. For example, phytoplankton monitoring includes continuous high-frequency series at LTER sites (since 1962), complemented by MUDAB and ICES datasets. Marine fish monitoring is also covered by long-term standardized ICES DATRAS trawl surveys (1965 - present), while freshwater fishes are surveyed under WFD EFI+ indices. Macrozoobenthos, zooplankton, macrophytes, mammals and birds are likewise well represented, making it possible to calculate abundance trends, diversity indices, and phenological metrics across multiple trophic levels.

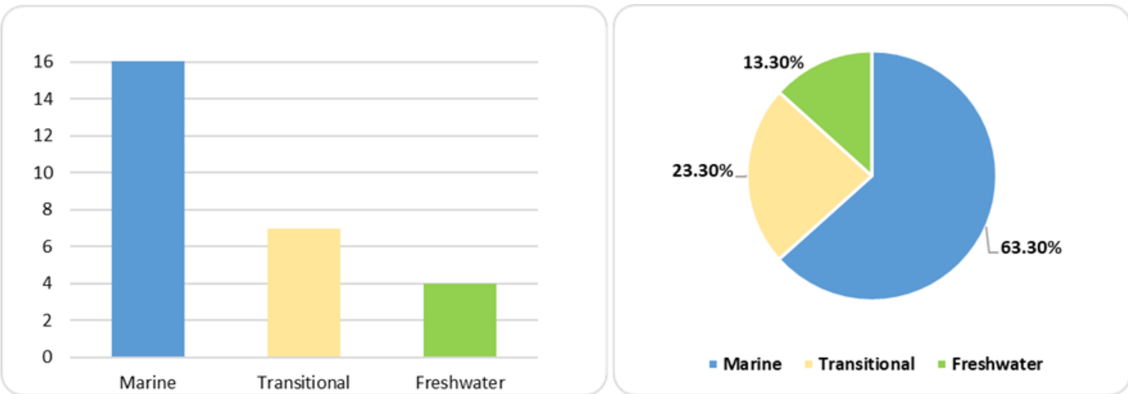


Fig. 2. Distribution of datasets across ecosystem domains (freshwater, transitional, marine) in Elbe - North Sea case study

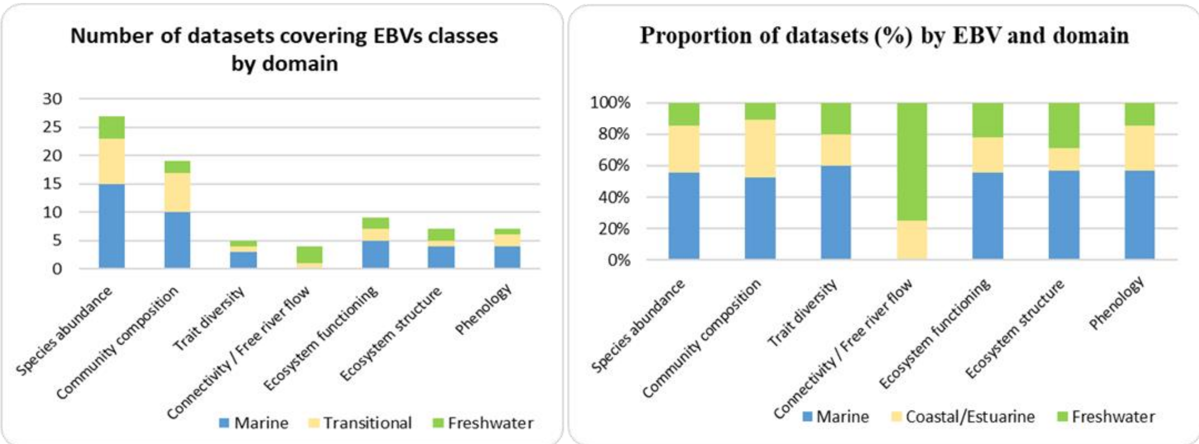


Fig. 3. Distribution of datasets supporting EBV classes in the Elbe–North Sea system. Left: number of datasets per EBV class by ecosystem domain. Right: proportional contribution (%) of each domain to EBV coverage

Among other EBVs, **Phenology**, though limited in datasets availability, emerges as a clear strength being supported by weekly phytoplankton observations at Helgoland, ICES phytoplankton and zooplankton datasets, and CMEMS biogeochemistry products that enable robust bloom timing analyses.

The **temporal coverage** of the Elbe–North Sea system is one of its strongest assets, with datasets extending beyond five decades and standardized taxonomic frameworks (often WoRMS aligned) that allow robust trend analysis. **Spatially**, marine areas are well covered by trawl grids, plankton stations, and EO-derived fields, while freshwater rivers and tributaries are systematically sampled according to WFD protocols. However, wetlands, floodplains, and deltaic habitats remain underrepresented, and connectivity monitoring is still too fragmented to support fully integrated EBVs.

From a **policy standpoint**, the data aligns closely with WFD (ecological status and biological quality elements), MSFD (biodiversity, eutrophication, fish, seafloor integrity), and the Habitats Directive (protected species and habitats). OSPAR and CBD frameworks also provide links to international indicators.

5.1.2. Readiness of the Elbe–North Sea monitoring system for upscaling to Essential Variables

To assess the readiness of the Elbe–North Sea monitoring system to produce EBVs and, where relevant, EOVs, a structured evaluation that combined quantitative scoring and expert judgement was applied. All inventoried datasets **(Table 1)** were evaluated according to domain (freshwater, estuary, marine), sampling method, temporal extent, spatial extent, taxonomic level, and data accessibility.

This allowed that each dataset to be appraised for their **suitability** to potentially contribute to any of the seven EBV classes/subclasses: **Species Populations** (abundance), **Community Composition**, **Trait Diversity**, **Ecosystem functioning** (including **Phenology and Connectivity**), and **Ecosystem Structure**. Thus, a binary matrix (1 = contributes to EBV generation, 0 = does not contribute) was initially built, which allowed the assignment of datasets to EBV classes independent of data volume or extent.

Further, once EBV contributions were identified, each dataset was scored, using a 0 - 5 ordinal scale, against criteria detailed in the **Table 2 and 3.** Finally, the individual dataset scores were aggregated into a mean readiness score per EV and criteria in order to evaluate the distance up to a full integration of current monitoring into a more global context.

The **readiness scores** (**Fig. 3, Table 2, 3**) evaluating the monitoring data structure and flow indicate a strong bias towards abundance, composition, and ecosystem functioning EBVs.

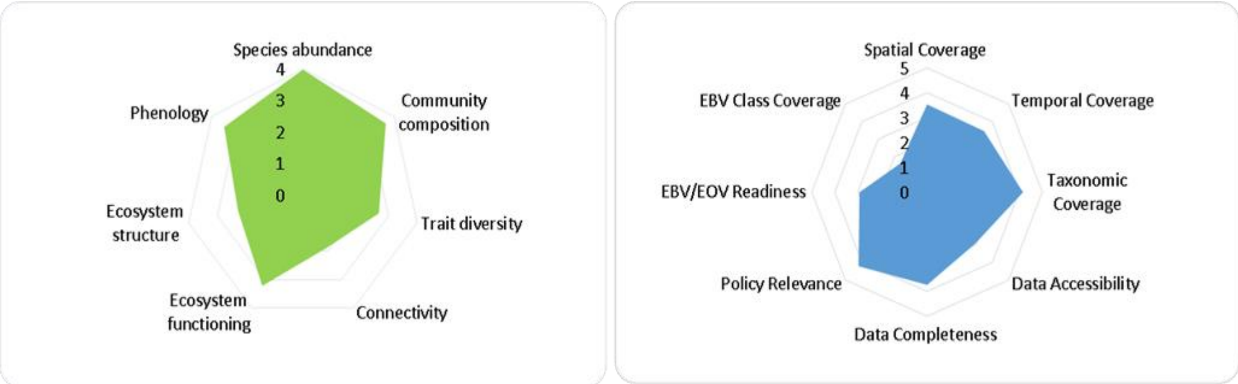


Fig. 3. Radar plots of EBV readiness scores (left) and monitoring system criteria scores (right) for the Elbe–North Sea case study

Table 2. Readiness assessment of EBV classes in the Elbe–North Sea monitoring system. **EBV readiness scores** were computed using a weighted multi-criteria approach combining dataset coverage (P), temporal consistency (T), spatial representativeness (S), accessibility (A), and maturity (M), where P represents the proportion of datasets supporting each EV class; S - share of freshwater, estuarine, marine datasets assigned to each EV; A - openness of data, weighted as: open - 1, partial - 0.5, restricted - 0.2; M - proportion of datasets aligned with standardized, operational monitoring frameworks (e.g., WFD, MSFD, HD). Each component was normalized to 0 - 1 (see the second column in Table 2) and aggregated using the equation: EBVs Score = 5 × (0.35 P + 0.25 T + 0.15 S + 0.10 A + 0.15 M). Higher scores indicate EBVs supported by long-term, multi-domain, standardized, and openly accessible datasets.

EBV class	EBVs Score		Assessment Criteria
Species abundance	**3.97**	**P = 0.7;T= 0.9; S = 0.8; A=0.6; M = 0.9**	Strong, multi-source coverage: ICES DATRAS fish (1965–2025), Helgoland Roads phytoplankton (1962–present), ICES phytoplankton & zoobenthos, TMAP birds, and MUDAB phytoplankton/benthos. Long time series and standardized protocols enable direct EBV use.
Community composition	**3.62**	**P = 0.65; T= 0.85; S = 0.8; A=0.6; M = 0.9**	Broad taxonomic coverage with species-level detail: phytoplankton (ICES, Helgoland, MUDAB), zoobenthos community matrices (ICES/MUDAB), fish assemblages (DATRAS). Suitable for diversity indices and multivariate modelling.
Trait diversity	**2.66**	**Pe = 0.35;Te= 0.5; Se = 0.5; Ae=0.6; Me = 0.85**	Fish size spectra and benthos traits available; ICES zoobenthos offers functional traits. However, zooplankton and phytoplankton traits are sparse. Cross-taxon harmonization needed for full EBV readiness.
Connectivity / Free River flow	**1.87**	**Pe = 0.3;Te= 0.5; Se = 0.4; Ae=0.5; Me = 0.4**	Supported mainly by freshwater datasets (GLD hydrology, FGG hydromorphology, WFD fish indices). Captures barriers, flow regimes, and river fragmentation. Missing unified link to biological responses at sea–river interface.
Ecosystem functioning	**3.21**	**Pe = 0.5;Te= 0.85; Se = 0.6; Ae=0.7; Me = 0.75**	Well covered by chlorophyll-a (MUDAB Water), phytoplankton phenology (Helgoland Roads), and CMEMS biogeochemistry (phytoplankton biomass, oxygen, nutrients). Provides productivity/eutrophication EBVs and GOOS EOV linkages.
Ecosystem structure	**2.28**	**Pe = 0.3;Te= 0.45; Se = 0.5; Ae=0.55; Me = 0.45**	Seafloor integrity is supported by macrozoobenthos (ICES/MUDAB) and phytobenthos (ICES). However, fewer stations and shorter time depth compared to pelagic EBVs; riverine/wetland habitats remain patchy.
Phenology	**3.45**	**Pe = 0.5;Te= 0.95; Se = 0.55; Ae=0.8; Me = 0.65**	Explicit coverage from Helgoland Roads LTER (weekly phytoplankton since 1962), ICES phytoplankton/zooplankton datasets, and CMEMS phenology products. Directly supports phenological EBVs (e.g., bloom timing); moderate taxonomic coverage.

Table 3. Datasets assessment criteria scores. For each criterion, normalized (weighted) scores of each dataset were averaged across all datasets and rescaled to 0 -5 values, using equation (eq.1&2). EBV/EOV readiness was calculated using (eq.3), which integrated temporal coverage, data accessibility, and policy driven maturity, as for example, the proportion of datasets aligned with WFD, MSFD, HD, using weighted contributions (40% temporal, 30% accessibility, 30% maturity). EBV class coverage was calculated as the proportion of the seven weighted EBV classes supported by at least one dataset and converted to the 0 - 5 scale (eq. 4)

Criterion	Score	Methodology	Assessment Criteria
Spatial Coverage (Si)	**3.77**	$S_i = 1/N\sum_{n=0}^{i} S_i$ **(1)** Weighted Di:0.33 - marine; 0.67 - marine + transitional; 1 - all 3 **Readiness score (R_r) = 5×Si (eq.2)**	Strong spatial representativeness. The system integrates freshwater (WFD), transitional (Elbe estuary), and marine (ICES, EMODnet, CMEMS) datasets. Very good marine grid coverage (North Sea trawl surveys, phytoplankton); gaps remain for transitional
Temporal Coverage	**3.20**	< 3 yrs - > 50 yrs (normalised scores : 0 - 1)	Strong; **> 50 years long** (e.g., Helgoland Roads phytoplankton since 1962; ICES fish since 1965). Supports phenology and long-term EBVs. Benthic datasets - shorter time span.

Taxonomic Coverage	**3.77**	Species-level, multi-taxon, WoRMS-aligned: 1.00 1group, standardized: 0.67;Low/medium: 0.33	Broad coverage (phyto-, zoo- and benthos, fish, birds, macrophytes). Taxonomy is standardized (WoRMS aligned). Functional group and trait datasets are still weak, especially for mammals.
Data Accessibility	**3.03**	Open: 1.00 Partially open: 0.50 Restricted:0.20	App.53% open access (ICES, EMODnet, CMEMS), app.23% partially open, app.24% restricted (MUDAB, mammal datasets). Access restrictions slow down interoperability for global EBV scaling.
Data Completeness	**4.17**	Complete: 1.00 Minor gaps or partial metadata:0.67 Project-based :0.33	Marine datasets are standardized (ICES, CMEMS). Freshwater (WFD) are complete but sometimes aggregated. Connectivity datasets (hydrology) lack biological attribution.
Policy Relevance	**4.22**	Pi:1.0 directly used in assessment; 0.5 indirectly used; 0.2 potentially relevant;	Very strong. Nearly all monitoring exists for policy: WFD (freshwater), MSFD (marine), Natura 2000 birds/mammals. Direct mapping to EBVs/EOVs (fish EBVs directly linked to MSFD D1/D3, phytoplankton EBV linked with D5 eutrophication).
EBV/EOV Readiness	**2.57**	**Er = 5(0.4T + 0.3A + 0.3M) (eq.3)**	Ready for abundance/composition/phenology EBVs and several EOVs (chlorophyll-a, nutrients, zooplankton). Less mature for **connectivity and structural EBVs** (wetland extent, barrier passability).
EBV Class Coverage (EBVcov)	**4.29**	**EBVcov = 5× EBVno/7 (eq.4)**	Strong for **Abundance, Composition, Functioning, Phenology**. Moderate for **Traits and Structure**. Weakest for **Connectivity** — despite hydrological data, barrier–species linkage is missing.

The heatmap (**Fig. 4)** discriminates where the most datasets covered by different monitoring schemes are concentrated, indicating also a focus on variables measuring abundance and composition of different biodiversity elements and to a limited extent on ecosystem characterization (structure and connectivity).

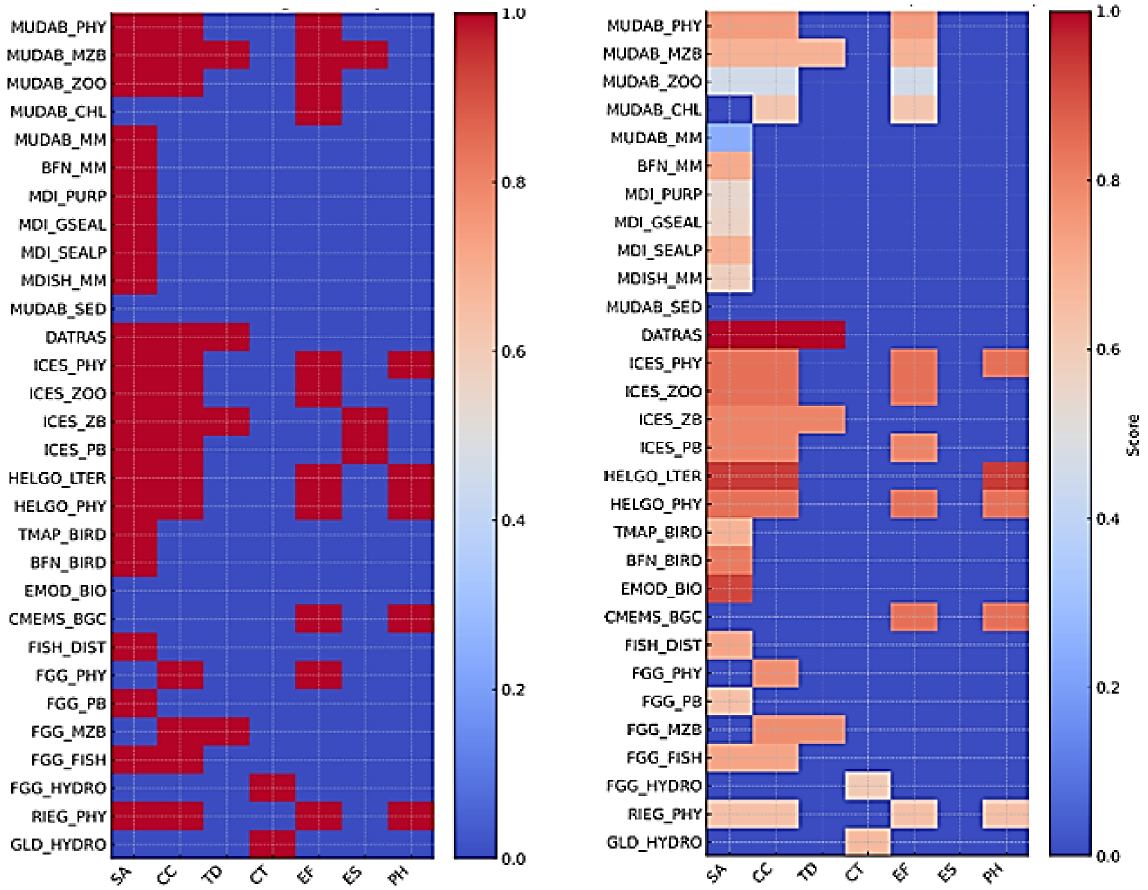


Fig. 4. Datasets coverage heatmap. Left: Contribution of individual monitoring datasets to EBV classes. With red are represented datasets that can be directly used to generate EBVs (SP - Species population/abundance; CC - Community composition; TD – Trait diversity; CT – Connectivity; EF – Ecosystem functioning; ES – Ecosystem Structure; PH – Phenology) , while blue color reflects limited relevance or missing information. Right: Datasets readiness map (each dataset has been scored by averaging spatial, temporal, taxonomic, accessibility, and completeness scores across datasets) (datasets abbreviations – Annex)

The PCA analysis (**Fig. 5**) reveals the pattern of EBVs covariance across datasets based on the EBVs they best support. Along PC1 (~40% variance), datasets that provide **species abundance and community composition**, such as ICES trawl surveys, Helgoland Roads phytoplankton, and ICES/MUDAB benthic programs, cluster together, indicating strong, mature monitoring with long time series and standardized taxonomy. PC2 (~24% variance) distinguishes between EBVs related to ecosystem functioning and phenology (pelagic datasets such as chlorophyll-a time series, CMEMS productivity, Helgoland phenology) and those supporting ecosystem structure and trait diversity (primarily benthic datasets and macrophyte/macrozoobenthos surveys). Connectivity datasets (hydrology, barriers, WFD hydromorphology) form a separate cluster, showing that while connectivity is monitored, it remains methodologically isolated from biological datasets. This reflects the current monitoring practice In the Elbe. Connectivity is monitored mainly through hydrology and hydromorphology programmes that assess river flow, barriers, and channel structure, these measurements being in general collected independently from biological surveys, using different spatial and temporal scales. This limits direct linkage to biological responses, resulting in connectivity data forming a separate monitoring stream rather than an integrated EBV component.

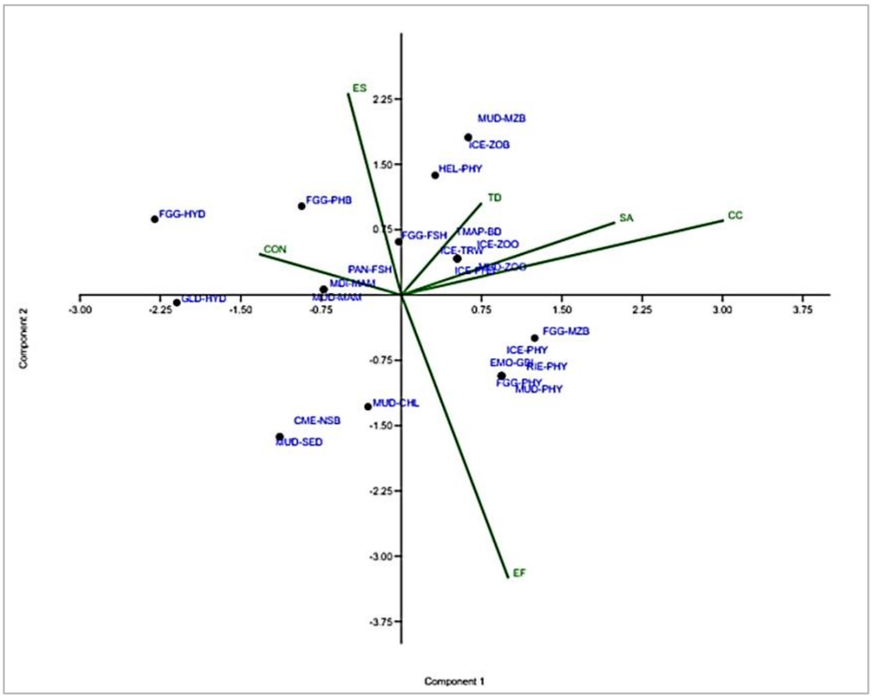


Fig. 5. PCA of EVs Coverage across Monitoring Datasets in the Elbe–North Sea System showing the most datasets revolving around PC1 and PC2 explain more than 60% of the observed variance

5.1.3. Data accessibility

The accessibility of the Elbe–North Sea datasets shows that 38% of the datasets are openly available, providing a strong foundation for EBV and EOV translation (**Fig. 6**). However, nearly the same share (41%) remains restricted, requiring login or controlled access, which may limit immediate integration and reuse. About 21% are partially accessible, usually by request. This indicates that while the region benefits from substantial open data infrastructures (ICES, CMEMS, EMODnet), restricted portals like MUDAB still could need open access policies.

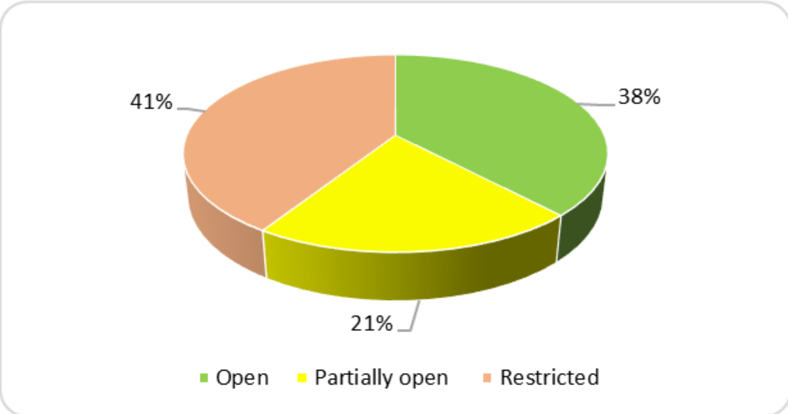


Fig. 6. Data accessibility shares in Elbe – North Sea

5.1.4. Needs for monitoring frameworks compliance with EBV/EOVs

The Elbe–North Sea system is rich in monitoring datasets, but their usefulness depends on how they are scaled and operationalized. The monitoring scheme integrates a wide range of methodologies, from high-frequency plankton sampling and Earth observation of primary productivity to station-based benthic surveys and river hydromorphology assessments (**Table 4**). This diversity ensures broad EBV coverage across abundance, composition, phenology, and ecosystem functioning. Overall, the mature datasets with **strong EBV potential** (e.g., plankton, fish, productivity) often have the best accessibility, while structural and connectivity indicators, despite their critical role, remain patchy and harder to access. Addressing these asymmetries in both monitoring and accessibility is key to strengthening the translation of the Elbe–North Sea system into global EBV/EOV frameworks. Fine temporal resolution is also critical for processes like phytoplankton phenology, while connectivity and fragmentation demand high spatial resolution and barrier mapping at reach or habitat scale. Birds and mammals need for migration-sensitive monitoring that captures short-term dynamics or seasonal corridors**.** Aligning spatial and temporal resolutions with EBV/EOV requirements creates the missing bridge between existing national/regional monitoring and international biodiversity observatories.

The **Fig. 7** schematically depicts the **data flow across different monitoring setups**. It emphasizes the role of open-access datasets in enabling a smooth transition from national monitoring (WFD, MSFD) to regional/EU frameworks (EMODnet, ICES), and further to BONs (EBV/EOV scaling), whilst the restricted datasets, could act as bottlenecks, slowing or blocking integration and upscaling.

Marine monitoring is extensive, led by MUDAB (phytoplankton, benthos, zooplankton, chlorophyll-a, mammals, sediments) - a large but restricted portal. These data are complemented by ICES open datasets (fish trawl surveys via DATRAS, plankton, benthos, phytobenthos), Helgoland Roads LTER phytoplankton series, and CMEMS biogeochemistry model outputs, which are fully open and feed directly into EBV/EOV derivation. Regional initiatives like EMODnet Biology and MDI-SH (marine mammals) provide open distribution data, while TMAP (Wadden Sea birds, via CWSS) requires requests for access.

On the freshwater side, the FGG-Elbe system compiles WFD BQEs (fish, phytoplankton, macrophytes, benthos, and hydromorphology) with varying access, while GLD Sachsen-Anhalt hydrology provides open contextual data. Long-term phytoplankton datasets (e.g. Rieger & Redelstein, 2025) are fully open and directly usable.

These datasets converge at integration nodes - national agencies (UBA, BfG), European data systems (ICES, EMODnet, CMEMS, JRC), and other bodies (CWSS). From there, they are transformed into EBVs/EOVs (abundance, composition, phenology, functioning, connectivity, structure). Finally, these feed into global frameworks (GOOS, GEO BON, IPBES, CBD).

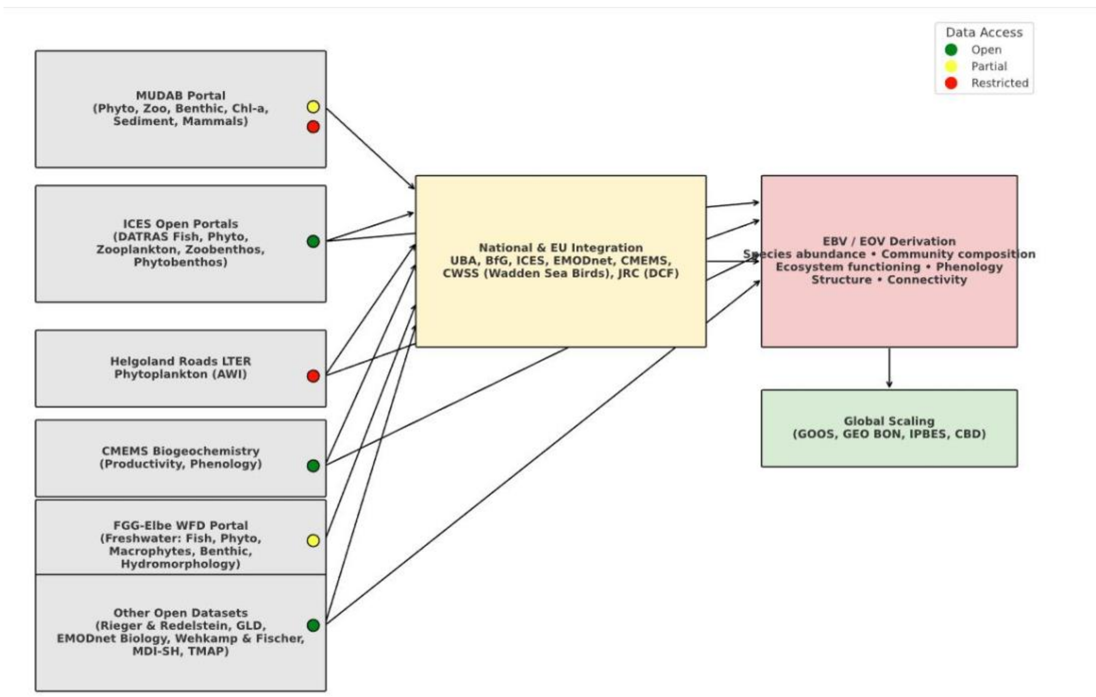


Fig. 7. Scheme of monitoring flow in the Elbe – North Sea study case

Table 4. Datasets and monitoring methodologies readiness for EBV/EOVs translation

Datasets	Monitoring methodology	Why it matters for EBVs/EOVs	EBV/EOV readiness
Freshwater and marine fish communities	Reach-scale segments (~10 km), seasonal or annual sampling	Captures shifts in community composition and abundance; scales to EFI+ and MSFD fish guild indicators.	Moderate - good methodology but access limits wider reuse
Phytoplankton phenology (e.g., Elbe-North Sea)	1–4 km coastal grid, weekly to monthly frequency during bloom periods	Resolves timing and intensity of blooms; key for ecosystem functioning EBVs and eutrophication indicators.	High - methodologically strong, mostly open, but restrictions exist as well (Helgoland Roads LTER)
Bird migration (Wadden Sea, estuary)	Stopover habitat resolution (~1–5 km), daily counts in migration seasons	Tracks distribution and phenology EBVs; aligns with Ramsar/Natura 2000 reporting.	Moderate - standardized, long-term, but limited access
Habitat fragmentation (floodplains, wetlands, seagrass meadows)	<100 m spatial resolution from satellite/UAV; annual updates	Necessary for ecosystem structure and connectivity EBVs; complements in situ habitat quality assessments.	Moderate - scalable but uneven coverage across domains
Primary productivity (EO-based)	250 m (MODIS) or 10–20 m (Sentinel-2), weekly to monthly	Provides high-resolution NPP/GPP estimates, scaling functioning EBVs and GOOS EOVs.	High - openly available, validated, directly EBV-relevant
Hydromorphology and river connectivity	Barrier inventories + discharge data; reach resolution; annual updates	Fills the major EBV gap (connectivity); links to WFD hydromorphological elements and HD migratory species.	Partial - valuable but fragmented, no integrated barrier-biota link
Benthic invertebrates and macroalgae	Station grids of ~5–10 km, seasonal sampling	Supports trait diversity and structure EBVs; weakly represented but critical for seafloor integrity (MSFD D6).	Moderate to High - standardized, but taxonomy gaps & access uneven
Marine mammals and top predators	Transects or aerial survey (~10–20 km), annual to multi-annual	Complements abundance and distribution EBVs, but requires harmonized protocols for integration.	Weak to Moderate - patchy coverage, poor accessibility

5.1.5. Conclusion

The Elbe–North Sea monitoring system is rich in datasets, but its translation into EBVs and EOVs is uneven. A critical dimension of the Elbe–North Sea monitoring system is data accessibility. While a majority of the datasets (e.g., ICES DATRAS, CMEMS, EMODnet) are open and directly reusable for EBVs/EOVs, several freshwater series (FGG fish indices, GLD hydrology) and some biodiversity datasets (Helgoland Roads LTER, MUDAB mammals, birds) remain restricted or only partially accessible. This creates a disproportion: although 38% of the inventory is technically open or partially open (21%), the restricted 41% often covers essential variables (e.g., hydromorphology, riverine fish indices) needed for filling connectivity and trait gaps. In contrast, open-access marine datasets (ICES DATRAS, CMEMS, EMODnet) already feed smoothly into international repositories, allowing them to be scaled efficiently into EBVs and EOVs.

5.2. Po - Adriatic Sea

5.2.1. Datasets and EVs suitability

The Po–Adriatic monitoring system shows a relatively **strong baseline for EBV/EOV integration**, though with distinct contrasts between domains due to uneven contribution of marine, freshwater, and estuarine/coastal datasets (**Fig. 8**). They contain rich biological quality element data (fish, benthos, macrophytes, phytobenthos), but much of this is either restricted or only partially available. Higher taxa such as mammals (except *Tursiops*) and amphibians, along with zooplankton, remain underrepresented or inconsistently monitored **(Fig. 9, Table 4).**

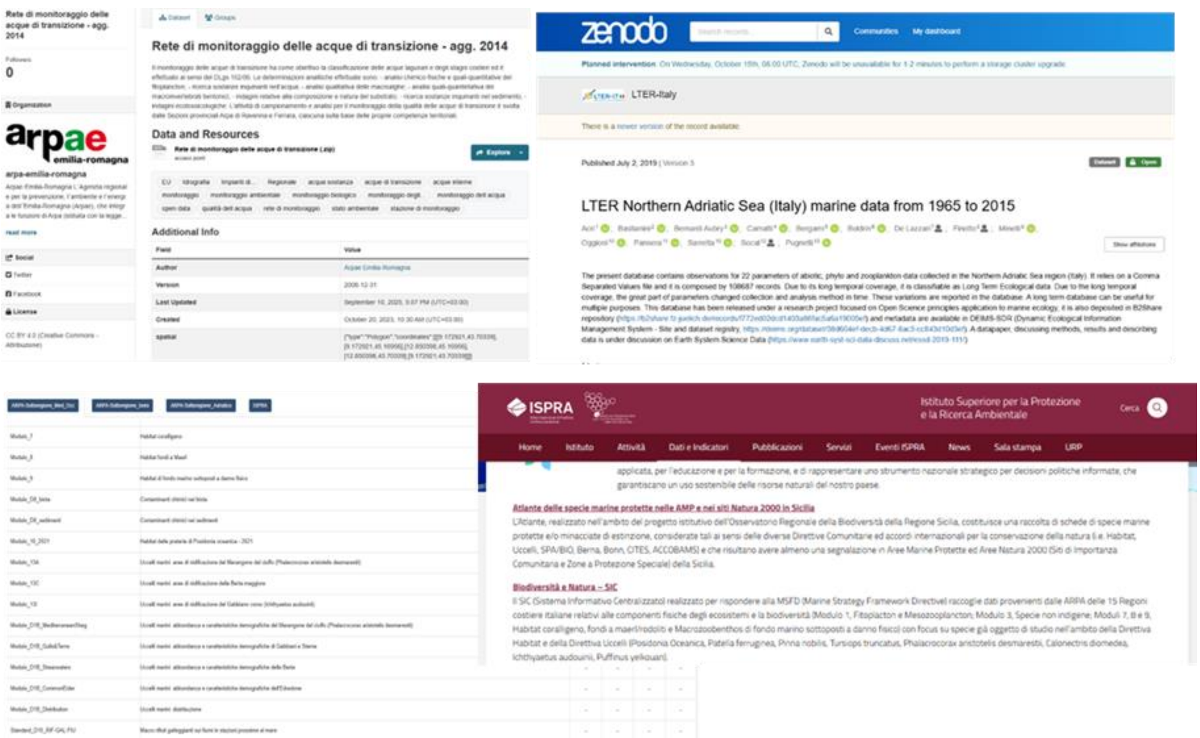


Fig. 8. Examples of integrated monitoring network supporting EBV/EOV observations across the Po - Adriatic river - transitional - coast continuum

Open marine datasets for phytoplankton phenology (LTER network datasets in different repositories) and marine productivity (CMEMS, OGS) exist, whilst benthos and fish assemblages are patchy and less systematically covered than in other regions. The transitional datasets (e.g., Gulf of Trieste, Emilia–Romagna coast, Po delta) indicate strong evidence, particularly for plankton composition and phenology, which suggests a higher readiness for spatial coverage and EBV class diversity. Freshwater datasets within the Po Basin (e.g., WFD monitoring, ISPRA, ARPAE), though substantial, are still constrained by limited accessibility. Temporal coverage varies in range from plankton LTER (app. 50 years) and CMEMS (app. 25 years) that provide strong long-term series to datasets extending less than the GEOBON minimum criterion for EBVs (<10 years). The **phenology EBVs** is sustained by estuarine phytoplankton data, but fragmentation persists overall. **Connectivity and hydromorphology** (e.g., AdBPo reports, ISPRA IDRAIM) are documented, but scattered and not openly disseminated, keeping readiness for ecosystem structure and connectivity at moderate levels. **Trait diversity** remains weakly covered, largely inferred from functional group indicators (e.g., STAR_ICMi for macroinvertebrates, MEDITS size data) (**Table 5**).

Table 5. Po–Adriatic datasets used for this analysis showing sources, domains (freshwater, transitional/estuarine, marine), time span, access, and suitability for EBV/EOV translation, and alignment to EBV/EOV (with details on data records, spatial and temporal extent)

Dataset / Source	Dataset Name	Domain	EBV Class Alignment	EOV Alignment	Spatial Coverage	Temporal Coverage	Records (approx.)	Access	Notes on Taxonomy / Methodology	Suitability	Spatial coverage source	Policy Relevance
CNR-ISMAR, LTER-Italy	**_LTER_NAS_1965_2015**	Marine	Species abundance; Community composition; Phenology	Phytoplankton & zooplankton biomass/diversity; Nutrients; Physico-chemical parameters	Northern Adriatic Sea	1965–2015	108,685	Open	Species-level; long-term ecological dataset; methodological changes documented.	High (long-term, detailed, multi-EBV/EOV, fully open)	https://zenodo.org/records/3516717	MSFD D1; MSFD D5
OGS	**C1-LTER Phytoplankton**	Marine	Species abundance; Community composition; Phenology	Phytoplankton biomass/diversity	Gulf of Trieste (C1 station)	2010–2020	529	Open	Species-level IDs; Utermöhl method; monthly fixed-depth sampling.	High (decadal, high-resolution LTER site; metadata; open)	https://nodc.ogs.it/ipt/resource?r=phytoplankton_north_adriatic_c1-lter_time-series_2010_onwards	MSFD D1; MSFD D5; WFD (coastal)

ARPAE Emilia-Romagna	**Rete acque di transizione – agg. 2014**	Transitional	Species abundance; Community compos. (phytoplankton, macroalga, benthic fauna)	Phytoplankton diversity; Water quality; Benthos	Emilia-Romagna transitional waters	2014–present	Not specified	Partial/ Open	WFD-compliant monitoring of phytoplankton, macroalgae, and benthos.	Moderate (regional WFD monitoring; strong methods but partly restricted)	https://dati.arpae.it/dataset/arpa_acq_transizione_retemon_14	WFD; supports MSFD D1/D5
ISPRA + Mediterranean partners	**MEDITS – International Bottom Trawl Survey**	Marine	Species abundance; Population structure; Community composition, Ecosyst. Struct.	Demersal fish biomass; Invertebrate biomass; Benthic community structure	Mediterranean Sea (incl. Adriatic)	1994–ongoing	~1100 hauls/year	Partial/ Restricted (DCF/data calls)	Standardized gear (GOC73); species-level IDs; harmonized protocols since 1994.	Moderate (long-term, standardized survey, but raw data restricted)	https://www.sibm.it/SITO%20MEDITS/principaleprogramme.htm	MSFD D1; MSFD D3; CFP
ClimateFish consortium (CIESM Tropical)	**ClimateFish**	Marine	Species abundance; Community composition	Fish biomass/diversity; Climate-related indicators	Coastal Mediterranean (7 countries)	2009–2021	3,142 transects	Open (CC-BY 4.0)	Species-level visual census of 15 target species using standardized transects.	High (multi-country, high-quality species data; climate-relevant; open)	https://www.seanoe.org/data/00756/86784/	MSFD D1; MSFD D2 (non-indigenous species)
CNR-IRBIM (Italy) + EU Mediterranean Member States	**MEDIAS – Pan-Mediterranean International Acoustic Survey**	Marine	Species abundance; Population distribution	Fish biomass; Small pelagic distribution	Adriatic Sea (13,200 NM²) + Mediterranean	Annual (DCF mandatory)	Not specified	Partial (description open, data via DCF)	Standardized acoustic survey of anchovy and sardine under EU DCF.	Moderate (stock indicators, but data are restricted)	https://www.medias-project.eu/	MSFD D1; MSFD D3; CFP

CMCC & OGS, Copernicus Marine Service	**MEDSEA_MULTIYEAR_BGC_006_008 – Mediterranean Biogeochemical Reanalysis**	Marine	Environmental conditions; Phenology; Community-level functional groups; Ecosystem function	Chlorophyll; Nutrients; Oxygen; Primary production	Mediterranean Sea (1/24° ≈ 4 km resolution)	1999–present	Model product (EO/model grids)	Open (Copernicus)	MedBFM3 model system with weekly assimilation of ESA-CCI chlorophyll; forced by CMCC physical reanalysis.	High (basin-scale EOV product; good accessibility; ready for reuse)	https://data.marine.copernicus.eu/product/MEDSEA_MULTIYEAR_BGC_006_008/description	MSFD D5; Copernicus
ARPAE Emilia-Romagna	**ARPAE Marine HAB dataset**	Marine	Ecosystem function (Harmful algal blooms)	Phytoplankton phenology; Eutrophication-related variables	Emilia-Romagna coastal waters	1990s–present	Summaries; detailed counts restricted	Partial (bulletins open; raw data restricted)	HAB monitoring series; summary products available; underlying raw counts not fully open.	Moderate (useful for HAB/eutrophication indicators; raw time series restricted)	https://dati.arpae.it	MSFD D5; WFD
EU-DCF / JRC (from MEDIAS surveys)	**MEDIAS – Commercial Fish**	Marine	Species abundance; Population distribution	Commercial fish biomass and abundance	Mediterranean & Adriatic	Annual (DCF cycles)	Not specified	Restricted (via DCF/JRC request)	Derived from MEDIAS acoustic surveys; key input to stock assessments; controlled access.	Moderate (important for stock and EBV indicators; access limitations reduce usability)	https://www.medias-project.eu/	MSFD D1; MSFD D3; CFP

ISPRA + Regional ARPA	**Po Basin Fish Fauna Monitoring**	Freshwater	Species abundance; Population structure; Community composition; Phenology	Freshwater fish biomass/diversity; Ecological status indicators	Po River Basin (Italy)	Ongoing (WFD cycles)	Not specified	Partial (in reports)	WFD-standardized fish surveys; species-level identifications; compiled in ISPRA/ARPA reporting.	Moderate (extensive WFD fish dataset; partial public availability)	ISPRA & regional ARPA portals	WFD D.Lgs. 152/06)BQE (fish); HD
Abbà et al. 2024, Journal of Limnology	**Distribution of Fish Species in the Upper Po River Basin (1988–2019)**	Freshwater	Species abundance; Population structure; Community composition; Phenology	Freshwater fish diversity; Ecological indicators	Upper Po River Basin (NW Italy)	1988–2019 (four campaigns)	≈1,136 site-visits	Open	Species-level data for 8 target species; electrofishing; RI and OF indices; drivers of change assessed.	High (long-term, HD-relevant dataset with strong methodological basis)	https://doi.org/10.4081/jlimnol.2024.2194	HD; WFD supporting
ARPAE Emilia-Romagna	**ARPAE Freshwater Fish – superficial waters**	Freshwater	Species abundance; Community composition	Freshwater fish abundance/diversity	Emilia-Romagna rivers (superficial waters)	2010–present	Not specified	Restricted	WFD fish BQE dataset; raw data not openly released.	Low (valuable WFD fish data, but dataset is closed to the public)	https://dati.arpae.it/dataset/arpa_acq_superficiali_retemon_dq60_amb_pesci_pdg_15	WFD; HD
ARPAE Emilia-Romagna	**Freshwater Invertebrate Occurrence (ARPAE)**	Freshwater	Species populations (macroinvertebrates)	Macroinvertebrate-based ecological indicators	Po Basin freshwater habitats	Ongoing	Not specified	Restricted	Critical WFD BQE dataset; occurrence/probability models; data not downloadable.	Low (critical WFD BQE dataset, but not publicly accessible)	https://dati.arpae.it	WFD BQE

ARPAE Emilia-Romagna	**Phytobenthos Communities (ARPAE Po Basin)**	Freshwater	Community composition (phytobenthos/diatoms), Ecosyst. structure	Phytobenthos indices (STAR_ICMi)	Po rivers and lakes	Ongoing	Not specified	Restricted (internal)	Important phytobenthos BQE dataset; indices reported, raw diatom data not open.	Low (important diatom BQE, but dataset is internal/closed)	https://dati.arpae.it	WFD BQE
ARPAE Emilia-Romagna	**STAR_ICMi / IBE Benthic Invertebrates (ARPAE)**	Freshwater	Community composition (benthic macroinvertebrate, Ecosyst. structure	Macroinvertebrate-based indices (STAR_ICMi, IBE)	Po Basin rivers and streams	Ongoing	Not specified	Restricted	WFD benthic invertebrate indices; raw taxa lists not openly available.	Low (widely used for WFD, but raw invertebrate data inaccessible)	https://dati.arpae.it	WFD BQE
ISPRA & SNPA	**National WFD Fish Dataset (ISPRA–SNPA)**	Freshwater	Species abundance; Distribution; Community composition	Fish BQE indicators	Italian rivers and lakes	Ongoing	Not specified	Partial (national aggregation)	National WFD dataset aggregating multiple regional surveys; limited open sharing of raw data.	Moderate (nationally aggregated; useful but limited access)	https://www.isprambiente.gov.it	WFD BQE; HD
Po River Basin Authority (AdBPo)	**Hydromorphology & Connectivity (AdBPo)**	Freshwater	Ecosystem structure (connectivity)	Hydromorphological indicators; barrier presence	Po River catchment	Ongoing	Not specified	Partial (reports open; data on request)	Barrier and passability mapping for hydromorphological assessments and river connectivity.	Moderate (key structural indicator for WFD; underlying data only on request)	https://adbpo.gov.it	WFD hydromorphology; HD (migratory species)

ISPRA	**ISPRA National Hydromorphology Monitoring**	Freshwater	Ecosystem structure (river continuity)	Hydromorphological continuity/disruption	Italian rivers (including Po Basin)	Ongoing	Not specified	Partial (reports; dataset restricted)	National hydromorphology indicators; overviews of longitudinal continuity disruption.	Moderate (national overview of river continuity; raw data restricted)	https://www.isprambiente.gov.it	WFD supporting; HD
ARPAE Emilia-Romagna	**ARPAE Freshwater HAB (cyanobacteria) Monitoring**	Freshwater	Ecosystem function (Harmful algal blooms)	Phytoplankton/cyanobacteria-related water quality indicators	Po Basin rivers and lakes	Ongoing	Not specified	Partial (reports/bulletins; raw data restricted)	Monitoring of cyanobacteria and HAB events; summary bulletins public; underlying data restricted.	Moderate (informative for water quality and WFD phytoplankton BQE; raw data restricted)	https://dati.arpae.it	WFD BQE (phytoplankton)

The bar and pie charts **(Fig. 9)** further illustrate the patterns in EBV coverage by ecosystem. The Po–Adriatic system shows **good coverage in species populations abundances and communities' composition across marine and freshwater, and less in transitional domains**. Unlike Elbe- North Sea case, the freshwater domain is slightly better represented by 47.4% compared to 42.1% for the marine domain.

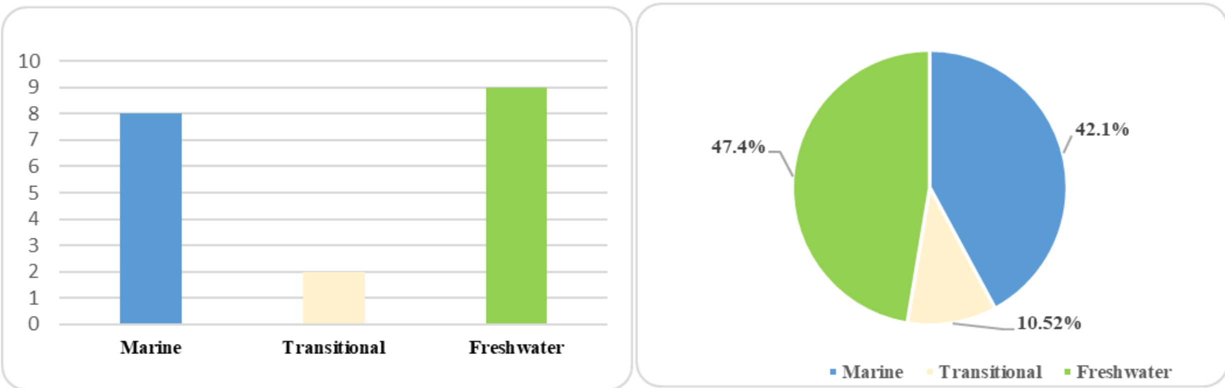
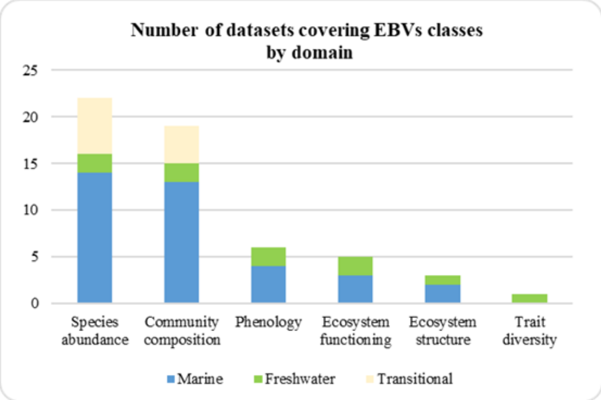


Fig. 9. Number (left) and proportion (right) of datasets shared by EBVs main classes and marine, transitional and freshwater domains across Po–Adriatic Sea

Freshwater monitoring programs in the Po basin measure fish and plankton abundance in practice, but those data have not been mobilized as standalone datasets (they are embedded in indices or reports). **Trait diversity** (functional/phenological metrics) datasets are exclusively for freshwaters (rivers), with no marine community dataset. Notably, transitional waters (estuarine or brackish habitats at the river-sea interface) have dedicated datasets only in Species Populations and Community Composition categories, pointing to a gap in monitoring of ecotonal (transitional) ecosystems (**Fig.10**).



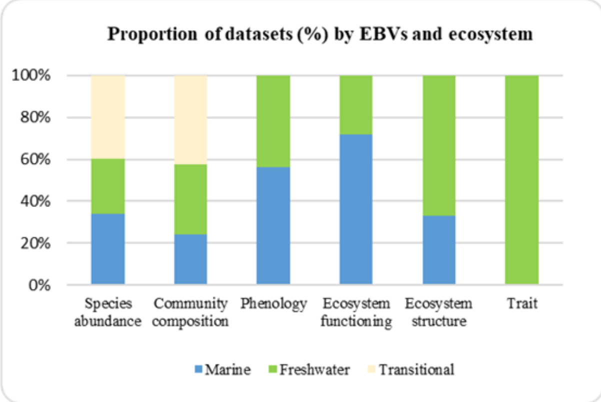
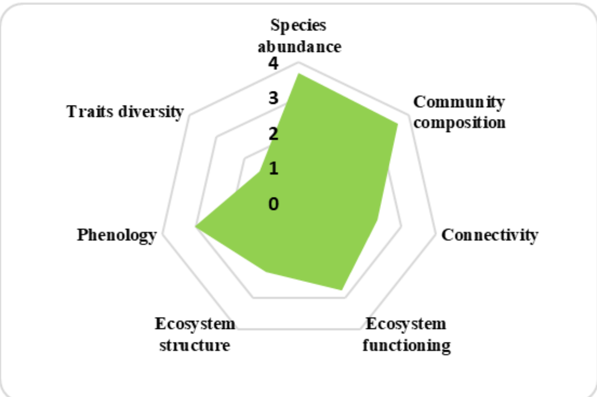


Fig. 10. Distribution of number (left) and proportion (right) of datasets across EBV classes and domains across Po–Adriatic Sea

5.2.2. Readiness of the Po - Adriatic Sea monitoring system for upscaling to Essential Variables

The Po–Adriatic system shows **moderate readiness (2.94)** to operationalize EBVs and EOVs. Apart Policy, which recorded the highest scores, spatial coverage scores followed the second (3.76), due to the integration of marine, estuarine and freshwater datasets, particularly for long-term coastal monitoring (e.g., Gulf of Trieste). Temporal depth and taxonomic coverage did not reach fully maturity: only a few datasets have >25 years of sustained sampling, monitoring remains strongly focused on plankton and fish, and several freshwater/estuarine datasets are still not openly accessible. EBV/EOV readiness score indicates that while abundance, phenology, and productivity EBVs can be derived from existing data, ecosystem structure and trait diversity are still weakly represented. **Policy relevance** is comparatively strong (score 5), as monitoring is largely driven by WFD/MSFD requirements, though full EVs operationalization is still hindered by fragmented data and gaps in habitat-scale monitoring



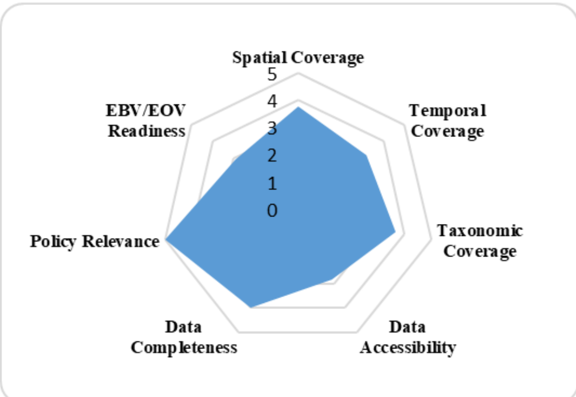


Fig. 11. Radar plots showing readiness scores based on datasets criteria assessment (left) and EBVs readiness scores in Po – Adriatic (right)

EBV readiness for the Po–Adriatic system was assessed using a weighted multi-criteria framework that evaluates how well existing datasets can support each EBV class. For every EBV, five criteria were quantified: **P** (proportion of datasets supporting the EBV), **T** (temporal coverage), **S** (spatial representativeness across freshwater, transitional, marine domains), **A** (data accessibility), and **M** (policy maturity related to monitoring program). Accessibility was scored as 1 = open, 0.5 = partial, 0.2 = restricted, based on dataset metadata. Policy Maturity was scored as 1 for datasets belonging to well-established national or European frameworks (e.g., WFD, MSFD, CFP, LTER), and 0.5 for research or project-based datasets. Spatial representativeness was based on the proportion of aquatic realms covered by datasets supporting the EBV. Each component was normalized to 0– 1 and aggregated using the following formula: **$EBV_{Score} = 5\times(0.35P+0.25T+0.15S+0.10A+0.15M)$ (Table 6)**

Table 6. Readiness assessment of EBV classes in the Elbe–North Sea monitoring system

EBV class	EBVs Score	Assessment Criteria	
Species abundance	3.71	P = 0.58; T = 0.64; S = 1.00; A = 0.60; M = 1.00	Coverage is strong across marine and freshwater habitats: long-term Adriatic phytoplankton series, MEDITS trawl surveys, Copernicus biogeochemistry, and WFD fish networks. Temporal consistency is moderate-to-high and methods are standardized in both marine (DCF/MSFD) and freshwater (WFD) systems. Data are partially accessible but mature and policy-embedded.
Community compositio n	3.61	P = 0.58; T = 0.64; S = 1.00; A = 0.60; M = 1.00	Multiple datasets provide species-level community matrices: phytoplankton, benthic organisms, fish assemblages from MEDITS, WFD benthos, and LTER coastal stations. Spatial and structural coverage is broad, supported by harmonized monitoring frameworks. Access is mixed but methodological maturity is high.
Trait diversity	1.44	P = 0.05; T = 0.02; S = 0.33; A = 0.20; M = 0.60	Trait information is sparse and inconsistent. Limited functional traits exist for fish and some benthic groups, while phytoplankton and zooplankton traits remain largely unavailable. Restricted access to key WFD biological datasets reduces readiness, and cross-ecosystem standardization is lacking.
Connectivit y / Free River flow	2.28	P = 0.16; T = 0.60; S = 0.33; A = 0.50; M = 1.00	Supported mainly by hydromorphological datasets (barrier mapping, passability, continuity indices), with partial coverage of migratory species distribution. Represents freshwater continuity well but lacks marine–freshwater integration and biological linkage (e.g., species-specific movement data). Access remains partly restricted.
Ecosystem functioning	2.78	P = 0.16; T = 0.73; S = 0.67; A = 0.67; M = 1.00	Good support from Copernicus biogeochemical products (chlorophyll, oxygen, and nutrients), HAB bulletins, and freshwater phytoplankton/cyanobacteria indicators. Temporal depth is strong

			in marine datasets; freshwater systems have patchier long-term coverage. Mixed access but high maturity (MSFD/WFD aligned).
Ecosystem structure	2.18	P = 0.11; T = 0.60; S = 0.33; A = 0.50; M = 1.00	Structural indicators include benthic communities (WFD benthos, MEDITS demersal assemblages) and hydromorphological continuity datasets. Coverage is uneven, with limited spatial and temporal consistency in freshwater biological structure. Restricted access to benthic BQEs constrains readiness.
Phenology	3.06	P = 0.26; T = 0.72; S = 0.67; A = 0.90; M = 1.00	Marine phenology is well supported: long-term phytoplankton time series, Copernicus phenology indicators, and HAB monitoring. Freshwater phenology exists mainly through WFD fish and phytoplankton cycles but remains less consistent. Data accessibility varies, but maturity is high across programs.

Table 7. Datasets assessment criteria scores (for methodology details see Table 3)

EBVs Dimension	Score	Assessment criteria
Spatial Coverage	**3.76**	All three domains (marine, freshwater, transitional) are represented.
Temporal Coverage	**3.21**	Plankton LTER (50 years) and CMEMS (25 years) are strong, but most datasets <15 years; transitional plankton exists, but spatial and temporal fragmentation persists.
Taxonomic Coverage	**3.66**	Plankton and fish are relatively strong; benthos, mammals, amphibians/reptiles, and zooplankton are poorly covered. Transitional datasets add phytoplankton/zooplankton.
Data Accessibility	**2.84**	CMEMS and some plankton datasets open; freshwater and estuarine datasets often restricted, reducing usability.
Data Completeness	**3.97**	Plankton and CMEMS well documented; estuarine data moderately complete; freshwater weaker but usable.
Policy Relevance	**5.00**	Linked to WFD/MSFD, but coverage remains patchy, especially for benthos and connectivity. Coastal inclusion helps slightly but not enough to raise the score.
EBV/EOV Readiness	**2.94**	Species population, Community composition, Ecosystem function (plankton productivity), phenology (HABs, blooms), and fish surveys usable; gaps in benthos/zooplankton keep readiness moderate.

The heatmaps (**Fig. 12**) highlights also a clear imbalance in EBV coverage across the Po - Adriatic datasets strengthening the previous findings. The strongest representation lies with **Species populations (Abundance) and Community Composition EBVs categories**, consistent with WFD/MSFD monitoring of plankton, benthos, fish, and related biological quality elements. **Ecosystem Structure** is covered, but unevenly, with existing datasets for the benthic mapping and hydromorphological/connectivity assessments. **Ecosystem Function** is mainly supported by marine - focused productivity and bloom datasets (OGS, CMEMS, ARPAE HAB). By contrast, **Traits** remain almost absent, with only indirect proxies available, while **Connectivity** is addressed only superficially through a few hydromorphological reports. Overall, the heatmap underscores that while state variables (abundance, composition) are robustly monitored, process-oriented EBVs (functioning, traits, and connectivity) are underdeveloped, limiting integration potential.

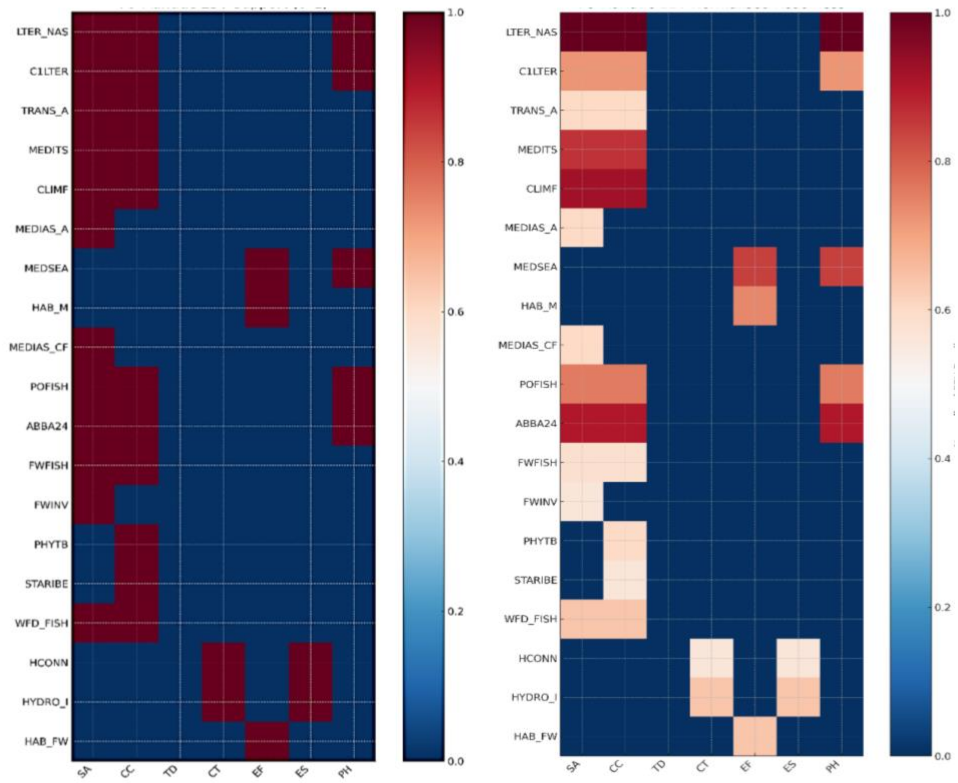


Fig. 12. Datasets coverage heatmap. Left: Contribution of individual monitoring datasets to EBV classes. With red are represented datasets that can be directly used to generate EBVs (SP - Species population/abundance; CC - Community composition; TD – Trait diversity; CT – Connectivity; EF – Ecosystem functioning; ES – Ecosystem Structure; PH – Phenology), while blue color reflects limited relevance or missing information. Right: Datasets readiness map (each dataset has been scored by averaging spatial, temporal, taxonomic, accessibility, and completeness scores across datasets) in the Po – Adriatic Sea study case (datasets abbreviation – Annex)

The first two components (PC1 & PC2) of the PCA explain ~83% of the total variance (**Fig. 13**). PC1 clearly separates datasets aligned with **abundance and composition** EBVs (e.g., LTER phytoplankton, ARPAE fish distributions) on the positive side, versus **functioning** EBVs (e.g., CMEMS productivity, OGS phenology). PC2 contrasts datasets tied to ecosystem **structure** (hydromorphology, benthos) vs. **connectivity** datasets on the bottom. In the top-left quadrant, LTER North Adriatic (1965–2015), LTER Phytoplankton (2010–2020), ARPAE freshwater fishes, ARPAE benthos show a strong alignment with state EBVs (species abundance, community composition), whilst at the right quadrant, OGS phenology/productivity, CMEMS MEDSEA BGC, ARPAW chl-a datasets are driving functioning EBVs/EOVs. In the top-left quadrant, the clustered datasets underpin structure and connectivity EBVs (ISPRA-hydromorphology, AdBPo - connectivity, benthos).

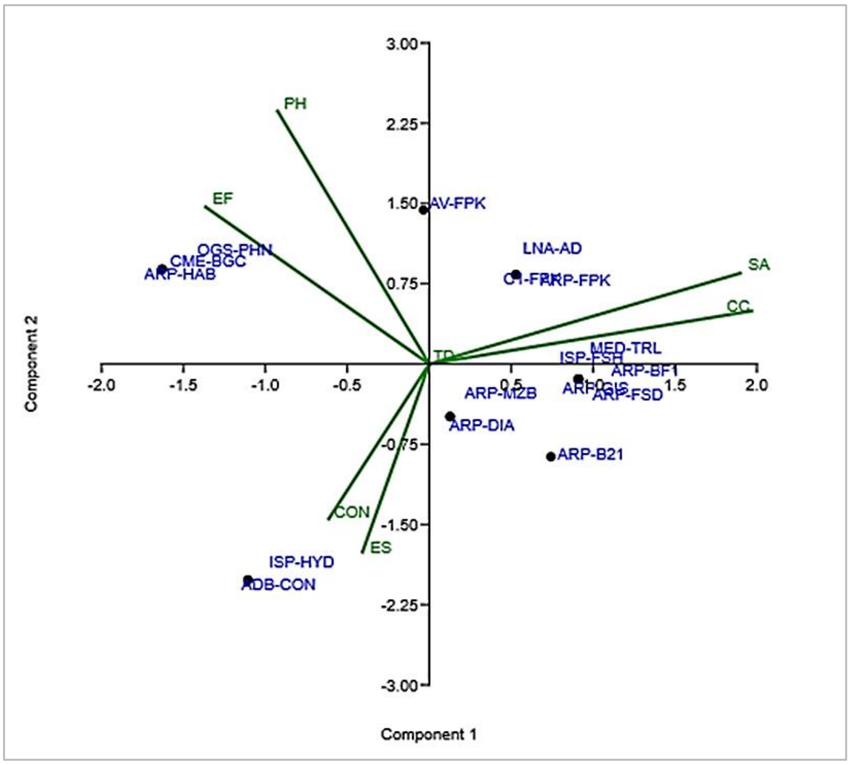


Fig. 13. PCA showing the most datasets clustering around PC1 and PC2, which explain 83.31% of variance

5.2.3. Data accessibility

About 38% of the datasets are openly available (fully public and usable), about ~21% are partially accessible, for instance through published summaries, or through permission/request) and about ~41% are closed, with data held internally by agencies and no public access. While the presence of open datasets (e.g. Zenodo or DOI-archived data) is an advantage, the high fraction of partially and non-open data limits the potential for integrating these sources into comprehensive EBV or EOV products (Fig. 14).

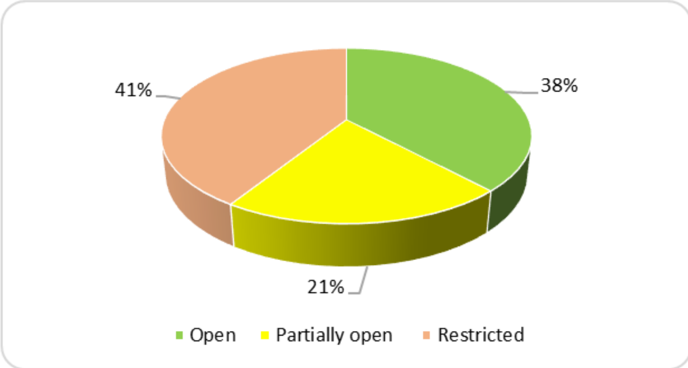


Fig. 14. Share of datasets accessibility within Po-Adriatic Sea case study

5.2.4. Needs for monitoring frameworks compliance with EBV/EOVs

The Po–Adriatic dataset inventory reveals strong but uneven coverage across EBV classes and ecosystem domains. As noted, many datasets are held by regional or national agencies with limited sharing. This fragmentation means that even when data exist, they are underused. While some long time-series exist (e.g. >50 years for Adriatic plankton), others are short or intermittent. Marine phytoplankton abundance is exceptionally well represented, with multi-decadal open datasets from LTER that provide high-quality records of plankton dynamics. Marine fish abundance is present through MEDITS and related surveys, but access is often restricted, while freshwater abundance data remain unavailable as open datasets, since they are embedded in indices rather than raw counts. Species distributions are better balanced across domains: marine fish are tracked through trawl surveys and climate-change projects, while freshwater fishes and macroinvertebrates are monitored by WFD programs. However, access is uneven, **marine data are partly open, whereas freshwater distributions are largely closed**, limiting reuse. Community composition is dominated by freshwater indices (fish, phytobenthos), reflecting WFD's focus on biological quality elements, but marine equivalents are absent. Trait diversity is represented only for freshwater plankton, where open datasets allow calculation of functional and seasonal indicators, while marine trait data remain a gap. In terms of ecosystem functioning, open datasets cover primary productivity (OGS, CMEMS) and harmful algal blooms (ARPAE), although the latter are only partially accessible. Finally, **ecosystem structure and connectivity** are addressed by hydromorphological datasets from the Po Basin Authority and ISPRA, which are highly relevant but restricted to summary reports. Meanwhile, **transitional waters** (Po delta, estuaries, and lagoons) are under-monitored not being explicitly represented by any dataset. Likely, some data exist (e.g. WFD "transitional water" monitoring for Po delta lagoons or coastal wetlands), but they have not been mobilized as distinct datasets.

The potential for EBV/EOV integration is high where data are open and continuous, but stronger data mobilization, especially for freshwater-sea connectivity, is essential to close gaps and enable cross-domain biodiversity assessments.

Most of datasets are already in structured formats (time series, GIS shapefiles, CSV), and much of their taxonomy is aligned with international standards (e.g., WoRMS for marine taxa), which makes them highly suitable for EBV/EOV conversion **(Table 8).**

Table 8. Datasets and monitoring methodologies readiness for EBV/EOVs translation of Po- Adriatic Sea

Datasets	Monitoring methodology	Why it matters for EBVs/EOVs
Freshwater fish assemblages (Po Basin – ISPRA/ARPAE)	Reach-scale River monitoring (~5–10 km segments), seasonal/annual sampling	Tracks species abundance and community composition EBVs; aligns with WFD fish BQEs and MSFD transitional fish guilds.
Marine fish (MEDITS trawl, 1994–present)	Stratified trawl surveys in Adriatic, ~5–20 km station grids, annual	Long time series for species abundance/distribution EBVs; directly feeds MSFD D1/D3 fish indicators and ICES/FAO stock assessments.
Phytoplankton phenology (C1 LTER, ARPAE coastal)	Coastal grids (1–4 km), weekly–monthly sampling, 2010–present	Captures bloom timing/intensity → EBVs for phenology and abundance; key for eutrophication indicators (MSFD D5, WFD).
Harmful Algal Blooms (ARPAE Emilia-Romagna)	Event-based and routine monitoring, multiple stations, seasonal focus	Early warning dataset; relevant for functional EBVs (ecosystem functioning), eutrophication, and health-linked EOVs.
Primary productivity (OGS/CMCC + Copernicus MEDSEA)	EO-derived (Sentinel-3, MODIS, 250 m–1 km resolution), weekly–monthly composites	High readiness for EBV ecosystem functioning; links to GOOS EOV productivity; scalable across Adriatic.
Benthic invertebrates & phytobenthos (ARPAE rivers, coastal)	WFD STAR_ICMi & IBE methods; station-based, seasonal to annual	Supports trait diversity and structure EBVs; aligns with WFD BQEs and MSFD seafloor integrity (D6).
Macroalgae & seagrass (Posidonia, Cymodocea meadows)	Transects & remote sensing (<100 m UAV/Sentinel-2), annual	Key for EBV ecosystem structure & habitat integrity; MSFD D6 relevance; coastal habitat health indicator.
Marine mammals (MDI-SH, ISPRA)	Aerial & boat transects, 10–20 km blocks, multi-annual	Species abundance/distribution EBVs; required for MSFD D1 (mammals) and Habitats Directive Annex II/IV species.
Bird migration (Po Delta wetlands)	Stopover counts (daily/seasonal), point counts & aerial	Links to EBVs on distribution/phenology; feeds Ramsar, Natura 2000, MSFD D1 (birds).
Hydromorphology / River Connectivity (Po Basin Authority, ISPRA)	Barrier inventories, discharge monitoring, GIS reach-scale, annual updates	Critical for EBV "Connectivity/Free river flow"; supports WFD hydromorphological elements, Habitats Directive (migratory fish).

The Po–Adriatic monitoring system connects local agencies, research institutes, the Po River Basin Authority and fisheries surveys, each contributing data on plankton, fish, benthos and connectivity with varying degrees of openness. These flows converge in national and EU hubs such as ISPRA, EMODnet and Copernicus, where they are integrated and, when possible, also feed directly into Essential Biodiversity and Ocean Variables. The resulting EBVs and EOVs support MSFD and WFD reporting and ultimately scale into global frameworks like GOOS, GEO BON, IPBES and the CBD (Fig. 15).

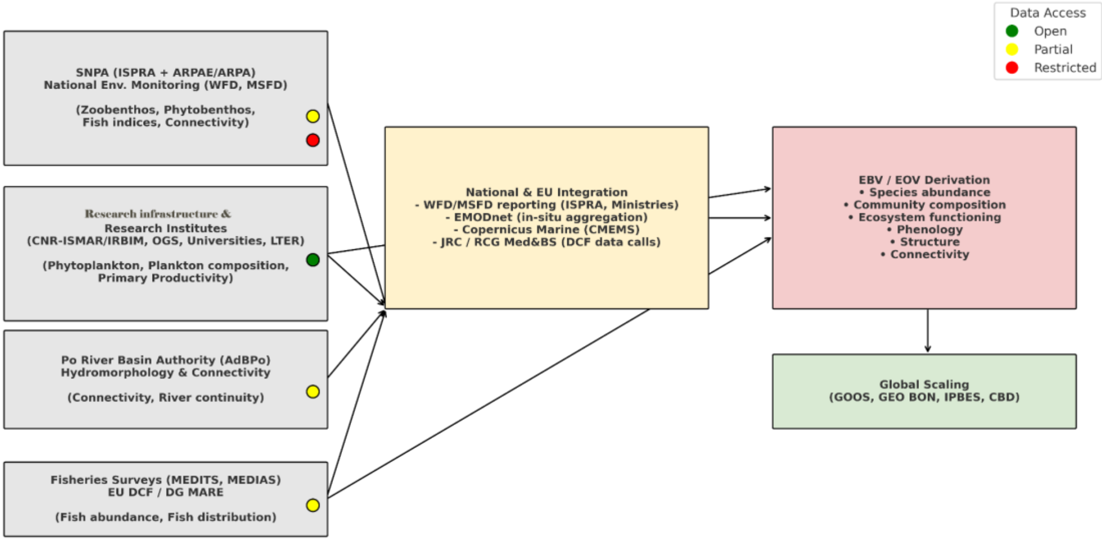


Fig. 15. Scheme of monitoring flow in the Po - Adriatic Sea case study

5.2.5. Conclusions

The Po–Adriatic analysis reveals a rich but uneven collection of biodiversity data, with strong potential to inform science and policy if gaps are addressed and access improves. Open datasets, such as long-term phytoplankton series and CMEMS, show how reusable data can support both climate and biodiversity assessments. While marine and freshwater EBVs are relatively well developed, transitional observations remain fragmented and often inaccessible. To operationalize EBVs across the land–sea continuum, greater openness, harmonization, and better coverage of traits and connectivity are needed to avoid underrepresentation of the continuum marine - freshwater - transitional systems.

5.3. **Danube - Black Sea**

5.3.1. Datasets and EVs suitability

The Danube - Black Sea benefits from a well-established transboundary monitoring infrastructure (e.g. ICPDR's TransNational Monitoring Network) **(Fig. 16)**, supporting long-term assessments of species abundance, community structure, ecosystem productivity, and connectivity. Many datasets align with policy frameworks such as the EU WFD and MSFD, enhancing data harmonization and policy relevance. However, spatial-temporal resolution remains uneven across taxa and regions, marine mammals and migratory birds, for instance, are monitored less frequently due to resource constraints (Paiu *et al*., 2024). Integration of Earth Observation (EO) and open-access data platforms (e.g. Copernicus, OBIS) increasingly complements *in situ* observations, improving spatial coverage but raising challenges in methodological comparability. Although Romania has established environmental monitoring frameworks, the availability of publicly accessible datasets from national authorities on platforms like OBIS, EMODnet, and PANGAEA remains limited (Table 9). This reflects both the restricted data-sharing practices among institutional stakeholders and a still-developing capacity for coordinated data publication in open-access repositories, particularly compared to the more visible outputs of multinational or collaborative initiatives.

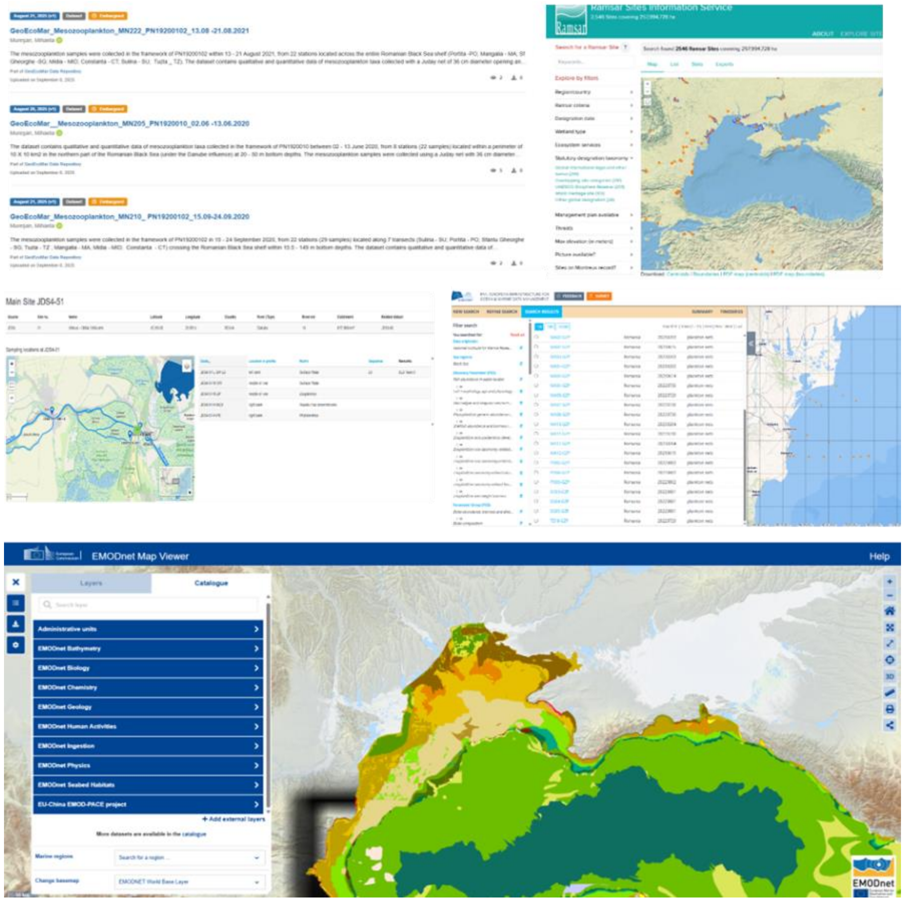


Fig. 16. Integrated monitoring network supporting EBV/EOV observations across the Danube - Black Sea Case Study

Table 9. Danube– Black Sea datasets used for this analysis showing sources, domains (freshwater, transitional, marine), time span, access, and suitability for EBV/EOV translation, alignment to EBV/EOV (with details on data records, spatial and temporal extent).The table also reports dataset suitability for EBV/EOV operationalization and traceability of data sources.

Dataset / Source	Spatial Domain	EBV Class Alignment	EOV Alignment	Spatial Coverage	Temporal Coverage	Records (approx.)	Access	Taxonomy / Methodology	Suitability	Source
NIMRD Phytoplankton (1961–1970) (EurOBIS)	Marine (RO shelf)	**Species abundance & biomass; community composition; phenology**	Phytoplankton biomass/diversity; productivity	RO shelf transects shallow to shelf	1961–1970 (Mar–Nov)	n/a (across 10 yrs)	Open (EurOBIS/ OBIS)	Taxa to species in many cases; harmonize to WoRMS	High	eurobis.org
NIMRD Phytoplankton (1975–1980) (OBIS)	Marine (RO shelf)	**Species abundance & biomass; community composition; phenology**	Phytoplankton biomass/diversity; productivity	Shallow to shelf; seasonal	1975–1980	n/a	Open (OBIS)	Abundance & biomass (cells L^{-1}; mg m^{-3})	High	obis.org
NIMRD Phytoplankton (2001–2005) (EMODnet/ EurOBIS/OBIS)	Marine (RO shelf)	**Species abundance Community composition; phenology**	Phytoplankton biomass/ diversity	20–50 coastal & shelf sites	2001–2005	n/a	Open	Standardized; EMODnet metadata	High	emodnet.ec.europa.eu
EMODnet Chemistry Black Sea (NIMRD)	NW Black Sea/Danube plume	**Functional EBVs (Chl-a proxy), nutrients, O_2**	EOVs: nutrients, oxygen, chlorophyll	Basin & RO shelf gridded layers	1970–2019+	Grids/collections	Open (ERDDAP/ GeoViewer)	QA/QC; MSFD-aligned ODV format	High	erddap.emodnet.eu
SeaDataNet / EO4SIBS MSFD datasets (NIMRD)	Marine (RO shelf; ~60–100 stations)	**Environmental drivers for EBVs**	EOVs (T/S, nutrients, O_2, Chl)	~58–99 stations	2017–2019	Cruise station files	Request (restricted)	ODV formats; QC described	High (drivers)	sdn2.rmri.ro
Zooplankton & Benthos (NIMRD; EMODnet Biology/SeaDataNet)	Marine (RO shelf)	**Species abundance Community composition**	Zooplankton biomass/abundance	RO shelf transects/stations	2000s–present	n/a	Partly open	Standardized gears; MSFD	Medium – High	blackseascene.net

Bottom-trawl survey (demersal) (NIMRD)	Marine (RO shelf)	**Species abundance; Community structure**	EOV: Fish abundance/biomass	Trawl grid in RO waters	1990s–present	n/a	Partly restricted	Standardized gears;; DCF	Medium	rmri.ro
BS4F/GFCM regional stocks & protocols	Marine (Black Sea GSA 29)	**Stock status proxies (abundance/biomass)**	Fisheries EOV	Regional (incl. RO)	Ongoing (benchmarks 2023–2024)	Reports	Open reports; data by request	Harmonized pelagic acoustic & demersal trawl guidance	Medium	FAO
Cetaceans – ASI/CeNoBS aerial survey 2019 (ACCOBAMS)	Marine (Black Sea incl. RO EEZ)	**Abundance & distribution**	Megafauna abundance/distribution	Basin aerial blocks crossing RO	2019; results published 2024	Georeferenced transects	Reports/paper open; raw restricted	First basin-wide robust estimates; complements stranding	Medium	accobams.org
Cetacean strandings (Mare Nostrum/OBIS-SEAMAP)	Marine (RO coast)	**Occurrence; Traits proxy (mortality events)**	—	RO coast (Navodari-Vama Veche)	2010–2022	Hundreds of records	Open map; reports	Citizen science, NGO surveys; QA varies	Low–Medium	seamap.env.duke.edu
Birds (Delta SPAs; ARBDD/Natura 2000 & Ramsar)	Estuarine/Delta	**Phenology; Abundance**	—	DDBR SPAs; colonies	2000s–present	Count series (reports)	Reports/papers	Methods heterogeneous; access limited	Medium	rsis.ramsar.org
Hydromorphology/Connectivity (DRBMP + AMBER)	River/Delta	**Connectivity EBV (pressures)**	—	Danube & tributaries (RO)	2009–present; DRBMP 2021–27	GIS layers	Public plans; atlas view	Barrier inventories & continuity objectives	Medium	icpdr.org
Copernicus Marine OMI – Black Sea chlorophyll	Marine (basin incl. RO shelf)	**Functioning EBVs (productivity proxy); phenology**	EOV: Primary productivity proxy (Chl-a)	1–4 km grids; full basin	1997–present	Continuous	Open	Multi-sensor reprocessing; QUIDs available	High	marine.copernicus.eu
Romanian Black Sea Phytoplankton (NIMRD, OBIS/EurOBIS)	Marine shelf (RO coast)	**Species populations (phytoplankton abundance, distribution); Community composition**	Phytoplankton biomass/diversity; primary productivity	Romanian Black Sea shelf transects (20–40 stations)	1956–1960, 2005	~6,000 occurrences, ~18,000 measurement records	Open (OBIS)	Species-level where available; WoRMS aligned;	High	OBIS metadata/Zenodo

Romanian Black Sea Zooplankton (NIMRD, OBIS)	Marine shelf (RO coast)	**Species populations (zooplankton abundance, distribution); Community composition**	Zooplankton biomass/abundance (EOV)	Romanian shelf transects & stations	1981–2000 (seasonal)	~59,000 occurrences, ~479,000 measurements	Open (OBIS)	Species-level IDs, mesh-specific sampling, consistent depth strata	Medium - High	OBIS dataset record
Danube Mouths Mesozooplankton 1979 (PANGAEA)	Estuarine /marine	**Community composition (plankton)**	Zooplankton biomass/abundance	13 stations off Danube mouths (3 transects)	1979 (spring & autumn)	~hundreds of sample records	Open (PANGAEA)	vertical net sampling, station metadata available	Medium	PANGAEA
Romanian Black Sea Zooplankton BRIDGE-BS_2022–2024 (GeoEcoMar)	Marine shelf (RO coast)	**Species populations (zooplankton abundance & distribution); Community composition**	Zooplankton biomass/abundance (EOV)	Romanian shelf	2022–2024	Multiple cruises, stations & depths	Open (Zenodo)	Standard net methods, functional groups included	High	Zenodo
GeoEcoMar Zooplankton Bridge-BS June 2023	Marine shelf (RO coast)	**Species populations; Community composition**	Zooplankton biomass/abundance (EOV)	5 stations, 12 samples (NW shelf)	Jun-23	~hundreds of records	Open (Zenodo)	taxonomy	Medium -High	Zenodo
Macrobenthos 1954–1968 (GeoEcoMar, OBIS)	Marine shelf (NW Black Sea)	**Community composition (benthos)**	Seafloor communities (EOV)	Romanian shelf (to 50 m depth)	1954–1968	567 samples, 97 species	Open (OBIS)	Morphological taxonomy	Medium	OBIS shapefiles and cruise metadata
Macrobenthos 2003–2011 (GeoEcoMar, OBIS)	Marine shelf (RO)	**Community composition**	Seafloor communities (EOV)	Romanian shelf (~40–60 stations)	2003–2011	~249 species with abundance/biomass	Open (OBIS/EurOBIS)	Semi-quantitative biomass and taxa abundance sampling	High	EurOBIS/OBIS maps
Macrozoobenthos & Traits	Marine shelf (NW Black Sea, RO & UA)	**Community composition & Species traits (functional traits)**	Seafloor communities (functional diversity)	237 stations NW shelf	1995, 2008–2017	215 taxa; 127 species with 27 traits	Open (Figshare)	Functional trait database structured by species; linked to trait vocab	High	Dataset DOI (Chevalier et al. 2025)

Cetacean Bycatch (Mare Nostrum, OBIS-SEAMAP)	Marine (RO coast)	**Species populations (marine mammals' distribution/abundance)**	Top predator abundance	RO coast (Sulina–Vama Veche)	2010–2011	12 bycatch records, 3 species	Open (OBIS-SEAMAP)	Opportunistic bycatch reporting (fishers); includes effort metadata	Low–Medium	SEAMAP survey map
EMBLAS-Plus Cetacean Survey (OBIS)	Marine mammals	**Species populations (distribution of cetaceans)**	Marine mammal distribution EOV	NW Black Sea (incl. RO waters)	2019 (survey season)	117 occurrence + effort records	Open (OBIS)	Boat-based survey protocol; standardized methods across basin	Medium–High	OBIS metadata and shapefiles
***Mnemiopsis leidyi* Invasion Database (SeaDataNet/EMODnet)**	Marine plankton (invasive)	**Species populations (invasive alien species)**	Plankton abundance/diversity (EOV)	Entire Black Sea (incl. RO shelf)	1980s–2000s	~3,600 records from 24 datasets	Partially open	Collated from national & institutional cruise data sources	Medium	BSC dataset registry
Copernicus Black Sea Chlorophyll & Productivity	Marine basin (EO)	**Ecosystem function (spring bloom phenology, primary productivity)**	EOV: chlorophyll, productivity	Basin-scale (incl. RO shelf)	1997–present (monthly/weekly)	Continuous gridded records	Open (Copernicus)	EO algorithms; calibrated against in situ data	High	CMEMS metadata portal
EMODnet Human Activities – Trawling Disturbance	Marine shelf (RO EEZ)	**Ecosystem function (seabed disturbance)**	Pressure EOV (trawling intensity)	RO shelf trawling grounds	~2010–2021	GIS grid cells	Open (EMODnet layers)	Fishing effort datasets by gear; anonymized but spatially detailed	Medium–High	EMODnet viewer
RivFISH (Zenodo 2024)	Freshwater fishes	**Species populations (distribution of freshwater fishes)**	–	European basins incl. Danube	Compiled up to 2020	Presence/absence for all species × basins	Open (Zenodo)	Harmonized taxonomy, presence–absence only; aligned with EFI+ & WISE	Medium-High	Dataset DOI + Zenodo shapefiles
Danube Delta Biodiversity DB (INCDDD)	Freshwater (lakes, channels, Delta)	**Species populations (fish, amphibians, reptiles, mammals); Community composition (phytoplankton, benthos, fish)**	–	Danube Delta wetlands	~1960s–present	Thousands of station records (internal)	Restricted (metadata only published)	Multi-taxa field campaigns; raw data structured in legacy DB	Medium	INCDDD maps, WISE metadata overlays

Joint Danube Surveys (ICPDR)	Freshwater (Danube mainstream & tributaries)	**Community composition (fish, benthos, plankton); Species populations (fish, invasive taxa)**	supports connectivity, water quality EOVs)	Danube River (full length, incl. RO)	2001, 2007, 2013, 2019	Hundreds of sites per campaign	Partially open (summary reports)	Coordinated by JDS; data aggregated by index	High	JDS metadata maps (ICPDR portal)
Danube Basin Alien Species Inventory (AISSIC)	Freshwater invasive taxa	**Species populations (invasive alien freshwater species)**	–	Danube basin (incl. Romania)	up to ~2015	129 taxa, ~3,600 records	Restricted/ partly open	Alien species registry;	Medium	ICPDR & national agency references
GeoEcoMar Delta Water Quality (Zenodo)	Freshwater/Delta	**Ecosystem function (nutrients, drivers of blooms)**	Water quality proxy for HAB EBVs	Danube Delta (arms & lakes)	2020–2021	Campaign datasets (CSV, water, sediments)	Open (Zenodo)	Nutrient & chlorophyll samples, multiscale transects	Medium - High	Zenodo DOI metadata
Danube Discharge at Ceatal Izmail (RivDIS/PANGAEA)	Freshwater hydrology	**Ecosystem function (flow regime, flooding)**	Hydrology EOV	Danube Delta apex (Ceatal Izmail)	1921–1985 (monthly)	64 years × 12 months	Open	Discharge station calibrated; metadata available	High	PANGAEA dataset portal
Sentinel-2 Inundation Maps (Zenodo, ECOPOTENTIAL)	Wetlands (Delta)	**Ecosystem function (flood regime, connectivity)**	Wetland extent EOV proxy	Danube Delta wetlands (RO)	2016–2017 (10 scenes)	10 raster maps (GeoTIFF, 10 m)	Open (Zenodo)	Remote sensing; 10 m resolution flood extent derived	Medium -High	Sentinel scenes and Zenodo metadata

The marine realm dominates the monitoring data availability - twenty-eight datasets (about 70% of all listed datasets are marine). In contrast, freshwater systems are under - represented (eight out of which only five are open/partially open datasets). Transitional data are minimal, just three datasets (among which a historical plankton survey at the Danube delta mouths, fully open via an online repository, a single habitat mapping dataset for Danube Delta wetlands and the other one, bird colony census in delta coastal areas, partially open, with information found in reports or summaries). Notably, none of the transitional entries are completely restricted, but the limited number of datasets highlights a gap in openly accessible data. On the contrary, although extensive freshwater biodiversity surveys exist (e.g. for Danube Delta fish, macrophytes, invertebrates), the accessibility remains also largely inaccessible in public repositories (often kept internal or unpublished). The marine focus is evident from numerous OBIS and EMODnet entries, plus later series up to 2005). Similarly, marine plankton, benthic and mammal data are openly shared, which result in strong coverage of the Species abundance EBV class. By contrast, freshwater species abundance data are virtually absent despite monitoring efforts. Transitional monitoring likewise relies on very few fair data, with limited species/community datasets openly available (Fig. **16, 17**).

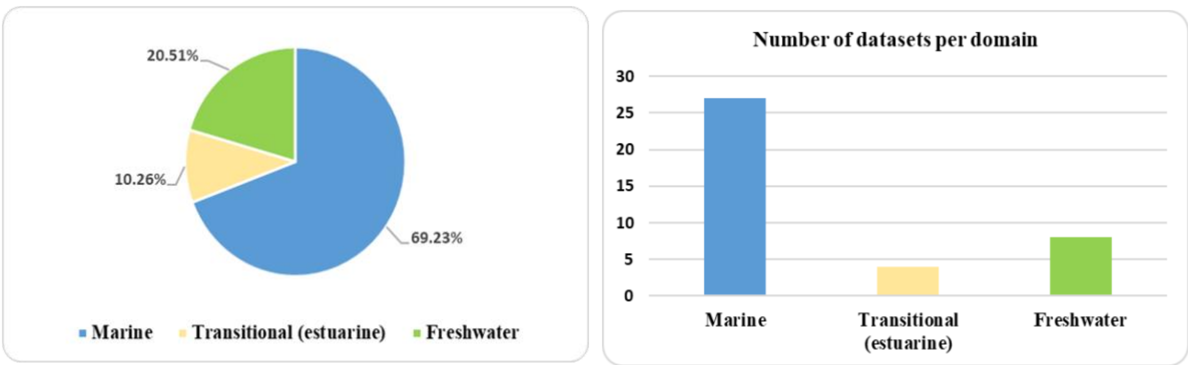


Fig. 16. Proportion (left) and number (right) of datasets shared by the marine, estuarine and freshwater ecosystems (Danube – Black Sea)

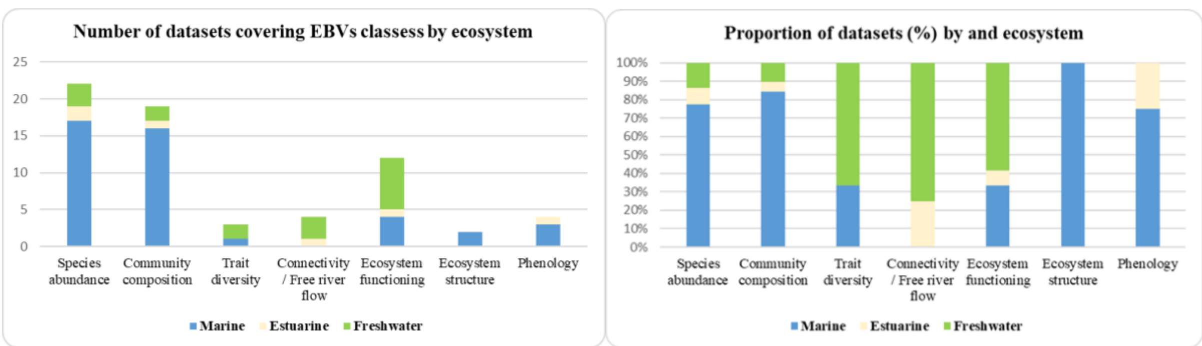


Fig.17. Number (left) and proportion (right) of datasets shared by EBVs main classes within marine, estuarine and freshwater ecosystems of the Danube - Black Sea case study

5.3.2. Readiness of the Danube–Black Sea monitoring system for upscaling to Essential Variables

The EBV readiness assessment across the Danube – Black Sea region highlights strong marine coverage but reveals major gaps in freshwater and transitional ecosystems. Marine and freshwater EBVs, especially for species abundance, and community composition show the highest readiness (score 2.4 – 2.6) due to some long-term datasets, broad spatial coverage, and strong policy alignment with MSFD (**Fig. 18**). While connectivity scores moderate (**2.1**) thanks to hydromorphology data, other EBVs suffer from limited temporal/spatial depths and restricted access. Estuarine ecosystems are the least developed, with most EBVs scoring 0 -1, reflecting the scarcity of biodiversity - focused monitoring.

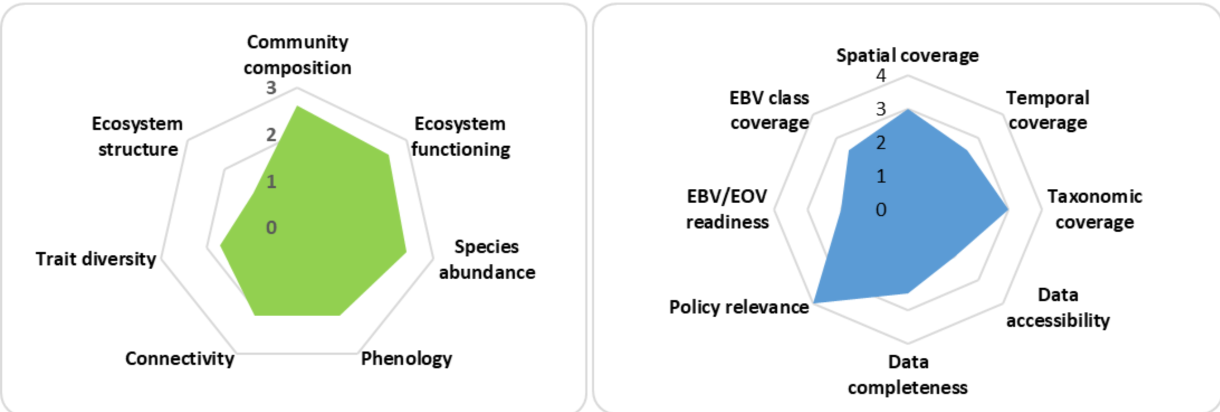


Fig. 18. Radar plots of EBVs showing the readiness scores of EBVs (left) and readiness scores based on criteria assessment of Danube - Black Sea monitoring datasets (right).

A critical shortfall across all domains is the lack of trait-based data, resulting in low readiness (**score 1.7**) provided the low taxonomic depth. Moreover, while **policy relevance** is generally strong (**score 4**), restricted data access and gaps in ecological detail constrain actual EBV operationalization. Nevertheless, the region demonstrates clear potential and alignment with policy needs, but realizing full EBV/EOV integration will require expanding trait, transitional, and freshwater data and enhancing data accessibility across domains, standardization, or comprehensive enough to support EBV/EOV translation process. This points out to a limited potential for their direct use in global biodiversity and ocean observation frameworks (**Tables 10, 11, Fig. 18**).

Table 10. Readiness assessment of EBV classes in the Danube –Black Sea Sea monitoring system

EBV class	EBVs Score	Assessment Criteria	
Species abundance	2.4	P = 0.48; T = 0.63; S = 1.00; A = 0.47; M = 0.74	Species abundance is well supported. Several provide multi-decadal time series (e.g., ZPK, MZB, Danube WFD fish, Copernicus Chl-a), but others are short or episodic. Spatial representation covers river, delta, and marine sectors, although unevenly. Access is mixed, with many datasets restricted or requiring requests. Overall, abundance is moderately well represented but not consistently open or long-term across all domains.
Community composition	2.6	P = 0.43; T = 0.64; S = 1.00; A = 0.47; M = 0.72	Community composition is comparatively strong due to taxonomic coverage. Many comply with WFD/MSFD protocols, ensuring standardized taxonomy and comparability. Coverage across realms is good, although some marine datasets are partial or outdated. Access remains a limiting factor, but taxonomic richness and methodological consistency support a higher readiness.
Trait diversity	1.7	P = 0.17; T = 0.30; S = 0.33; A = 0.20; M = 0.50	Trait information is available only through a few specialized datasets (e.g., MZB traits, fish size data, selected zooplankton functional groups). Most monitoring programs do not include functional or life-history traits. Limited taxonomic breadth, short time series, and incomplete accessibility reduce overall readiness. As in many basins, trait diversity remains the least developed EBV.
Connectivity / Free River flow	2.28	P = 0.17; T = 0.45; S = 0.33; A = 0.40; M = 0.70	Connectivity is supported mainly by hydromorphological and hydrological datasets (flow regimes, barriers, flood maps). Riverine datasets are strong (Danube discharge, connectivity mapping, hydromorphology indices), but biological indicators of connectivity are scarce. While structural information is solid, functional and cross-domain connectivity links are still limited.
Ecosystem functioning	2.5	P = 0.43; T = 0.66; S = 0.67; A = 0.70; M = 0.78	Functioning is moderately strong due to robust chlorophyll-a and productivity datasets (Copernicus, CMEMS), eutrophication indicators, water quality series, HAB monitoring, and real-time hydrological drivers. Marine functioning is well captured, but freshwater and estuarine functional data are more fragmented. Open access is high for EO products but low for national monitoring datasets. Overall, functioning EBVs are feasible but uneven across domains.
Ecosystem structure	1.2	P = 0.22; T = 0.50; S = 0.33; A = 0.40; M = 0.65	Structural EBVs are poorly represented. Only a few benthic, macrophyte, or habitat-integrity datasets exist, and most are spatially limited or outdated. River habitat structure is partially available via WFD hydromorphology, but marine habitat/mapping datasets are sparse. Restricted access and inconsistent methodology reduce interoperability. Structural EBVs remain underdeveloped.
Phenology	2.1	P = 0.30; T = 0.67; S = 0.67; A = 0.75; M = 0.70	Phenology is supported mainly by satellite-derived bloom timing products and a few long-term phytoplankton/zooplankton datasets. Some bird and biological seasonal datasets contribute but are not continuous. Marine phenology is better represented than freshwater or delta sectors. Accessibility is mixed, with EO data open but most *in-situ* series restricted. Overall readiness is moderate.

Table 11. Assessment criteria scores of Danube - Black Sea datasets (see Table 3 for details on methodology for scores calculation)

Criterion	Score	Rationales
Spatial Coverage	2	Marine datasets show moderate coastal and shelf coverage (Romanian shelf transects, Copernicus EO), estuarine datasets are fewer but exist (e.g., Delta birds, mesozooplankton), freshwater datasets include basin-wide inventories (JDS, AISSIC) and regional maps (Danube Delta).
Temporal Coverage	2.5	Presence of long-term marine monitoring (e.g., phytoplankton since 1950s, zooplankton, Copernicus EO), estuarine and freshwater cover shorter periods but include also some datasets from the 1960s–2020s.
Taxonomic Coverage	3	Strong marine plankton and benthos taxonomy; fish species in marine and freshwater at specific level; birds, amphibians, reptiles, mammals are included in targeted surveys or regional inventories.
Data Accessibility	2	Only some datasets are fully open (OBIS, Zenodo, Copernicus), others are partially accessible or published as summary reports (e.g., BSIMAP, ICPDR). Most remain fully restricted.
Data Completeness	2.5	Key EBVs like abundance and composition are well represented across domains. Functional, trait and hydrology-based EOVs are more fragmented. Estuarine and wetland data less dense. Metadata for most datasets is robust, yet some records lack supporting environmental variables.
Policy Relevance	4	Strong alignment with MSFD, WFD, and regional policies. Most datasets are developed under, or directly inform, national and EU obligations. Direct use in status assessments and monitoring frameworks.
EBV/EOV Readiness	2	Readiness increased for abundance, composition, eutrophication proxies, but remains lower for trait diversity and connectivity. Integrated freshwater-marine EBV frameworks still fragmented. Improvement in standardization, open formats, and sampling effort coverage.
EBV Class Coverage	2	Core EBV classes like abundance and community composition are widely covered; ecosystem structure and functioning moderately so. Trait diversity and connectivity remain underrepresented in terms of both spatial and taxonomic granularity.

Datasets clustering pattern is shown within the PCA space (**Fig. 19**), which reveals important structural focus in the biodiversity datasets across the Danube - Black Sea region. The first two principal components account for over 71% of the total variance (PC1: 47.5%, PC2: 23.7%). PC1 indicates a dominant gradient toward datasets focused on composition and abundance (i.e., macrozoobenthos, phytoplankton and zooplankton diversity, marine mammal records). The second component (PC2) highlights additional contrasts, separating datasets with high trait and composition relevance, positioned in the upper right quadrant, from those linked to phenology or environmental variables. Meanwhile, a third group of datasets concerned with ecosystem functioning or connectivity, including Copernicus and EMODnet data, load negatively on PC1, indicating their role as contextual or supporting datasets rather than primary biodiversity observations. Traits and connectivity remain underrepresented in the PCA space, poorly aligned with other EBVs. Their marginal presence highlights a data gap in current monitoring efforts.

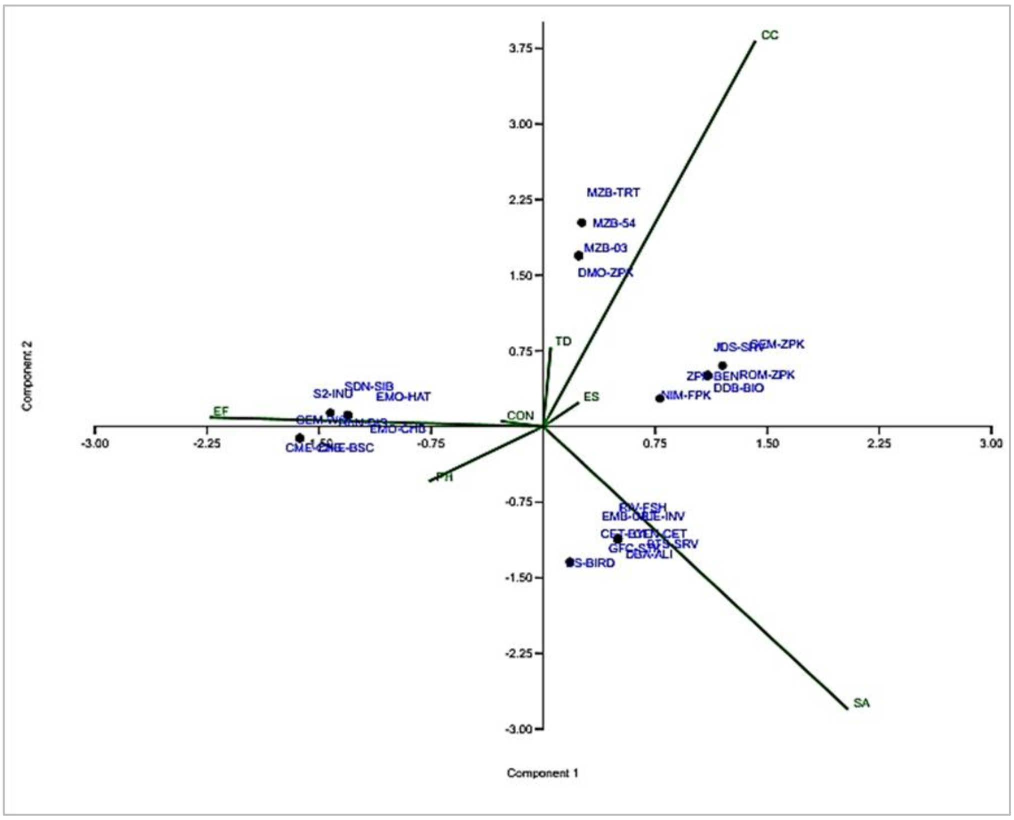


Fig. 19. PCA showing the most datasets revolving around PC1 and PC2, which explain more than 71% of variance

The heatmap highlights also the uneven contribution of existing datasets to different EBVs classes in the Danube - Black Sea region, suggesting that while regular monitoring supports certain EBVs well, others, particularly those requiring trait integration or spatial-temporal connectivity, are far from being operational.

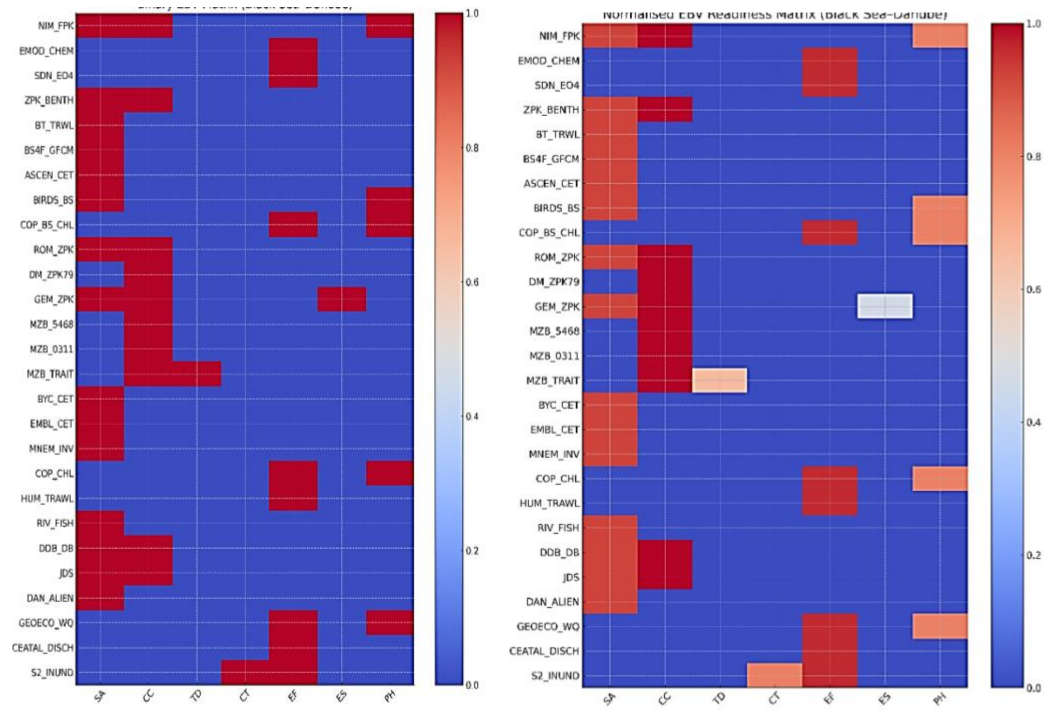


Fig. 20. Datasets coverage heatmap in Danube – Black Sea. Left: Contribution of individual monitoring datasets to EBV classes. With red are represented datasets that can be directly used to generate EBVs (SP - Species population/abundance; CC - Community composition; TD – Trait diversity; CT – Connectivity; EF – Ecosystem functioning; ES – Ecosystem Structure; PH – Phenology), while blue color reflects limited relevance or missing information. Right: Datasets readiness map (each dataset has been scored by averaging spatial, temporal, taxonomic, accessibility, and completeness scores across datasets) (datasets abbreviation – Annex)

5.3.3. Data accessibility

Although 69.7% of the assessed datasets **(Fig. 21)** are classified as open access, this primarily reflects data shared via international repositories (e.g., EMODnet, OBIS, Zenodo), often generated through scientific projects or research institutions such as NIMRD, GeoEcoMar, INCDDD, or ICPDR. In contrast, data originating from national authorities, particularly ministries or environmental agencies, are less represented among open datasets. Romania's environmental monitoring frameworks illustrate this imbalance. For freshwater systems, the Danube's status is monitored under the EU Water Framework Directive (WFD) through national agencies like Administrația Națională "Apele Române" and regional water directorates. These institutions collect comprehensive biological and physicochemical data through surveillance and operational networks. While these datasets inform critical management decisions and are coordinated at basin level by the ICPDR via the Trans-National Monitoring Network (TNMN), raw datasets (e.g., species-level counts or water quality indicators/parameters) are typically not publicly accessible. Instead, only aggregated outputs (e.g., ecological status classes or pressures) are made available in River Basin Management Plans or through summary products on ICPDR platforms.

A similar situation exists for Romania's marine monitoring under the Black Sea Commission and the EU Marine Strategy Framework Directive (MSFD). Long-term datasets, some of which span back to the 1960s, provide rich information on phytoplankton, benthos, fish, and marine mammals. However, while summary assessments are often published, access to detailed biological data remains uneven. Most raw datasets are only available through collaborations or formal requests, limiting their use in open science or biodiversity indicator frameworks like EBVs and EOVs.

Thus, the current picture of open data is shaped more by scientific initiatives than by institutional data-sharing policies. While technical monitoring is strong in both freshwater and marine domains, accessibility remains constrained, particularly for high-resolution biological data held by national authorities.

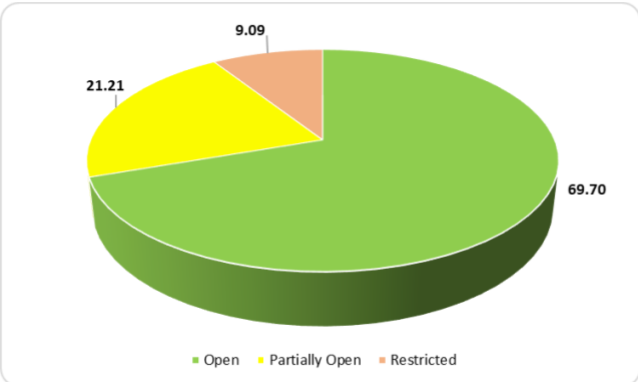


Fig. 21. Share of datasets with different accessibility levels within the Danube - Black Sea case study

The Danube–Black Sea biodiversity observation framework exhibits a low degree of methodological maturity and conceptual alignment with GEO BON and GOOS standards for the generation of EBVs and EOVs. Though the network combines long-term *in situ* monitoring of freshwater and marine biota with Earth Observation (EO) products, addressing multiple EBV classes - species populations, community composition, ecosystem structure, and functioning across connected riverine, transitional, and marine domains, data integration remains poor due to lack of coordination at national level.

Spatial representativeness is one of the strengths of the system. The monitoring design spans key biogeographic gradients, from river reaches and deltaic wetlands to the Black Sea shelf, meeting EBV criteria for 1–10 km spatial resolution. Nevertheless, transitional and connectivity zones including freshwater - marine processes, remains under-sampled.

Temporal resolution and consistency are adequate for only some taxonomic groups, with seasonal to annual observations enabling trend detection in marine benthic fauna, and phyto-/zooplankton. However, higher-frequency (weekly to monthly) sampling is required for dynamic variables such as plankton phenology and primary productivity, consistent with EBV temporal criteria for fast-responding taxa. Methodological consistency across institutions (INCDDD, ARBDD, and NIMRD) is assumed, yet long-term calibration and intercalibration remain essential to preserve comparability.

The monitoring framework **(Table 11)** shows high ecological relevance, with measured parameters closely aligned to EBV classes and WFD/MSFD biological quality elements. Equally important is the integration of environmental drivers (nutrients, oxygen, flow, temperature), which remains inconsistent but is critical for interpreting biodiversity change within the broader ecosystem context.

Finally, data openness and interoperability require further strengthening. While platforms such as EMODnet, OBIS, and ICPDR host significant datasets, full compliance with FAIR data principles is still incomplete. Establishing harmonized metadata standards, shared repositories, and automated data exchange protocols would substantially improve scalability and cross-system synthesis.

Table 11. Datasets and monitoring methodologies readiness for EBV/EOVs translation in Danube - Black Sea study case

Datasets	Monitoring methodology	Why it matters for EBVs/EOVs
Freshwater fish assemblages (INCDDD, ARBDD, ICPDR)	Reach-scale monitoring in Danube and tributaries (~5–10 km segments), seasonal/annual	Tracks species abundance and composition EBVs; supports migratory fish/connectivity EBVs; aligns with WFD fish BQEs and HD Annex II species.
Freshwater phytoplankton (INCDDD, ARBDD, ICPDR)	Riverine and delta stations (~40–60 sites)	Captures abundance EBVs (algal biomass, blooms) and phenology EBVs (bloom timing); relevant to eutrophication EOVs and WFD phytoplankton BQEs.
Freshwater macroinvertebrates (INCDDD, ARBDD, ICPDR)	Reach-scale sampling at 80–100 stations, seasonal/annual	Provides composition and structure EBVs; sensitive to water quality change; links to benthic EOVs and WFD invertebrate BQEs.
Freshwater phytobenthos (INCDDD, ARBDD)	Diatom-based monitoring, seasonal, multiple Danube sites	Captures composition EBVs (community shifts); supports eutrophication EBVs/EOVs; aligns with WFD phytobenthos BQEs.
Marine phytoplankton (NIMRD, GEM, OBIS, EMODnet)	Black Sea coastal/shelf grid (~20–50 sites), seasonal	Tracks abundance EBVs (chlorophyll/biomass), phenology EBVs (bloom dynamics); key for eutrophication indicators (MSFD D5, WFD coastal).

Marine zooplankton (NIMRD, GEM, OBIS, PANGAEA)	Transects/stations on Romanian shelf, seasonal	Supports abundance EBVs; essential for food-web EOVs; contributes to MSFD D4 indicators.
Marine benthos (NIMRD, GEM, EMODnet, OBIS)	Shelf surveys (~40 stations)	Provides composition and structure EBVs; aligns with MSFD D6 seafloor integrity and WFD benthic BQEs.
Marine fish (NIMRD, CFP, ICES/FAO)	Trawl surveys and stock monitoring, annual	Long series for abundance and distribution EBVs; feeds MSFD D1/D3 fish indicators and stock assessments.
Marine mammals (NIMRD, Mare Nostrum, ACCOBAMS)	Aerial/boat transects in Black Sea, multi-annual	Provides abundance/distribution EBVs for top predators; relevant to MSFD D1 mammals and HD Annex II species.
Bird migration (wetlands, ARBDD)	Stopover and winter counts in Danube Delta, seasonal	Captures phenology EBVs (migration timing); contributes to Ramsar, Natura 2000, and MSFD D1 (birds).
Hydromorphology / Connectivity (ICPDR, ARBDD, GEM)	Basin-wide barrier inventories, GIS mapping, annual updates	Tracks connectivity EBVs (free river flow); critical for migratory fish; aligns with WFD hydromorphology and HD.
Primary productivity (NIMRD, Copernicus MEDSEA EO)	EO-derived (Sentinel, MODIS), 250 m^{-1} km resolution, weekly–monthly	Provides functioning EBVs (ecosystem productivity); scalable to EOV productivity; relevant to MSFD D5 and GOOS.

The diagram (**Fig. 22**) illustrates the multi-tiered data flow supporting EBV/EOV derivation across the Danube - Black Sea region. It highlights the integration of diverse institutional, thematic, and observational data streams ranging from national marine institutes to regional open portals (EMODnet, OBIS, PANGAEA) and Copernicus EO products. However, the data access analysis reveals persistent barriers to FAIR compliance, with several datasets remaining partially open or restricted, which limits interoperability and scalability to the global level (GOOS, GEO BON, IPBES, CBD). Strengthening data-sharing mechanisms and metadata harmonization across institutional and thematic repositories is therefore essential to fully operationalize EBVs and EOVs and to support regional contributions to global biodiversity observation systems.

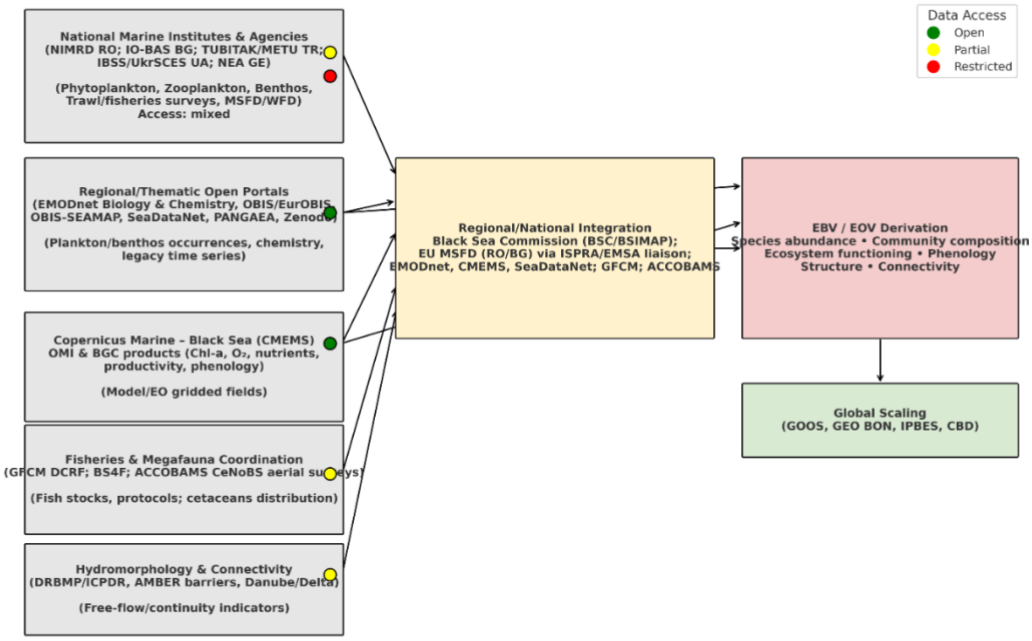


Fig. 22. Scheme of monitoring flow in the Danube - Black Sea case study

5.3.4. Conclusions

The Danube–Black Sea monitoring portfolio is relatively diverse, covering both freshwater and marine systems with some long-running datasets on phytoplankton, benthos, and hydromorphology, particularly covered under the WFD in the freshwater domain and under MSFD in the marine domain.

From an EBV/EOV perspective, the monitoring is skewed toward abundance and composition, while traits, phenology, and ecosystem functioning are much less represented, often appearing only indirectly through indices or proxies. This imbalance constrains the ability to fully capture ecosystem change and biodiversity dynamics across the land–sea continuum.

A second limitation is data accessibility and format readiness. While some datasets are openly available (e.g., Copernicus EO, OBIS, EMODnet), many remain aggregated into indices (EFI+, IPS, STAR_ICMi, M-AMBI) or restricted to national reporting formats. Without access to the raw species-level or biomass data, their translation into EBVs and EOVs is partial at best.

To close these gaps, efforts should focus on Improving accessibility and standardization of existing raw monitoring data, expanding monitoring of traits, connectivity, phenology, and ecosystem functioning, and strengthening integration across freshwater and marine domains to better represent the Danube–Black Sea as a coupled system.

5.4. **Guadalquivir – Atlantic Ocean**

5.4.1. Datasets and EVs suitability

A total of **22 distinct monitoring datasets** were identified across the Guadalquivir River–Transitional–Coastal system. Spatially, the datasets collectively cover the full river - sea continuum, from the upper river network to the coastal shelf. Approximately equal effort is distributed among freshwater (36.36%), marine/coastal domains (36.36%), and lower to transitional/estuarine (27%) **(Fig. 23)**.

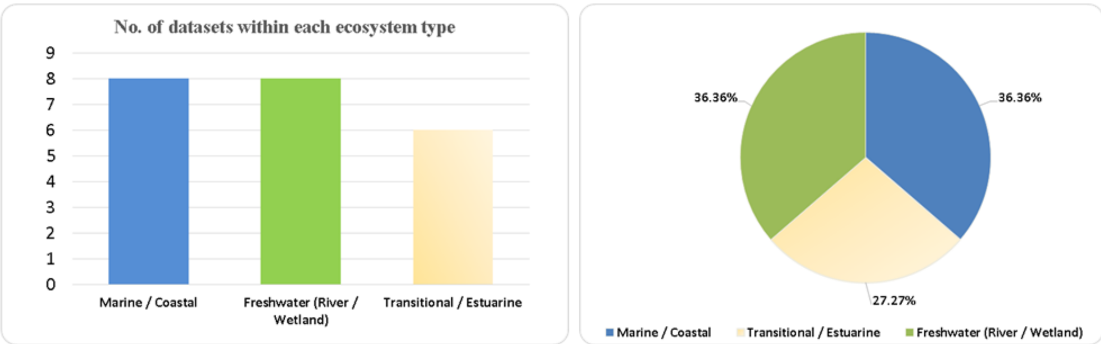


Fig.23. Number (left) and proportion (right) of datasets shared by EBVs main classes within marine, transitional and freshwater ecosystems of the Guadalquivir - Atlantic Ocean case study

The regional monitoring networks coordinated mainly by CHG, ICMAN-CSIC, IFAPA provide a **balanced monitoring coverage** across the Guadalquivir system, which reflects the continuity of the river - sea gradient, although the underlying spatial resolution remains heterogeneous, from point - based stations to satellite - derived 250 m - 10 km grids. The datasets availability highlights that most monitoring efforts originate from established regulatory frameworks, principally the EU Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD), supplemented by academic long-term research programs (LTERs), project-based surveys, and Earth-observation data streams **(Table 12).**

Temporal resolution and consistency vary substantially across programs. Core WFD and LTER datasets exhibit multi-decadal continuity and seasonal to monthly sampling, providing a solid temporal backbone for trend detection. Conversely, several estuarine and project - specific surveys remain temporally fragmented, limiting their long-term EBV utility without harmonization or data rescue efforts.

Integration with environmental drivers and EOVs represents one of the key strengths of the Guadalquivir monitoring landscape. Hydrographic (REDMAR), physico-chemical (RTRM, STOCA), and biogeochemical (CMEMS) datasets provide direct coupling potential with biodiversity variables, fulfilling a core requirement of the GEO BON - GOOS interoperability framework. Such integration enables process-based interpretation of biodiversity change and supports scaling from basin-level observations to global EBV–EOV indicators.

Despite limitations, the Guadalquivir basin monitoring initiatives collectively support most of the EBV subcategories across both marine, freshwater and estuary domains **(Fig. 24).**

Table 12. Catalog of datasets used in the Guadalquivir – Atlantic Sea EBV/EOV assessment including domains (freshwater, transitional, marine), alignment with EBVs and EOVs, spatial and temporal coverage, data accessibility (FAIRness), and methodological notes. The table also reports dataset suitability for EBV/EOV operationalization and traceability of data sources.

Dataset / Source	Dataset Name	Domain	EBV Class Alignment	EOV Alignment	Spatial Coverage	Temporal Coverage / Resolution	Access	Managing Institution	Notes on Taxonomy / Methodology	Overall Suitability	Source	Policy Relevance
Red de Control de Aguas de Transición y Costeras (TRANSICION_COSTERA)	Confederación Hidrográfica del Guadalquivir. (2016). Red de control de las aguas de transición y costeras (TRANSICION_COSTERA). IDECHG Geoportal.	Transitional / Coastal	Species abundance; Community composition	Zoobenthos; Plankton; Hydrography	20 stations spanning salinity gradient (Yesos-Pluma)	Seasonal/annual; multi-cycle (WFD)	Standard WFD formats; data on request (CHG)	Confederación Hidrográfica del Guadalquivir (CHG)	Phytoplankton, macroinvertebrates, fish, physico-chemical; Core WFD network; spatial basis for estuary/coastal EBVs/EOVs	High	IDECHG Geoportal – TRANSICION_COSTERA	WFD
Programa de Control Biológico (aguas superficiales, transición y costeras)	CHG. (2022). Plan Hidrológico de la Demarcación del Guadalquivir 2022–2027, Anexo 1.	Freshwater / Transitional / Coastal	Species abundance; Community composition	Hydrography; Biogeochemistry (supporting)	Representative across basin + estuary/coast	Annual (surveillance/operational) across cycles	Public summaries; raw data on request	CHG + MITECO	Fish, phytobenthos, macroinvertebrates, phytoplankton; Defines frequency, BQEs; official WFD plan	High	Plan Hidrológico 2022–2027, Anexo 1 – Red de Control	WFD

Guadalquivir Long-Term Ecological Research Site (LTER)	ICMAN–CSIC & IFAPA. (1997–2022). Guadalquivir Estuary LTER [Dataset]. DEIMS–SDR.	Estuarine	Species abundance; Community composition, Ecosystem functioning	Plankton biomass; Hydrography; Biogeochem	5 fixed stations along salinity gradient (0–50 km)	1997–present; monthly	Metadata open; data by request (DEIMS)	IFAPA & ICMAN–CSIC	Plankton, fish, crustaceans, nutrients; Multi-decadal biotic & environmental series	High	DEIMS–SDR record	WFD (support), HD/Natura2000
Red de Medida en Tiempo Real (RTRM) – Estuario	Navarro, G. et al. (2008 -2010). Real-time monitoring network of the Guadalquivir Estuary (RTRM). CSIC.	Estuarine / Coastal	Ecosystem functioning; Community composition	Hydrography; Biogeochemistry	4 fixed nodes (07,09,89) + Salmedina buoy	2008 - 2010 continuous (10–30 min) + periodic campaigns	Partial via publications; project archive	ICMAN–CSIC & Autoridad Portuaria de Sevilla (APS)	Salinity, turbidity, DO, fluorescence (chl-a proxy), EOV backbone; complements LTER	High	ICMAN RTRM project summary	WFD/MSFD support
Puerto de Sevilla – Programa de Seguimiento Ambiental (Macrofauna Béntica)	Universidad de Sevilla & Autoridad Portuaria de Sevilla. (2015–2019). Seguimiento de la macrofauna bentónica en el Puerto de Sevilla.	Estuarine (Port)	Species abundance; Community composition	Zoobenthos	6 sites (Yesos, Esparraguera, Puntalete, Salinas, Bonanza, Broa)	2015 - 2019; seasonal (EIA context)	Reports (non-FAIR)	Autoridad Portuaria de Sevilla / Univ. de Sevilla	Benthic macrofauna;High taxonomic resolution; sediment quality	Moderate	APS Environmental Reports	WFD BQE (benthos)

Reserva de Pesca de la Desembocadura del Guadalquivir	Junta de Andalucía. (2004-present). Reserva de Pesca de la Desembocadura del Guadalquivir.	Estuarine / Coastal	Species abundance	Fish distribution/biomass (from fisheries)	Zones A - D across mouth - shelf	2004 - present (variable frequency)	Summaries public; data on request	Junta de Andalucía (AGAPA)	Fish CPUE, species composition, sizes; Policy-relevant fish EBVs at plume	Moderate	AGAPA - Reserva de Pesca	MSFD D1/D3; CFP
STOCA (Seguimiento de las Aguas del Golfo de Cádiz) – radial GD	IEO–CSIC. (2008–present). Programa STOCA -Seguimiento de las Aguas del Golfo de Cádiz.	Coastal / Shelf	Species abundance; Community composition, Ecosystem functioning	Hydrography; Biogeochemistry; Plankton	Radial from plume offshore	2008-present; quarterly	IEO repository (request)	IEO–CSIC	Plankton, CTD, nutrients, chl-a; links coastal plume to open ocean	High	IEO Oceanographic Monitoring	MSFD
REDMAR - Puertos del Estado (Bonanza & Sevilla)	Puertos del Estado. (1992-present). REDMAR sea-level and tide gauge network.	Estuarine / Coastal	Ecosystem functioning	Hydrography	Two key stations (Bonanza mareograph; Sevilla locks)	1992-present; continuous (min-level)	Open via Portus API	Puertos del Estado (Ministerio de Transportes)	Sea-level, currents, temperature, salinity	High (supporting)	REDMAR Portal	WFD/MSFD support;
Doñana Monitoring Program (LTER)	EBD–CSIC. (1995–present). Doñana Biological Reserve Long-Term Monitoring Program. DEIMS–SDR.	Coastal / Wetlands	Species abundance; Ecosystem structure	(biological); support via env. stations	Extensive marsh + coastal lagoons	1995–present; monthly/annual	Metadata public; data on request	Estación Biológica de Doñana (EBD–CSIC)	Birds, amphibians, reptiles, mammals; habitats; trait/phenology source; coastal biodiversity link	High	Doñana LTER site	HD/Natura2000; WFD coastal support

Doñana Marine Edge (LTER)	-	Coastal / Marine	Species abundance; Community composition	Plankton; Hydrography (limited)	Marine edge near Doñana	Seasonal campaigns	Restricted	EBD - CSIC	Coastal plankton, macrophytes, fish; Complements CHG coastal monitoring	Moderate	-	MSFD support
CHG Reservoir Monitoring (Eutrophication)	—	Freshwater	Community composition, Ecosystem functioning	Biogeochemistry	Reservoirs & lakes (basin-wide)	Monthly–quarterly	Access on request	CHG	Phytoplankton, chl-a, nutrients; harmful algal blooms & productivity shifts	High	Plan Hidrológico / CHG Red de Control	WFD
IFAPA Fish Sampling Network	—	River + Estuary	Species abundance;	— (support)	Representative reaches (river + transitional)	Campaign-based (multi-year)	Project data	IFAPA	Fish species & sizes; complements CHG fish; less consistent frequency	Moderate	—	WFD support
UCA / ICMAN Benthic Metabolism Study	—	Estuarine (lower)	Ecosystem functioning	Biogeochemistry	2 fixed sites in hyperturbid zone	2018–2020; seasonal	Research data	UCA & ICMAN–CSIC	Sediment O_2; nutrient fluxes; metabolism; Short-term functional	Moderate	—	MSFD eutrophication
CHG Hydromorphological Connectivity Mapping	—	River + Estuary	Ecosystem structure	Hydrology	Entire basin segmentation	6-year updates (planning cycles)	Open report + GIS	CHG	Barriers, free-flowing segments, connectivity indices	High (structural)	Plan Hidrológico / IDECHG	WFD; HD

CHG "Especies Invasoras" (Invasive Species)	—	Basin-wide	Species abundance (invasive); Ecosystem structure	— (context)	Basin + estuary spatial layer	Irregular updates	Downloadable shapefile (IDECHG)	CHG	Invasive alien taxa (plants, inverts, vertebrates); Ready spatial EBV product	Moderate–High	IDECHG – ESPECIES_INVASORAS	EU IAS; WFD support
Groundwater & Springs (Manantiales)	—	Freshwater	Ecosystem structure (support)	Hydrology	Point-based spring network	Monthly	Public via IDECHG	CHG	Hydrochemistry, water level; occasional fauna	Supportive	IDECHG – MANANTIALES	WFD (support)
Satellite-Derived Primary Productivity (CMEMS/ NASA)	—	Marine / Plume	Ecosystem functioning	Biogeochemistry; SST	Full plume & shelf coverage	Daily–weekly (global)	Fully open (CMEMS)	EU Copernicus / NASA	NPP, chl-a, SST, bloom timing; EBV upscaling (productivity, phenology)	High (EO)	CMEMS Catalogue	MSFD; GOOS
Puertos del Estado – Meteorological Stations	—	Estuarine / Coastal	Ecosystem functioning (support)	— (driver integration)	Co-located with hydro nodes	Continuous	Open via Portus	Puertos del Estado	Wind, pressure, rainfall (EBV/EOV coupling)	Supportive	Portus (Puertos del Estado)	WFD/MSFD support
LIFE Projects (e.g., Conhabit, Migratoebre)	—	Basin / Estuary	Species abundance; Ecosystem structure	— (partial)	Project-specific geographic focus	Short-term (project duration)	Reports & deliverables (open)	Junta / EU Consortia	Target taxa (birds, fish, habitats); add temporal depth; not systematic monitoring	Moderate	Project sites / reports	EU LIFE / HD

University of Sevilla – Fish (2015–2018)	—	Transitional	Species abundance	Fish distribution/biomass	≈6 stations (Upfront, 15 PSU, 5 PSU, DONANA, CANAL, FARO)	2015–2018; seasonal/annual	Project reports / publications	Universidad de Sevilla	Estuarine fish assemblages; Good taxonomy; moderate time span	Moderate	—	WFD fish BQEs (support)
ICMAN/CSIC Zooplankton Community (2008–2011)	—	Estuarine	Species abundance, Community composition	Plankton biomass/size spectra	Multi-station transects (salinity gradient)	2008–2011; seasonal	Publications / digital.CSIC	ICMAN–CSIC	Mesozooplankton composition; size spectra; Good taxonomic resolution; calibration dataset	Moderate–High	digital.CSIC record	WFD support; MSFD pelagic
CHG WFD Riverine Surveillance Network	—	Freshwater	Species abundance, Community composition, Ecosystem structure	Hydrology; Biogeochem (support)	Representative across basin (rivers/reservoirs)	Annual; multi-decadal	Public summary; raw data on request	CHG	Fish, phytobenthos, macroinvertebrates, phytoplankton across basin	High	CHG Red de Control (ríos)	WFD

The **Species Populations** class is by far the most represented, accounting for nearly half of all dataset alignments. Within this category, marine and estuarine EBVs (fish distribution, abundance, and other migratory species) are supported by multiple long-term monitoring programs, most notably the CHG WFD, IEO STOCA, IFAPA, and AGAPA Fisheries Reserve datasets. These programs combine ecological and fishery-based sampling with hydrographic and biogeochemical data, providing an good foundation for biodiversity - environment linkages under both WFD and MSFD mandates. The **Community Composition and Ecosystem Function** classes are moderately represented (each 25–30% of total entries), primarily through planktonic datasets such as the ICMAN LTER and IEO STOCA, which jointly cover composition, productivity, and bloom dynamics. These records allow integration of functional biodiversity indicators with EOVs such as chlorophyll-a, temperature, and nutrients. However, coverage of benthic functional processes (e.g., metabolism, seabed disturbance) remains sparse and localized. **Functional Phenology,** though underrepresented as a formal monitoring objective, are implicitly covered by several long-term datasets across the Guadalquivir system. In the marine domain, high-frequency RTRM and CMEMS datasets capture the timing and intensity of phytoplankton blooms, key for linking biodiversity change with climatic and hydrodynamic drivers.

In the transitional zone, the ICMAN LTER provides seasonal resolution of plankton and fish reproductive cycles, enabling quantification of intra-annual variability and phenological shifts along the salinity gradient. In freshwater and wetland areas, long-term Doñana biological monitoring supports the **Species Traits,** namely the assessment of migration and breeding phenology of birds, amphibians, and mammals. Nevertheless, trait-based freshwater biodiversity data (e.g., life-history or trophic traits) are effectively absent from routine monitoring.

The freshwater domain exhibits strong alignment with community composition EBVs, mainly through the CHG WFD Riverine and Reservoir Monitoring networks. These datasets provide extensive spatial coverage and regular temporal resolution for phytoplankton, phytobenthos, benthic invertebrates, and fish communities. Functional aspects, such as eutrophication or harmful algal blooms, are well documented through CHG reservoir eutrophication programs, providing opportunities to upscale EBVs related to productivity and water quality.

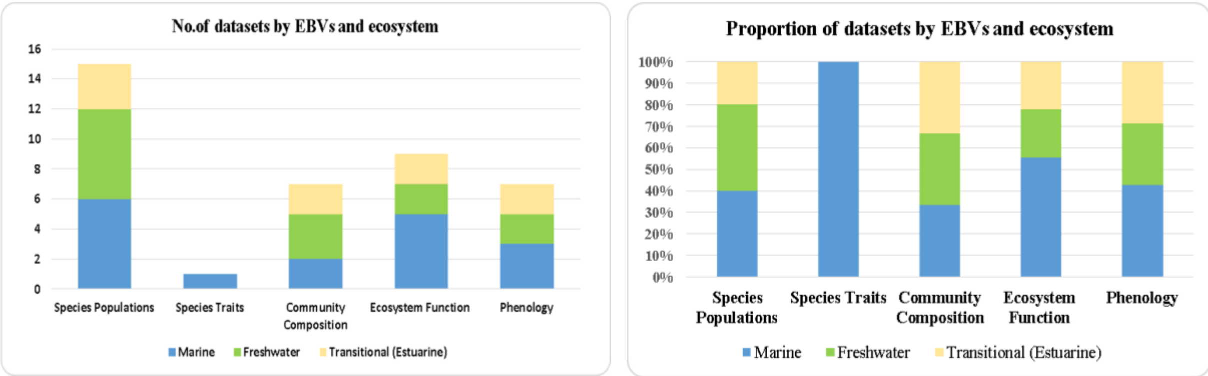


Fig.24. Distribution of datasets across EBV classes and ecosystem domains (freshwater, marine and transitional)

5.4.2. Readiness of the Guadalquivir – Atlantic Ocean monitoring system for upscaling to Essential Variables

Species Populations /Abundance along with **Ecosystem Functioning** reached the highest readiness scores (3.36 and 3.4), driven by multi-decadal, spatially broad networks (**CHG WFD**, **ICMAN LTER**, **IEO STOCA**, **IFAPA**, **AGAPA**). **Ecosystem Functioning** is buoyed by **RTRM**, **CMEMS**, **STOCA**, and reservoir productivity/ HAB monitoring. These excel on environmental integration (EOV coupling) and temporal resolution; however, biological function is sometimes inferred (e.g., phenology from chl-*a*), keeping scores moderate overall. These score high on spatial representativeness and temporal consistency and have strong ecological relevance. Openness/Restricted is mixed (request-based for some series), moderating scores. **Community Composition** is **moderate to high** (3.15). Long-term benthic/plankton programs provide strong ecological relevance but variable openness and taxonomy consistency across cycles limit standardization. **Structural Ecosystem** data exist (Doñana habitats, LIFE projects), but updates are irregularly provided (6-year cycles or project-based) and access is often report - level rather than harmonized/FAIR datasets. **Connectivity / Free River Flow** is 3.03. CHG Connectivity Mapping and REDMAR deliver strong physical continuity metrics, but biological linkage (e.g., migration success, passage efficiency) is weak in routine monitoring, tempering readiness despite good structural coverage **(Table 13)**.

The Guadalquivir monitoring system exhibits solid spatial and temporal representativeness (both 3.4), reflecting strong coverage across the river–estuary–coast continuum and multi-cycle time series under WFD/MSFD. Policy relevance scores highest (4.1), showing that the backbone of the network is regulation-driven and designed to report status and trends.

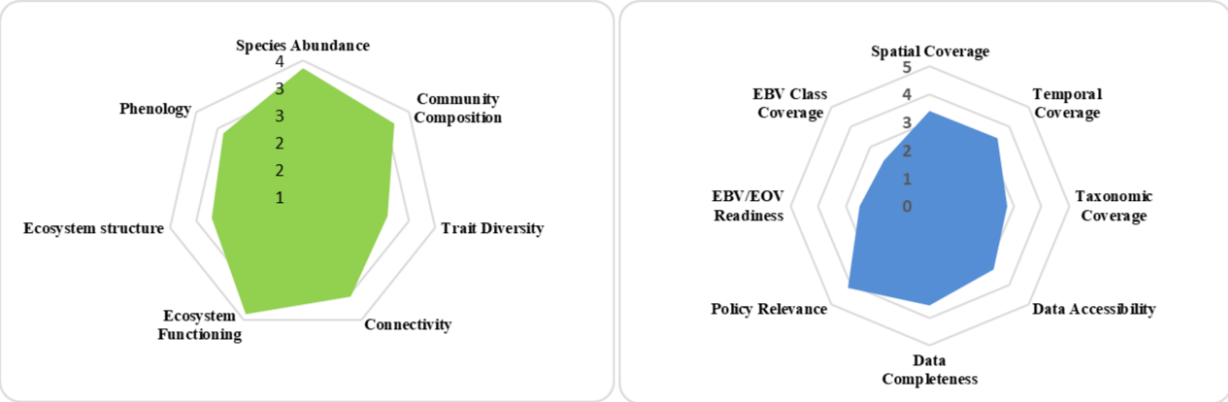


Fig. 25. Radar plots of EBVs showing the readiness scores of EBVs (left) and readiness scores based on criteria assessment of Guadalquivir – Atlantic Ocean monitoring datasets (right).

However, Taxonomic Coverage is only moderate (2.8), due to a mix of rich biotic datasets (WFD, LTER, STOCA) and driver-only networks (REDMAR, meteorology, EO) which have low or no taxonomic content. Data Accessibility (3.2) remains uneven: while IDECHG, Portus, and CMEMS are open and standardized, many biological time series still require request-based access, limiting FAIR compliance.

Data Completeness is moderate - to - good (3.6): core programs are consistent, but short-term projects and port/EIA datasets introduce gaps. The derived EBV/EOV Readiness (2.5) and EBV Class Coverage (2.3) confirm a structural bias toward Species Populations and Community Composition, with Ecosystem Structure and Connectivity underrepresented in routine, open, and regularly updated forms. Functional processes (productivity, phenology) are strengthened by RTRM–CMEMS–STOCA integration, indicating high potential for GEOBON/GOOS interoperability once openness and taxonomic breadth improve **(Table 14).**

Table 13. Readiness assessment of EBV classes in the Guadalquivir – Atlantic Ocean monitoring system

EBV class	EBVs Score	Assessment Criteria	
Species abundance	**3.36**	**Pe = 0.64; Te= 0.53; Se=1; Ae=0.49; Me= 0.78**	Broad multi-domain coverage from WFD networks, LTER stations, fisheries CPUE (AGAPA), and CMEMS productivity ensures strong support for organismal abundance. Time series are generally multi-decadal (CHG rivers, reservoirs, coastal LTER, REDMAR), though not always continuous. Spatial representativeness is complete (freshwater–estuary–coast). Data access is mixed—several WFD datasets remain request-based, while maturity is high due to compliance with WFD/MSFD/Natura2000 standards.
Community compositio n	**3.15**	**Pe = 0.45; Te = 0.62;**	Supported by multiple biotic groups (phytoplankton, benthos, fish, and zooplankton) across CHG programs, STOCA, LTER sites, and Doñana coastal surveys. Taxonomic detail is strong but access

		Se = 1; Ae=0.38; Me = 0.85	constraints for WFD benthos/fish reduce usability. Spatial domain coverage is full, and long-running freshwater and estuarine series exist. Methodological standardization (WFD/MSFD) supports EBV operability.
Trait diversity	**2.59**	**Pe = 0.09; Te= 0.6; Se = 1; Ae=0.75; Me = 0.75**	Trait information is available but limited, mainly from fish size structure (AGAPA, IFAPA, CHG rivers) and benthic functional indicators (APS benthos, ICMan zooplankton spectra). Temporal depth is moderate (several multi-year projects), and spatial representativeness is good, but access is uneven and methodological maturity is only moderate due to absence of explicit trait-based monitoring.
Connectivity / Free River flow	**3.03**	**Pe = 0.09; Te= 0.7; Se = 1; Ae=1; Me = 1**	Supported mainly by CHG hydromorphological connectivity mapping, REDMAR sea-level and current data, and LTER estuarine hydrodynamics. Connectivity datasets are highly standardized, openly accessible, and available across all realms. Temporal coverage is good (6-year WFD cycles; long-term REDMAR). This EBV is methodologically mature even though biological indicators are covered only indirectly.
Ecosystem functioning	**3.4**	**Pe = 0.54; Te= 0.608; Se = 1; Ae=0.55; Me = 0.875**	Well supported by robust biogeochemical datasets including STOCA, CMEMS productivity/chl-a, RTRM, CHG eutrophication monitoring, and LTER nutrient series. Long time series and full domain coverage strengthen the indicator. Data accessibility varies (CMEMS fully open; WFD nutrient datasets partly restricted), but methodological maturity is high thanks to alignment with MSFD D5, GOOS EOVs, and WFD eutrophication protocols.
Phenology	**2.864**	**Pe = 0.136; Te= 0.67; Se = 1; Ae=0.833; Me = 0.833**	Supported by plankton cycles from LTER (monthly), STOCA (seasonal), RTRM (high-frequency proxies), CMEMS bloom-timing, and Doñana wildlife phenology. Long-running time series in coastal and marine areas compensate for more limited freshwater phenology. Accessibility is relatively high due to CMEMS and LTER metadata availability, and methodological maturity is strong for plankton phenology (WFD/MSFD/GOOS).
Ecosystem structure	**2.72**	**Pe = 0.22; Te= 0.48; Se = 1; Ae=0.74; Me = 0.8**	Primarily derived from benthic community datasets (APS benthos, WFD macroinvertebrates), hydromorphology mapping, seafloor-related STOCA variables, and habitat data from Doñana LTER. Spatial representativeness is complete, but freshwater benthos datasets are often closed, and temporal depth is variable. Still, WFD hydromorphology ensures high methodological consistency across domains.

Table 14. Datasets assessment criteria scores (for methodology details see Table 3) of Guadalquivir – Atlantic Ocean of EVs derived datasets

CRITERION	MEAN SCORE	Assessment Criteria
Spatial Coverage	**3.4**	Strong overall spatial representativeness: the monitoring network spans riverine, transitional, and coastal units. Transitional zones (e.g., Guadalquivir Estuary) are especially well covered, though marine shelf coverage is comparatively sparser.
Temporal Coverage	**3.4**	Good temporal depth: multi-decadal WFD cycles, long-term LTER series, and continuous hydrological datasets provide a solid foundation. Short-term project datasets, however, reduce continuity in some domains.
Taxonomic Coverage	**2.8**	Moderate: a mix of rich biotic datasets (WFD, LTER, STOCA) and EBVs supporting networks (REDMAR, meteorology, EO). Gaps exist for higher trophic levels (birds, mammals) and functional traits.
Data Accessibility	**3.2**	Mixed accessibility: open for physical–chemical data (IDECHG, CMEMS, Portus), but biological series remain request-based, limiting interoperability.
Data Completeness	**3.6**	Generally consistent across WFD and LTER datasets, though project-based efforts and EIA-derived datasets show irregular completeness.
Policy Relevance	**4.1**	Very high: most datasets are policy-driven, providing direct links to biological quality elements and MSFD descriptors. Serves as the core EBV evidence base.
EBV/EOV Readiness	**2.5**	Moderate: strong in population and functional EBVs, weaker for structural and connectivity dimensions. Reflects early integration potential but incomplete maturity.
EBV Class Coverage	**2.3**	Partial coverage: datasets typically address one or two EBV classes, with few cross-domain (multi-EBV) observatories such as ICMAN LTER and CHG WFD.

The Guadalquivir monitoring system demonstrates a robust policy-anchored foundation for biodiversity observation, with strong spatial and temporal representativeness and long-established regulatory alignment. Datasets collectively cover the entire river - transitional - marine gradient. However, biological detail and openness remain uneven, particularly for taxonomic and structural EBVs. Overall **readiness** is moderate to high, dominated by species population and functional EBVs, while ecosystem structure and connectivity are underdeveloped as operational indicators.

Within the PCA space, PC1 and PC2 explain 74.2% of variance (**Fig. 26**). PC1 (46.5% of variance) contrasts the CHG/ICMAN LTER, STOCA, Doñana Monitoring and WFD biological centered on Species Populations and Community Composition against physical (functional) driver datasets (REDMAR, Puertos, RTRM) (negative loadings). PC2 differentiates datasets with higher contributions to species traits, such as phenology and behavioral indicators (EBD Doñana, LIFE projects), from those dominated by community-level. Overall, the PCA indicates a dominance of Guadalquivir’s monitoring biased to population abundance and composition data collection, while functional and structural EBVs datasets divergence suggests partial integration across monitoring domains.

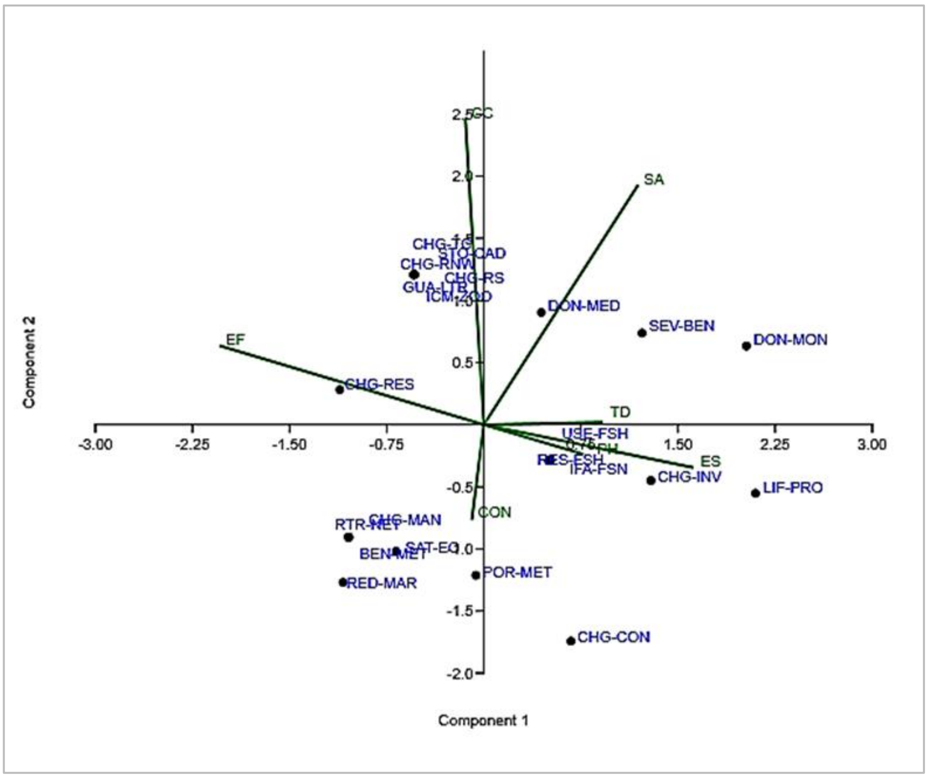


Fig. 26. PCA of Guadalquivir monitoring datasets by EBV alignment

The heatmaps **(Fig.27)** show a fragmented nature of biodiversity monitoring in the Guadalquivir system. No dataset scores strongly across all EBV dimensions, instead, each dataset contributes to two to four EBV types. This confirms that EBV development is domain-specific rather than integrated. Spatially and thematically, datasets complement rather than overlap, implying that future EBV operationalization should focus on linking the data (population monitoring, metabolism, hydro connectivity) into a coherent multi-EBV observatory framework.

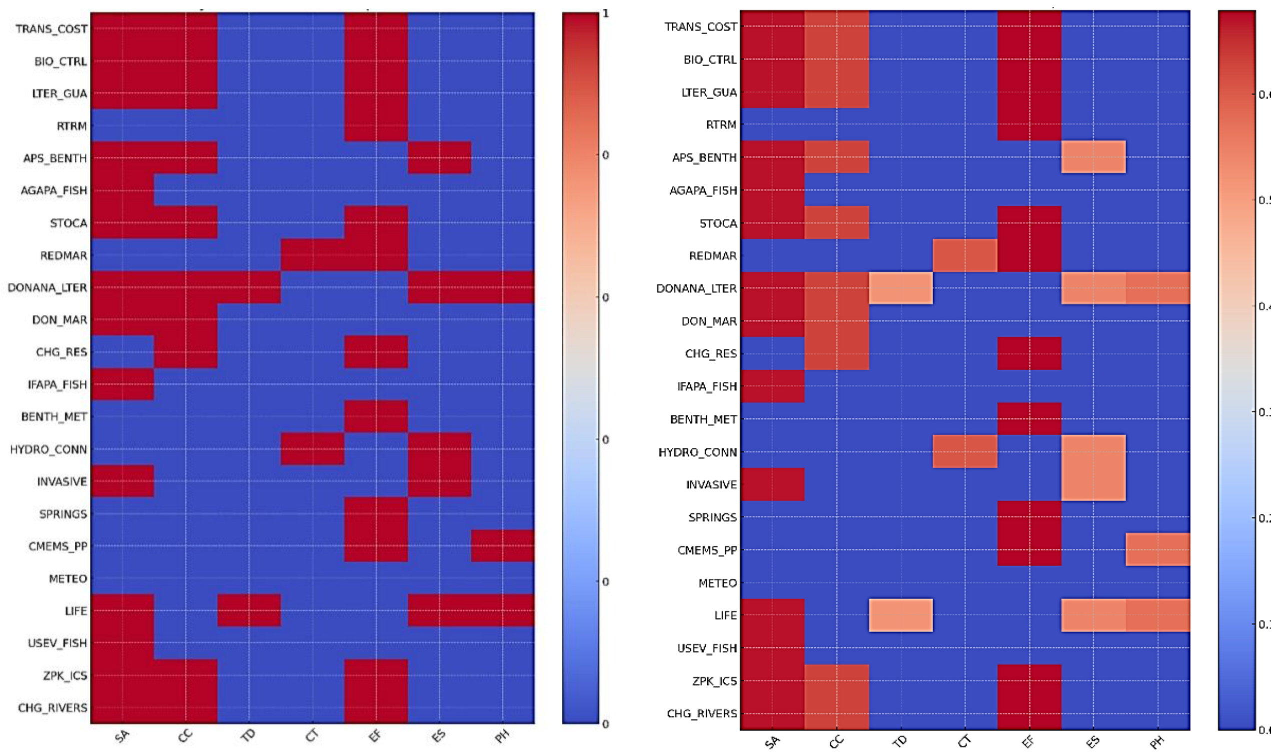


Fig. 27. Datasets coverage heatmap in the Guadalquivir – Atlantic Ocean. Left: Contribution of individual monitoring datasets to EBV classes. With red are represented datasets that can be directly used to generate EBVs (SP - Species population/abundance; CC - Community composition; TD – Trait diversity; CT – Connectivity; EF – Ecosystem functioning; ES – Ecosystem Structure; PH – Phenology), while blue color reflects limited relevance or missing information. Right: Datasets readiness map (each dataset has been scored by averaging spatial, temporal, taxonomic, accessibility, and completeness scores across datasets) (datasets abbreviation – Annex)

5.4.3. Data accessibility

Across the 22 datasets provided by the Guadalquivir monitoring programs or projects, half of them are only partially open, reflecting request-based access for biological time series (WFD/LTER), while just over one-third are fully open, mainly EO sources (Portus/REDMAR, meteorology, CMEMS), many CHG and Puertos del Estado layers being discoverable through IDECHG and Portus platforms, but raw biological datasets often remain request - based or partially restricted. Restricted datasets are few but important (port EIA macrofauna, some LTER data) (**Fig. 28**). This openness profile is consistent with a policy-oriented system that prioritizes compliance reporting but still requires FAIR data modernization for seamless EBV/EOV integration.

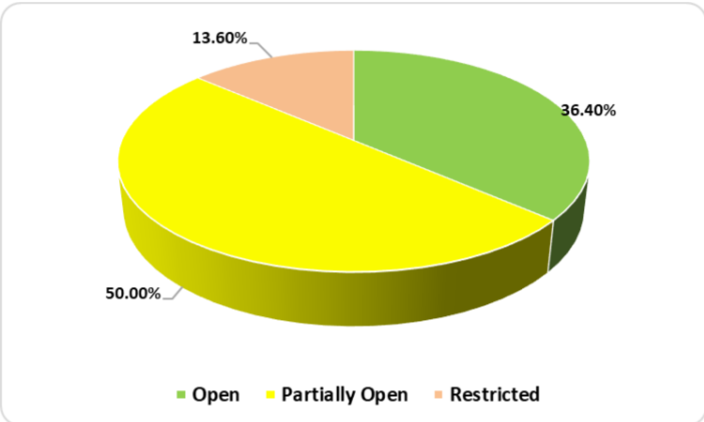


Fig. 28. Data accessibility shares in Guadalquivir - Atlantic Ocean case study

This structural bias mirrors a broader challenge across European monitoring systems: while policy frameworks ensure consistency in **species- and community-based metrics**, they underrepresent **process-oriented observations** needed to align with **GEO BON** and **GOOS** global standards. Nevertheless, the presence of long-term environmental and functional datasets (e.g., RTRM, CMEMS, ICMAN LTER) provides a foundation for progressive integration. These programs could serve as **bridging mechanisms** between regulatory data streams and the production of standardized EBVs/EOVs for international reporting, such as SDG 14.2, CBD post-2020 targets, and IPBES Essential Indicators.

Table 15. Datasets and monitoring methodologies readiness for EBV/EOVs translation in Guadalquivir – Atlantic Ocean study case

Datasets	Monitoring methodology	Why it matters for EBVs/EOVs
CHG WFD Riverine & Transitional Monitoring	Fixed network of surveillance and operational stations (~10–20 km spacing); biological (fish, benthos, phytoplankton) and physico-chemical sampling at seasonal–annual frequency using standardized EU WFD protocols.	Ensures statistically robust, long-term trend detection across gradients; directly supports *species populations*, *community composition* and *ecosystem structure* EBVs.
ICMAN–IFAPA LTER (Guadalquivir Estuary)	5 fixed stations along salinity gradient (0–35 PSU); monthly sampling of plankton, fish and crustaceans with CTD/nutrient profiles since 1997.	Long-term temporal consistency ideal for *community composition* and *ecosystem functioning* EBVs; represents a globally comparable estuarine LTER approach.
RTRM (Real-Time Monitoring Network)	High-frequency multiparameter sensors (10–30 min) at 4 fixed nodes + Salmedina buoy; measures DO, turbidity, salinity, fluorescence.	Captures fine-scale environmental drivers of *ecosystem function* and *connectivity* EOVs (turbidity–oxygen coupling); complements discrete biotic sampling.
Port of Seville Macrofauna Monitoring	Seasonal benthic sampling at 6 fixed port stations using van Veen grab; full taxonomic identification and sediment characterization.	Strong for *benthic community composition* EBVs in disturbed zones; methodologically sound but spatially narrow.
AGAPA Fisheries Reserve (Desembocadura)	Standardized artisanal/recreational fish sampling and CPUE-based surveys across four estuarine–coastal management zones; annual/seasonal.	Provides *species population* and *ecosystem function* EBVs; crucial for MSFD D1/D3 fish indicators.
IEO–CSIC STOCA (Gulf of Cádiz)	Fixed radial transect (GD) from estuary to shelf; quarterly sampling for CTD, nutrients, plankton, chl-a; consistent gear and protocols.	Delivers multi-decadal planktonic and hydrographic data for *ecosystem function* and *community composition* EBVs.
REDMAR (Puertos del Estado)	Continuous tide-gauge and sea-level records (Bonanza, Sevilla); 1-min temporal resolution.	Key for *connectivity* and *hydrographic EOVs* underpinning salinity and flow dynamics influencing biodiversity.
Doñana Monitoring Program (EBD–CSIC)	Multi-taxa (birds, amphibians, mammals, reptiles) census networks; monthly–annual frequency; >30 years; georeferenced transects and fixed plots.	Provides long-term *species population*, *phenology (traits)* and *ecosystem structure* data; key for habitat-level EBVs.
Benthic Metabolism & Fluxes (UCA/ICMAN)	Benthic chamber incubations and nutrient flux assays; seasonal 2018–2020; two fixed hyperturbid estuary sites.	Quantifies *ecosystem function* EBVs (production–respiration balance); methodologically strong but spatially limited.

CHG Hydromorphological Connectivity Mapping	Basin-wide GIS segmentation; barrier inventory, longitudinal continuity indices, updated each WFD cycle (6 years).	Provides *ecosystem structure* and *connectivity* EBVs critical for river network integrity.
CHG "Especies Invasoras" Layer	GIS-based layer of invasive taxa occurrences, updated via field surveys and administrative records; variable frequency.	Direct input for *species populations* and *ecosystem structure* EBVs; supports EU IAS reporting.
Reservoir Monitoring (CHG Eutrophication Program)	Monthly–quarterly sampling of phytoplankton, nutrients, and chl-a in reservoirs and lakes; standardized WFD protocols.	Detects *harmful algal blooms* and *primary productivity* EBVs; links to EOV nutrient cycles.
CMEMS/NASA EO Primary Productivity	Satellite-derived NPP, SST, and chl-a at 250 m–1 km, daily–weekly resolution.	Supports *ecosystem functioning* EBVs and *EOV productivity* across coastal–plume zones.
LIFE Projects (Conhabit, Migratoebre, etc.)	Project-based monitoring of target taxa and habitats; 2- 4-year cycles; variable spatial design.	Supports *species population* and *connectivity* EBVs; supplements gaps in policy networks.

The Guadalquivir system is among the few European estuaries with long and diverse time-series data to support operational EBV and EOV derivation. However, improved coordination across institutional networks, better data accessibility, and systematic inclusion of functional and trait-based metrics are essential next steps toward full EBV readiness and integration into global biodiversity observation frameworks **(Fig. 29).**

The Guadalquivir River–Estuary–Shelf system is characterized by a fragmented but complementary monitoring landscape. At the national level, the Confederación Hidrográfica del Guadalquivir (CHG) coordinates WFD surveillance networks covering freshwater, transitional, and coastal domainFs, while specialized institutions such as ICMAN-CSIC, IFAPA, and the IEO- CSIC operate long-term ecological and oceanographic programs focused on estuarine and marine biodiversity. Additional inputs arise from the Doñana LTER and Puertos del Estado's REDMAR/PORTUS stations, providing crucial hydrodynamic and connectivity information. While the monitoring scheme demonstrates a mature institutional backbone, several limitations remain. Data accessibility is only partially open for many biological datasets (e.g., LTER, WFD biota), constraining reuse and EBV upscaling. Methodological heterogeneity between freshwater and marine domains further hinders full interoperability. Nevertheless, the combination of long-term CHG, ICMAN, and IEO programs provides a solid foundation for EBV/EOV derivation, positioning the Guadalquivir system as a strong pilot site for integrated biodiversity–ecosystem observation in Europe.

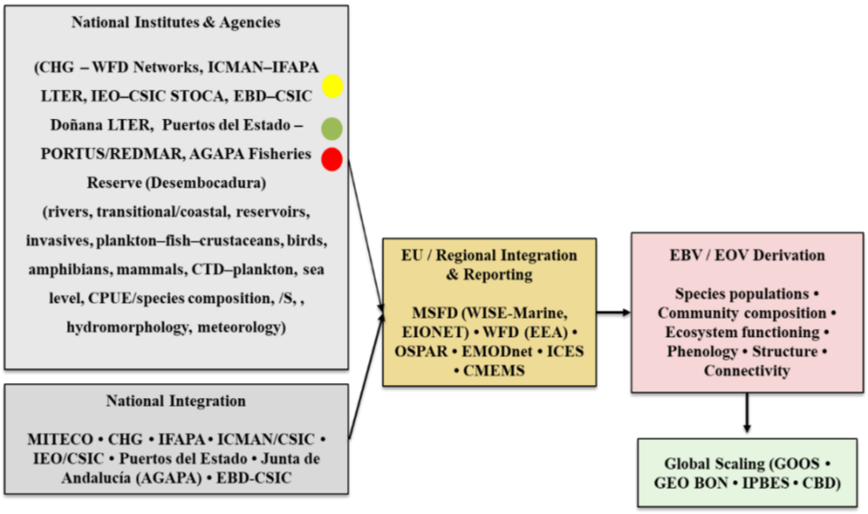


Fig. 29. Scheme of monitoring flow in the Guadalquivir - Atlantic Ocean case study

5.4.4. Conclusions

Overall, the Guadalquivir - Atlantic Ocean case study demonstrates a high institutional and methodological readiness for integration into global biodiversity and ecosystem observation frameworks. Decades of coordinated monitoring, rooted in the WFD and extended through LTER, and oceanographic programs, ensure strong ecological coverage across the river - estuary - coastal continuum.

However, operational readiness remains uneven: biological datasets are often fragmented or partially accessible, and integration across domains still relies on project-based rather than systemic data flows. Strengthening data interoperability, ensuring FAIR-compliant publication, and linking biological with physical and biogeochemical indicators will be decisive for the basin's full EBV/EOV maturity.

In essence, the Guadalquivir stands out as a technically advanced but administratively constrained observatory, with substantial potential to evolve into a regional benchmark for integrated biodiversity–ecosystem monitoring under the GEO BON and GOOS frameworks.

5. GENERAL REMARKS & CONCLUSIONS

Across the Elbe–North Sea, Po–Adriatic, Danube–Black Sea, and Guadalquivir–Atlantic systems, a common pattern emerges: the raw biodiversity information is abundant, but its transformation into harmonized Essential Variables (EBVs & EOVs) remains uneven and largely dependent on how accessible, standardized, and interoperable the monitoring systems are. All sites hold long-standing monitoring programs driven by policy mandates (WFD, MSFD, Natura 2000), which ensures continuity and coverage. Yet, their readiness to generate operational EBVs varies substantially because the monitoring traditions differ between freshwater, estuarine, and marine domains.

Marine components are consistently the most EBV-ready. This is not surprising: marine monitoring initiatives such as ICES, CMEMS, Copernicus Marine Service, and EMODnet have long provided standardized, open-access, multi-decadal time series. These align closely with the GEO BON principles of global comparability, temporal consistency, and methodological transparency. In all four case studies, this results in strong EBVs for species abundance, community composition, ecosystem functioning, and phenology, all of which match the recommended EBV classes outlined in BON-in-a-Box (Griffith et al., 2024).

By contrast, freshwater and transitional (estuarine) systems represent the main bottleneck for EBV interoperability. Although they meet policy-driven requirements (particularly through WFD), they generally lack: long-term biological time series, open-access data delivery, cross-taxon trait information, consistent hydromorphological and connectivity datasets that link pressure to biological response.

This is particularly evident in the Danube–Black Sea and to a certain extent in Po–Adriatic systems, where access restrictions and heterogeneous national–regional monitoring systems impede the development of continuous EBVs. As GEO BON emphasizes, “data availability ≠ EBV readiness”: even abundant data cannot generate EBVs without interoperability, standard formats, and transparent metadata. The Guadalquivir-Atlantic and Elbe systems stands out due to intense monitoring efforts put in transitional systems. Here, estuarine wetlands, hydrological connectivity, and species groups (fish, plankton, benthos, waterbirds) are monitored systematically across the salinity gradient. This density and continuity of monitoring elevate EBVs like connectivity and ecosystem structure, which perform poorly elsewhere. Guadalquivir illustrates a key lesson from GEO BON’s Strategic Plan: EBV production improves rapidly when freshwater, wetland, and coastal data are collected in coordinated frameworks rather than isolated programs.

The Elbe–North Sea system is exceptional with >50 years of plankton and biogeochemical monitoring (e.g., Helgoland Roads). This type of time series matches GEO BON’s criteria for “long-term sustained observing systems” and provides robust inputs for phenology and ecosystem functioning EBVs. The other systems, especially Po and parts of the Danube, depend more on project-driven or regional datasets with fragmented temporal coverage, undermining their potential for trend-based EBVs.

A cross-cutting topic is that trait diversity remains the weakest EBV class across all systems. Functional trait datasets are either taxonomically limited (mostly fish or benthos) or too short-term for system-level EBVs. This mirrors GEO BON's global assessment (GEO BON, 2024) that "trait-based EBVs require integration rather than new monitoring programs": traits exist in scattered research datasets, but not yet in standard monitoring workflows.

Finally, Earth Observation (EO) plays a transformative role across all case studies. CMEMS, Sentinel-2, and satellite-derived productivity or bloom indices provide consistent, high-resolution, open data that elevate the readiness of ecosystem functioning and phenology EBVs, especially in marine and coastal components. GEO BON explicitly highlights EO as a backbone for scalable EBVs, and the four systems confirm this through improved scores for functioning and phenology wherever EO is used (Scholes et al., 2017).

Overall, the synthesis across the four systems reinforces GEO BON's central message: the pathway to operational EBVs lies not in expanding monitoring but in improving interoperability, accessibility, and cross-realm integration. All four systems hold rich, policy-driven datasets, but only those with strong data sharing, standardized protocols, and multi-realm coordination achieve high EBV readiness. To conclude, the key highlights and messages to convey from the current study are:

- Most marine datasets are consistently EBV-ready, with long-term, standardized, and open-access time series (ICES, CMEMS), fully aligned with GEO BON's standards. Data systems are generally more mature and standardized.
- Freshwater and estuarine components remain the limiting factor, particularly for connectivity, hydromorphology, and habitat structure, currently a globally recognized challenge as also identified by GEO BON.
- Data accessibility, not data quantity, is the primary barrier: many biological datasets remain restricted, preventing their transformation into EBVs.
- Temporal consistency sharply differentiates regions: Elbe leads; Po and Danube remain highly fragmented; Guadalquivir benefits from WFD continuity.

- Earth Observation substantially enhances EBV readiness, especially for ecosystem functioning and phenology.

Full EBV/EOV readiness requires integration, not additional monitoring.

The data exists — barriers are mostly:

- access,
- harmonization,
- taxonomic standardization (e.g., WoRMS matching),
- Connecting freshwater and marine datasets.

Shift from "collecting more data" to "connecting existing data". EBV readiness will improve most by **interoperability**, not by expanding sampling networks.

CALL TO ACTION FOR POLICY – MAKERS AND DATA OPERATORS

Upscaling of Monitoring Data to EBVs and EOVs

To achieve EBV and EOV readiness, monitoring systems must shift from producing isolated datasets to delivering **interoperable, EBV-ready data products**. This requires a common data logic rather than uniform sampling methods.

Concretely, monitoring outputs:

- **MUST** be described using shared taxonomic identifiers, controlled vocabularies for sampling and traits, harmonized spatial references, and transparent metadata. EBVs should be generated as **derived indicators**, such as population trends, phenology metrics, or connectivity indices, supported by documented and repeatable workflows. Without this EBV derivation layer, abundant raw data cannot be transformed into comparable biodiversity variables.
- Publicly funded biodiversity data **MUST** be openly available under **FAIR principles**, with machine-readable metadata, persistent identifiers, and clear licenses. EBV and EOV production depends on automated data access; datasets locked in reports, spreadsheets, or restricted portals cannot be scaled regionally or globally.
- Upscaling to EBVs and EOVs **MUST** benefit from a shared spatial referencing frameworks that link river reaches, transitional and marine waters, as well as systematic coupling of biological observations with environmental drivers such as nutrients, oxygen, temperature, flow, and circulation.
- Earth Observation (EO) (Satellite-derived products) **MUST** be treated as a core component of EBV and EOV workflows, including its use for event detection and targeted biological response monitoring.

- Upscaling monitoring data to EBVs and EOVs **MUST** benefit from a dedicated expertise in data stewardship, integration, and indicator derivation. These functions should be recognized and funded as long-term infrastructure rather than short-term project outputs. Institutional capacity is a decisive but often underestimated factor.

Upscaling monitoring data to EBVs and EOVs is fundamentally a systems and governance challenge.

SELECTED BIBLIOGRAPHY

GEO BON (Group on Earth Observations Biodiversity Observation Network). (2024). GEO BON Implementation Plan 2024–2030. GEO BON Secretariat, Leipzig, Germany.

Kissling, W. D., Ahumada, J. A., Bowser, A., Fernandez, M., Fernández, N., Gray, C. M., … Pereira, H. M. (2018). Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. Biological Reviews, 93(1), 600–625. https://doi.org/10.1111/brv.12359

Kissling, W. D., De Bruin, S., Hardisty, A., García Roselló, E., Sal, S., & Cavalcante, T. (2023). From data to Essential Biodiversity Variables: progress, challenges, and future directions. Ecological Informatics, 76, 102152. https://doi.org/10.1016/j.ecoinf.2023.102152

Pereira, H. M., Ferrier, S., Walters, M., Geller, G., Jongman, R. H. G., Scholes, R. J., … Wegmann, M. (2013). Essential Biodiversity Variables. Science, 339(6117), 277–278. https://doi.org/10.1126/science.1229931

Burson, A., Stomp, M., Greenwell, E., Grosse, J. & Huisman, J. (2016). Competition for nutrients and phytoplankton dynamics in the German Bight. Biogeochemistry, 131, pp. 119–132. https://doi.org/10.1007/s10533-016-0270-6

Bundesamt für Naturschutz (BfN) (2020). Natura 2000 in Germany – Protected Areas Information Portal. German Federal Agency for Nature Conservation. Available at: https://www.bfn.de (Accessed: 10.10.2025).

Capuzzo, E., Lynam, C.P., Barry, J., Stephens, D., Forster, R.M., Greenwood, N., McQuatters - Gollop, A., Silva, T., van Leeuwen, S.M.& Engelhard, G.H. (2018). A decline in North Sea phytoplankton chlorophyll since 1998 drives primary production trends. Marine Ecology Progress Series, 604, pp. 61–76. https://doi.org/10.3354/meps12776

Hein, T., Funk, A., Zsuffa, I., Cocco, E., Bloesch, J., Baumgartner, C. & Reckendorfer, W. (2016). Riverine floodplains: ecological gradients and restoration challenges. River Research and Applications, 32(7), pp. 1408–1422. https://doi.org/10.1002/rra.3010

IKSE (International Commission for the Protection of the Elbe River) (2022). Management Plan for the River Basin District Elbe 2022–2027. Magdeburg: IKSE. Available at: https://www.ikse-mkol.org (Accessed: 30.10.2025).

Kratzer, S., Brockmann, C., Sorensen, K., & Mueller, D. (2020). Water quality trends and eutrophication dynamics in the Elbe estuary and German Bight. Journal of Hydrology, 587, 124–148. https://doi.org/10.1016/j.jhydrol.2020.124948

Krause-Jensen, D., Marbà, N., Sanz-Lázaro, C., Mascaró, O., Serafini, T., Berry, A., Staehr, P.A. & Duarte, C.M. (2021). Seagrass restoration across Europe: current status and future prospects. Frontiers in Marine Science, 8, 667–697. https://doi.org/10.3389/fmars.2021.667697

Reusch, T.B.H., Dierking, J., Andersson, H.C., Bonsdorff, E., Carstensen, J., Casini, M., Gårdmark, A., Järvinen, M., Klais, R., Niiranen, S., Ojaveer, H., Uusitalo, L., & Zandersen, M. (2018). The Baltic Sea as a time machine for the future coastal ocean. Science Advances, 4(5), eaar8195. https://doi.org/10.1126/sciadv.aar8195

Stapf, J., Schrottke, K., Bartholomä, A., & Flemming, B. (2023). Hydromorphodynamics of the Elbe Estuary: tidal processes and sediment transport under climate and anthropogenic pressure. Estuarine, Coastal and Shelf Science, 283, 108–125. https://doi.org/10.1016/j.ecss.2023.108125

Stelzenmüller, V., Schulze, T., Gimpel, A., Bartelings, H., Doring, F., Gutow, L., Kloppmann, M., Probst, W.N. & Rogers, L.A. (2021). Biodiversity status and Natura 2000 assessments in German marine waters: status, trends and data needs. ICES Journal of Marine Science, 78(8), pp. 2836–2851. https://doi.org/10.1093/icesjms/fsab157

Balzarolo, M., Ferré, A., Cecchi, G., & Ferrari, C. (2010). Vegetation dynamics and habitat change in coastal wetlands of the Po Delta from 1980 to 2006 using satellite remote sensing. Journal of Coastal Conservation, 14, pp. 173–182. https://doi.org/10.1007/s11852-009-0087-y

CMEMS – Copernicus Marine Environment Monitoring Service (2023). Mediterranean Sea biogeochemical reanalysis and monitoring products. Available at: https://marine.copernicus.eu (Accessed: 11.10.2025).

Natura 2000 Network – Po Delta (European Environment Agency / European Commission) (2024). Protected Sites (Ramsar, Natura 2000) – Po Delta Site Management Plan. Available at: https://natura2000.eea.europa.eu (Accessed: 12.10.2025).

Nogherotto, R., Turco, M., Cassiani, M., Zardi, D., & Benetti, G. (2022). Hydrological and climatic drivers shaping the Po River basin: past trends and future projections. Science of the Total Environment, 806, 150–161. https://doi.org/10.1016/j.scitotenv.2021.150161

RAC/SPA – Regional Activity Centre for Specially Protected Areas (2010). Ecosystems and biodiversity of the Adriatic Sea: pressures, trends, and conservation priorities. UNEP/MAP report. Tunis: United Nations Environment Programme.

RAMSAR (2023). Po Delta Ramsar Site Information Sheet (IT044). Ramsar Convention Secretariat. A BSC – Black Sea Commission. (2008). State of the Environment of the Black Sea (2001–2006). Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC) 2008-3. Istanbul, Türkiye.

Giosan, L., Coolen, M. J. L., Kaplan, J. O., Constantinescu, S., Filip, F., Filipova-Marinova, M., et al. (2012). Early anthropogenic transformation of the Danube–Black Sea system. Scientific Reports, 2, 582. https://doi.org/10.1038/srep00582

ICPDR – International Commission for the Protection of the Danube River. (2015). Danube River Basin Management Plan Update 2015: Part A – Basin-wide overview. Vienna, Austria. https://www.icpdr.org

ICPDR – International Commission for the Protection of the Danube River. (2021). Joint Danube Survey 4 – Final Scientific Report. Vienna, Austria. https://www.icpdr.org

Mee, L. (1992). The Black Sea in crisis: A need for concerted international action. Ambio, 21(4), 278–286.

Mee, L., & Topping, G. (1999). The Black Sea: New challenges for the rehabilitation of an international sea. Ocean & Coastal Management, 42(2–4), 119–136. https://doi.org/10.1016/S0964-5691(99)00029-8

Panin, N., & Jipa, D. (2002). Danube River sediment input and its interaction with the northwestern Black Sea. Estuarine, Coastal and Shelf Science, 54(3), 551–562. https://doi.org/10.1006/ecss.2000.0665

Ramsar Convention Secretariat. (2023). Danube Delta (Romania) Ramsar Site Information Sheet. Ramsar Site No. 521. https://rsis.ramsar.org

UNESCO. (2023). Danube Delta Biosphere Reserve – World Heritage List. United Nations Educational, Scientific and Cultural Organization. https://whc.unesco.org/en/list/588

Zaitsev, Y., & Mamaev, V. (1997). Marine biological diversity in the Black Sea: A study of change and decline. United Nations Publications.vailable at: https://rsis.ramsar.org (Accessed: 28.10.2025).

CHG – Confederación Hidrográfica del Guadalquivir. (2022). Plan Hidrológico de la Demarcación Hidrográfica del Guadalquivir 2022–2027. Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO). https://www.chguadalquivir.es

Martín, B., Ramírez, J. A., & Rendón, M. A. (2021). Long-term trends and drivers of waterbird populations in Doñana wetlands. Ecological Indicators, 124, 107426. https://doi.org/10.1016/j.ecolind.2021.107426

Montes, C., Bravo, M., Moreira, J. M., & Ruiz, J. (1998). Restoration of the Doñana wetlands: A case study. Ministerio de Medio Ambiente, Madrid.

Navarro, G., & Ruiz, J. (2013). Hysteresis and resilience in plankton dynamics of a coastal ecosystem (Gulf of Cádiz). Marine Ecology Progress Series, 475, 15–30. https://doi.org/10.3354/meps10098

Ramsar Convention Secretariat. (2023). Doñana (Spain) Ramsar Site Information Sheet. Ramsar Sites Information Service. https://rsis.ramsar.org

Ruiz, J., García-Lafuente, J., Navarro, G., & Vélez-Belchí, P. (2015). Nutrient dynamics and primary production associated with the Guadalquivir River plume in the Gulf of Cádiz. Continental Shelf Research, 101, 34–47. https://doi.org/10.1016/j.csr.2015.04.010

Sánchez, M. I., Trobajo, R., & García, M. (2020). Ecological status and hydrology of the Guadalquivir estuary: Drivers and management challenges. Science of the Total Environment, 706, 135722. https://doi.org/10.1016/j.scitotenv.2019.135722

Annex

List of datasets abbreviations in study cases

Abbrev	Dataset / Programme Elbe – North Sea Case Study
HELGROADS	Helgoland Roads Plankton Time Series
ICES_PHYTO	ICES Phytoplankton Dataset
ICES_ZOO	ICES Zooplankton Dataset
ICES_BENTH	ICES Zoobenthos Dataset
ICES_FISH	ICES DATRAS Fish Survey
TMAP_BIRDS	Trilateral Monitoring and Assessment Programme – Birds
MUDAB_W	MUDAB Water Quality Dataset
MUDAB_BENTH	MUDAB Benthos Dataset
ELBE_WFD	Elbe WFD Freshwater Monitoring
ELBE_HYDRO	GLD Hydrology & Hydromorphology
SEDIMENT_ELBE	Elbe Sediment and Contaminants Monitoring
ELBE_FISH	WFD Fish / Riverine Fish Dataset
CMEMS_BGC_NS	CMEMS North Sea Biogeochemistry Reanalysis
CMEMS_PHY_NS	CMEMS North Sea Physical Reanalysis
BIRDS_ELBE	Elbe Coastal Birds Monitoring

Abbrev	Dataset / Programme Po – Adriatic Case Study
NADR_ZEN	Northern Adriatic Long-Term Ecological Dataset (Zenodo 1965–2015)
C1_LTER	Gulf of Trieste C1 LTER Phytoplankton Time Series
ER_TRANS	Emilia–Romagna Transitional Waters Monitoring
MEDITS	Mediterranean International Bottom Trawl Survey
UVC_MED	Mediterranean Underwater Visual Census (7-country dataset)
MEDIAS	Mediterranean Acoustic Survey for Pelagic Fish
CMEMS_MEDBGC	Copernicus MEDSEA Biogeochemistry Reanalysis

Abbrev	Dataset / Programme Po – Adriatic Case Study
HAB_ER	Emilia–Romagna HAB Monitoring
DCF_FISH	DCF Fisheries Biomass / Stock Assessment Data
PO_WFD_FISH	Po River Basin WFD Fish Monitoring
PO_LONG_FISH	Long-term Freshwater Fish Dataset (1988–2019)
ER_RIVERS_FISH	Emilia–Romagna River Fish Dataset
PO_MACROINV	Po Basin Macroinvertebrates Dataset
PO_DIATOMS	Po Basin Phytobenthos / Diatoms Dataset
PO_BENTHOS	Po Basin Benthic Invertebrate Indices
IT_WFD_FISH	Italian National WFD Fish Aggregated Dataset
PO_HYDROMORPH	Po Basin Hydromorphological Connectivity Mapping
IT_HYDROMORPH	Italian National Hydromorphology Indicators
PO_HAB_FN	Po Basin Harmful Algal Bloom / Cyanobacteria Monitoring

Abbrev	Dataset / Programme Name Black Sea – Danube Case Study
NIM_FPK	NIMRD Fitzpatrick Plankton & Fish Dataset
EMOD_CHEM	EMODnet Chemistry – Black Sea
SDN_EO4	SeaDataNet / EO4SIBS MSFD Dataset
ZPK_BENTH	Zooplankton & Benthos Survey
BT_TRWL	Bottom Trawl Survey – Black Sea
BS4F_GFCM	BS4F / GFCM Regional Stocks
ASCEN_CET	ASI / CeNoBS Cetacean Survey 2001
BIRDS_BS	Black Sea Birds Monitoring
COP_BS_CHL	Copernicus Marine Black Sea – Chlorophyll
ROM_ZPK	Romanian Black Sea Zooplankton Dataset
DM_ZPK79	Danube Mouths Zooplankton 1979
GEM_ZPK	GeoEcoMar Zooplankton
MZB_5468	Macrozoobenthos 1954–1968
MZB_0311	Macrozoobenthos 2003–2011
MZB_TRAIT	Macrozoobenthos Traits Dataset
BYC_CET	Cetacean Bycatch Dataset
EMBL_CET	EMBLAS Cetacean Survey
MNEM_INV	*Mnemiopsis leidyi* Invasion Database
COP_CHL	Copernicus Black Sea – Chlorophyll
HUM_TRAWL	EMODnet Human Activities – Bottom Trawling Distribution
RIV_FISH	River Fish Monitoring (Danube Basin)
DDB_DB	Danube Delta Biodiversity Database

Abbrev	Dataset / Programme Name Black Sea – Danube Case Study
JDS	Joint Danube Surveys
DAN_ALIEN	Danube Basin Alien Species Inventory
GEOECO_WQ	GeoEcoMar Delta Water Quality
CEATAL_DISCH	Danube Discharge at Ceatal Izmail
S2_INUND	Sentinel-2 Inundation Maps

Abbrev	Dataset / Programme Name Guadalquivir – Atlantic Case Study
TRANS_COST	Red de Control de Aguas de Transición y Costeras
BIO_CTRL	CHG Biological Control Programme
LTER_GUA	Guadalquivir LTER (Plankton–Fish–Nutrients)
RTRM	Real-Time Monitoring Network of the Guadalquivir Estuary
APS_BENTH	Puerto de Sevilla Benthic Monitoring
AGAPA_FISH	Fish Reserve of the Guadalquivir Mouth
STOCA	IEO STOCA – Gulf of Cádiz Monitoring
REDMAR	Puertos del Estado REDMAR Network
DONANA_LTER	Doñana Biological Reserve Monitoring
DON_MAR	Doñana Marine Edge LTER
CHG_RES	CHG Reservoir Phytoplankton & Water Quality
IFAPA_FISH	IFAPA Fish Sampling Network
BENTH_MET	Benthic Metabolism Study (ICMAN/UCA)
HYDRO_CONN	CHG Hydromorphological Connectivity Mapping
INVASIVE	CHG Invasive Species Inventory
SPRINGS	CHG Groundwater & Springs Monitoring
CMEMS_PP	CMEMS Primary Productivity (Mediterranean/Atlantic)
METEO	Puertos del Estado Meteorological Stations
LIFE	LIFE Projects (Conhabit, Migratoebre etc.)
USEV_FISH	University of Sevilla Fish Dataset
ZPK_ICS	ICMAN Zooplankton Community Dataset
CHG_RIVERS	CHG WFD Riverine Surveillance Network

MARCO-BOLO

STRENGTHENING BIODIVERSITY OBSERVATION IN SUPPORT OF DECISION MAKING

Project Coordinator
Nicolas Pade | nicolas.pade@embrc.eu

Project Manager
Giulia Vecchi | giulia.vecchi@embrc.eu

Press and Communications
Mathilde Vidal | mathilde@erinn.eu

Website: MarcoBolo-Project.eu
Twitter: @MARCOBOLO_EU
LinkedIn: MARCO-BOLO
BlueSky: @marco-bolo.bsky.social

Funded by the European Union

UK Research and Innovation