MARCO-BOLO

STRENGTHENING BIODIVERSITY OBSERVATION IN SUPPORT OF DECISION MAKING

Deliverable 3.1

Assessment and analysis of current marine, coastal, freshwater and terrestrial biodiversity observation variables, methods/protocols and tools

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Executive Summary

The primary aim of this deliverable is to gather comprehensive information on the key methodologies and protocols used for biodiversity monitoring across Europe. The key steps of the deliverable are:

1. Outline the process for systematically gathering and analyzing information from various resources to ensure comprehensive information retrieval.
2. Provide an overview of the collected information, including biodiversity monitoring variables, methods, protocols, and tools across different countries and ecosystems.
3. Identify commonalities and gaps among and use this analysis to recommend actions for aligning and harmonizing land-sea biodiversity monitoring efforts.

By leveraging the collective expertise of all partners, a comprehensive set of resources was selected, including European legislations (such as the Habitats and Birds Directives, the Water Framework Directive, and the Marine Strategy Framework Directive) as well as ESFRI Research Infrastructure and other global and international initiatives.

The study identifies macro-regions and countries that are the most frequently monitored. Abundance, species composition, and biomass are commonly observed variables. Monitoring methods are better shared within marine ecosystems under the MSFD. The diversity in method descriptions across countries and ecosystems poses challenges for direct comparisons, highlighting the need for standardised protocols. Biodiversity tools are dispersed across various sources, with genetic data analysis tools prevalent but image analysis and sampling support tools underrepresented. This dispersion makes access difficult, emphasising the need for centralised portals categorised by domains of application. Non-EU countries struggle to align with EU frameworks, resulting in incomplete information. Citizen science initiatives, while valuable for expanding monitoring coverage, often lack detailed methodological integration, reducing reliability.

This study offers a valid approach to assess the status of biodiversity monitoring methods across the land-sea continuum in Europe. The results provide valuable insights and can serve as foundational knowledge for enhancing the existing methodological framework in biodiversity monitoring. The target audience for these results includes policymakers involved in environmental monitoring and conservation, environmental agencies, and organizations engaged in biodiversity data collection and analysis. Here is a summary of recommendations for improving biodiversity monitoring in Europe, structured around **three main pillars**:

1. Information Systems and Access
    a. Information Convergence: WISE-Marine serves as a model for information convergence in MSFD monitoring across diverse regions and countries, focusing on a specific domain. Developing similar portals for other domains could be beneficial. Additionally, a centralised portal for accessing all tools for biodiversity analysis could serve as a valuable resource.

   b. Accessibility: Improving the availability and accessibility of information for stakeholders, including researchers, policymakers, and the public, is crucial for enhancing transparency and informed decision-making.
2. Standardization and Harmonization
   a. Semantic Harmonisation: Implementing standardized semantic labels (e.g., controlled vocabularies and thesauri) can help address inconsistencies in terminology for observation variables.
   b. Methods Harmonisation: Adopting widely accepted and agreed-upon methods across ecosystems, such as the Ocean Best Practices System (OBPS) for the marine realm, can improve the consistency of biodiversity observations. Additionally, developing standardized metadata to describe protocols can help integrate data from different methods.
3. Collaboration and Sharing: promoting collaboration among monitoring networks, research institutions, and governmental bodies is essential for sharing best practices, methodologies, and resources to improve biodiversity monitoring.

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1. Introduction and objectives

This deliverable reports the main achievements of the first task of Work Package 3 (WP3 - “Linking land and sea biodiversity observation”) of the MARCO-BOLO project. WP3 has the overall objective to advance the understanding of direct and indirect drivers of biodiversity loss along a land-to-sea continuum and their interrelations in freshwater, transitional, coastal and marine ecosystems across Europe Within this WP, Task 3.1 focuses on conducting a comprehensive assessment and analysis across European countries, to collect information, at the national and international levels, about the monitoring variables, the methodologies, and the digital technology tools employed to investigate biodiversity in terrestrial, continental, and marine ecosystems. This information retrieval started with an accurate selection process, carried out together with all the project partners involved in WP3, targeting existing resources of biodiversity monitoring studies and activities, including legislative frameworks, research infrastructures, international guidelines and other pertinent initiatives. The retrieval process mainly relied on the most recent web-based sources, such as the legislation reporting and dedicated web portals.

The key objectives of this deliverable are:

- Outline the process followed to ensure a systematic and comprehensive retrieval of data, by describing the procedure and approach employed for conducting the analysis and gathering of information from the various resources.
- Provide a comprehensive overview of the collected information, by reporting the outcome of the retrieval process, pertaining to biodiversity monitoring variables, methods/protocols and tools across different countries and ecosystems.
- Identify commonalities and gaps observed among the retrieved sources and across the countries and the methods. This analysis aims to highlight areas of consistency as well as areas where discrepancies or deficiencies exist, thereby offering insights into potential actions for improvement or alignment.
- Use the findings from the previous steps as the foundation for providing recommendations for the alignment and harmonisation of land-sea biodiversity monitoring efforts. These recommendations should be informed by the identified commonalities and gaps, aiming to streamline monitoring practices and enhance collaboration across geographical and methodological boundaries.

To lay the groundwork for an alignment in the monitoring effort, conducting such a analysis is a key starting point to understand the state of biodiversity monitoring methods within the European context. As data workflows, repositories from monitoring activities and research infrastructures proliferate rapidly, a gap in our understanding of the main monitoring protocols, best practices methods, and guidelines across Europe exists. This gap is further aggravated by the fragmented development of standardised monitoring protocols and harmonised monitoring designs across European institutions.

As highlighted by Liquete et al. (2023), from the H2020 EuropaBON project, biodiversity monitoring is a complex and costly effort, usually under the responsibility of various competent authorities and sectors within EU Member States (MS). Currently, the landscape of biodiversity monitoring and data aggregation in Europe is quite fragmented, comprising a multitude of schemes, programmes, agencies, and infrastructures that operate at international, national, regional or local scale, often with minimal coordination. Indeed, even though they share similar mandates or missions, few synergies are actively sought out. Furthermore, Southern and Eastern European waters are in general underrepresented in biodiversity monitoring programmes (Jessop et al., 2022).

This fragmentation results in a lack of data harmonisation among different monitoring schemes and regions, which are characterised by differences in sampling protocols, application of monitoring or analysis methods, and the absence of metadata standards and accessible results. Consequently, the capacity to develop common methods, metrics and tools (e.g., indicators, Virtual Research Environments, Essential Biodiversity Variables metrics, Standard Operating Procedures and other standardised observations) across all European ecosystems is hampered.

This situation produces several gaps and bottlenecks that directly and indirectly impacts on biodiversity monitoring data flows across Europe, especially in terms of data harmonisation, standardisation, and integration.

The data-to-information transition requires the availability of associated metadata, which involves assessing how data are collected across multiple monitoring programs and how they are made accessible and reusable. Embracing the FAIR principles (Findable, Accessible, Interoperable, Reusable) is essential to ensure scientific reproducibility, transparency and to maximise the production of information comparable among different regions and for different purposes. Indeed, an improved sampling and standardised collection of biodiversity data across the EU is an essential prerequisite for a robust and unbiased assessment of biodiversity change at both national and EU level (Liquete et al., 2023).

Furthermore, the processing of diverse data types collected by monitoring programs can be supported by technological advanced tools, such as Virtual Research Environments (VRE), software and plugins, which enable more sophisticated analysis of biodiversity variables, such as abundance, species distribution, species identification traits. Therefore, it is crucial to both implement and promote existing tools, while also developing new ones, to enhance the quality of biodiversity studies. According to this additional aspect, this deliverable also encompasses a compilation of tools for biodiversity analysis (such as VRE and software), alongside with the aggregation of sampling and analysis methodologies. This twofold approach aims to enhance the understanding of the real use of these resources and facilities for biodiversity research within the European context, spanning across monitoring initiatives, research infrastructures and legislative frameworks. Notably, the scarcity of web tools and applications designed to facilitate data harmonisation and standardisation underscores the need for a thorough investigation into the current landscape (Morán-Ordóñez et al., 2023).

The landscape of biodiversity monitoring is characterised by a diversity of national approaches, with many countries having developed their own national monitoring programmes, with defined methodologies and guidelines. In navigating this complexity, the choice of a monitoring protocol should be context-specific, considering existing schemes, coverage gaps, and resource availability. Therefore, the adaptation of existing protocols or the harmonisation of minimum standards can streamline efforts and promote compatibility (Silva del Pozo et al., 2023).

By comprehensively understanding the current state of biodiversity monitoring in Europe, including its gaps and barriers, there are opportunities to integrate and implement strategies for a more solid and resilient biodiversity monitoring system. Such a system would serve not only the scientific community, but also inform policy decision-makers and other stakeholders. Hence, the deliverable 3.1 serves as an entry point to highlight the approaches used by existing legislation and initiatives, at both national and international levels to establish biodiversity protocols. It delineates an overview of methods and tools, starting from how each operational body applies current monitoring legislation, complemented by a compilation of single national (or regional) monitoring protocols. This view highlights the possibilities and challenges involved in harmonising methods, which is becoming mandatory for efficient future policy implementation.

2. Information sources and retrieval

The assessment and analysis process was constructed through several key steps. Within the WP3 community, the first step involved identifying the sources necessary for information retrieval. Leveraging the collective expertise of all partners ensured comprehensive coverage of the available resources. The selected ones included European legislations such as the Habitats and Birds directives (EEC 1992 and EC 2009; H&BDs), the Water Framework Directive (EC 2000; WFD), and the Marine Strategy Framework Directive (EC 2008; MSFD), alongside ESFRI Research Infrastructure, and other global and international initiatives.

The next step was to delineate how to gather information. This process primarily consisted in setting up an Excel-based worktable to systematically collect current biodiversity observation variables, sampling and analysis methods and tools. The classification of information for each biological group and variable entailed defining the table structure, including column labels, specifying e.g., methods for sampling and analysis, country, ecosystem, reference to the methods alongside a second sheet for tool related information, such as links and description.

This comprehensive survey serves as a crucial resource to understand how biodiversity observations are collected within monitoring schemes across Europe, by different institutions, programs and legislative reporting, providing an overarching view of the current operational landscape. This groundwork lays the foundation for subsequent analysis, aimed at identifying commonalities and gaps, essential for informing future strategies and harmonisation efforts.

2.1 Definition of the list of target information sources and categories

The first step of the work, dealing with the selection of the sources, consisted in a collaborative effort among the partner community within WP3, leveraging their diverse interests and expertise in environmental research to effectively profile potential sources within the European monitoring framework. The first phase involved compiling a categorised list of various sources by type and assigning priority classes to establish the order of consultation during the operational phase. During this period, the list was shared with WP3 partners to collaboratively refine it, particularly to include details of national monitoring programmes, known to or involving the partners. Through this iterative process, the list of sources was furtherly supplemented and tailored to reflect and include the expertise of the partners.

By engaging in this systematic approach, the partners ensured a thorough exploration of potential sources, thus laying a robust foundation for the subsequent retrieval process.

The list of sources selected are summarised in the following table:

Source name	Source short name	Source type	Geographic scale
Integrated European Long-Term Ecosystem, critical zone and socio-ecological Research	**eLTER-RI**	Research Infrastructure	European
International Centre for the Advanced Studies on River-Sea Systems	**DANUBIUS-RI**	Research Infrastructure	European
European Marine Biological Resource Centre	**EMBRC-ERIC**	Research Infrastructure	European
LifeWatch	**LifeWatch-ERIC**	Research Infrastructure	European
Distributed System of Scientific Collections	**DiSSCo-RI**	Research Infrastructure	European
Elixir	**Elixir**	Research Infrastructure	European
European Infrastructure for plant phenotyping	**EMPHASIS**	Research Infrastructure	European
Water Framework Directive	**WFD**	Legislation	European
Marine Strategy Framework Directive	**MSFD**	Legislation	European
Habitat and Bird Directive	**H&BD**	Legislation	European
Water Information System for Europe	**WISE**	Other	European
Copernicus		Other	European
European Environmental Agency	**EEA**	Global Initiative	European
The Pan-European Common Bird Monitoring Scheme	**PECBMS**	Other	European

International Union for Conservation of Nature	**IUCN**	Global Initiative	Global
Higher Institute of Environmental Protection and Research	**ISPRA**	National Monitoring Programme	National (IT)
Pan-European Infrastructure for ocean & marine data management	**Seadatanet**	Global Initiative	European
European Environment Information and Observation Network	**Eionet**	Partnership network	European
Europa Biodiversity Observation Network	**EuropaBon**	EU Project	European
Marine Biological Association (CPR Survey)	**CPR Survey**	Global Initiative	Global
SeagrassNet monitoring program	**SeagrassNet**	Global Initiative	Global
Reef Life Survey	**RLS**	Citizen Science Initiative	Global
GOOS BioEco portal	**GOOS**	Global Initiative	Global
The Baltic Marine Environment Protection Commission (“Helsinki Commission”)	**HELCOM**	Regional Initiative	European
Environmental Monitoring in the Black Sea	**EMBLAS**	Research Infrastructure	European
EU Citizen Science		Citizen Science Initiatives Portal	European
Estrategias Marinas de España: Programas de Seguimiento (Spain)	**EsMarEs (MITRED)**	National Monitoring Programme	National (ES)

Protocolos de muestreo, laboratorio y cálculo de índices	**MITRED**	National Initiatives	National (ES)
Réseau d'Observation du Phytoplancton (FR)	**PHYTOBS - BENTHOBS**	National Monitoring Programme	National (FR)
The Ministry of Environment, Waters, and Forests		National Monitoring Programme	National (RO)

Each source is described by using descriptive labels as follows:

- Source name: it refers to the full name of the source from which information on observed biodiversity variables/tools is retrieved.

- Source short name: the short name or acronym of the source used for brevity and quick identification in the worktable.

- Source type: it categorises the typology (category) of the source, which is further described below.

- Link: each source is associated with a link to its website or a description for easy reference.

- Geographic scale: it indicates the geographic range at which the source is applicable for collecting the observations.

The source types used are:

(**a**) Legislative frameworks;

(**b**) Research infrastructures;

(**c**) Global Initiatives;

(**d**) Other/Partnership Network/EU project;

(**e**) National (or Regional) Initiatives (or Monitoring Programmes);

(**f**) Citizen Science Initiatives.

Legislation frameworks (a) - In the context of EU assessment, reliable sources of biodiversity information play a crucial role in national monitoring efforts, mandated by key directives such as the MSFD, the WFD and the H&BD. The MSFD (2008/56/CE) specifically requires MS to monitor and report on the environmental status of all marine EU waters for the achievement of the Good Environmental Status (GES). This includes biodiversity criteria covering principal species groups and broad habitat types, with monitoring programmes requiring reporting every six years. Similarly, the WFD (2000/60/CE) mandates MS to monitor and report on the ecological and chemical status of water bodies, including several biological quality elements. The objective is to safeguard and, where necessary, restore water bodies to achieve good status, which undergoes review every six years to ensure effectiveness and relevance.

The Habitats Directive (92/43/CEE) and Birds Directive (2009/147/CE) require MS to monitor and report on the conservation status of species and habitats of community interest along with all wild bird species. This entails assessing habitat extent and condition, as well as population size, trends and distribution of the protected species. These assessments require reporting every six years.

Research Infrastructure (RIs) (b) - RIs have been selected as potential aggregating sources for biodiversity monitoring-related information:

eLTER-RI: offering access to over 500 sites across Europe, it facilitates research aimed at understanding the ecological changes over the long term, typically decades

DANUBIUS-RI: providing integrated knowledge on River-Sea Systems it contributes to the understanding of this complex aquatic continuum

EMBRC-ERIC: offering access to marine biological organisms and their habitats for experimental purposes and applied research, it supports advancements in marine biology and related fields

LifeWatch-ERIC: this RI provides access to a wealth of biodiversity content, services and communities

DiSSCo-RI: focused on Natural Science Collections, DiSSCo-RI works to preserve and provide access to biological specimens for research and education purposes

ELIXIR-ERIC: it serves as a platform to store, archive, integrate, and disseminate life science data produced by researchers, facilitating collaboration and knowledge sharing in life science

EMPHASIS: it enables researchers to use facilities, resources, and services for plant phenotyping across Europe, contributing to advancements in agricultural and environmental research

Global Initiatives (c) - This group encompasses:

- The portal of the European Environmental Agency (EEA), serving as a central hub for accessing environmental data and information across Europe;
- IUCN (International Union for Conservation of Nature), a global environmental network engaged in conservation and research efforts worldwide;
- SeaDatanet, a distributed Marine Data Infrastructure that facilitates the collection, sharing, and management of marine data;

- The Global Ocean Observing System, (GOOS) BioEco portal, a global metadata repository focused on bioecological data, currently under development to enhance global understanding and collaboration in this field;
- Two global monitoring networks:
  - Continuous Plankton Recording (CPR) survey, which focuses on plankton communities, providing valuable insights into marine ecosystems and their dynamics;
  - Seagrassnet, a protocol and web-based data reporting system dedicated to monitoring seagrass habitats on a global scale, aiding in the conservation and management of these critical ecosystems.

Additional sources - Other (d), include:

- WISE – "The Water Information System for Europe" a portal that provides data and information reporting on water quality, quantity, and aquatic biodiversity, in partnership with the European Environmental Agency (EEA), offering comprehensive insights into European aquatic ecosystems.
- Copernicus - the European programme for Earth Observation offers applications in various fields, including environmental monitoring, climate change assessment, and disaster management, providing valuable data and insights for biodiversity analysis and conservation efforts.
- the Pan-European Common Bird Monitoring Scheme (PECBMS) - a long-term monitoring system that tracks the state of bird population across Europe and ecosystems, contributing crucial data for biodiversity conservation and management strategies.
- the European Environment Information and Observation Network (Eionet) - a partnership network of the European Environmental Agency (EEA), that facilitates the exchange of environmental information and knowledge across Europe, supporting evidence-based decision-making and policy development
- EuropaBON - an EU project aiming to identify user and policy needs for biodiversity monitoring and works towards setting up a centre to coordinate monitoring activities across Europe, enhancing collaboration and efficiency in biodiversity conservation efforts.

To encompass more specific source categories on National (or Regional) scale, contribution from partners have been incorporated (**e**), with sources from various national monitoring initiatives and programmes such as:

- The Italian Institute for Environmental Protection and Research, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale): ISPRA acts under the vigilance and policy guidance of the Italian Ministry for the Environment and it plays a significant role in the

Italian environmental monitoring efforts, contributing valuable data and insights to national and international biodiversity assessments.

- the Ministry of Environment, Waters, and Forests (Romania): Romania's Ministry of Environment, Waters, and Forests actively participates in national monitoring initiatives, providing essential data on biodiversity and environmental conditions within the country.
- Réseau d'Observation du Phytoplancton (France): this network in France focuses on observing phytoplankton, offering insights into aquatic ecosystems and their biodiversity status.
- Estrategias Marinas de España: Programas de Seguimiento- EsMarEs (MITRED): MITRED monitoring protocols and initiatives, including the National monitoring program and National Initiative of Spain, contribute crucial data to Spain's efforts in assessing and managing marine biodiversity.
- As for Regional Initiative, consideration was given to “the Baltic Marine Environment Protection Commission” (HELCOM), also known as the “Helsinki Commission”, which plays a pivotal role in coordinating efforts to protect and monitor the Baltic Sea marine environment.

Finally, for the collection of initiatives involving citizen scientists (f), emphasis was placed on the EU-Citizen Science projects portal, which serves as a comprehensive platform for accessing citizen science initiatives aimed at monitoring biodiversity across Europe.

To classify properly each entry, the structured worktable in Excel format for variables incorporated the following categories:

- <u>Biodiversity observation variable</u>: it refers to the specific biological parameter monitored and measured through the specified method for a given group of fauna or flora. Examples include abundance, taxonomic composition, species distribution and other relevant metrics used to assess the biodiversity status within ecosystems.

- <u>Source</u>: the acronym of the sources (see list above) from which the information on observed biodiversity variables was retrieved.

- <u>Source type</u>: the category of the monitoring entity, as outlined and described previously, from which the variable information was retrieved

- <u>Reference for the method of sampling</u>: the reference to the document where the method of sampling, observation and/or collection for the specified variable of the targeted biological group is reported or can be referenced. This may include scientific articles, technical reports or protocols detailing the methodology.

- Reference for the method of analysis: the reference to the document detailing the analytical method used for the observed variable or biological group. The reference may be a scientific article, a technical report or a protocol where the method is reported or can be traced back.

- Link to the method: a web link (if available), where the description of the method can be retrieved and consulted online.

- Institution: the organisation or official body responsible for performing the monitoring activities.

- Geographic distribution: it indicates whether the specific method reported to collect the variable is used by a single or several Countries, an entire region (maritime/continental), or applied on a European scale in general.

- Ecosystem: it specifies whether the observed variable or the monitored biological group belongs to freshwater, marine, coastal and/or transitional waters, or continental ecosystem.

- Unit of measure: if known, it includes the unit of measure typically used for the considered variables, such as number of individuals per square kilometre (N individuals/Km^2).

- Emerging variable: it indicates yes/no to signify whether the biodiversity variables considered are emerging in the monitoring activities (e.g. eDNA).

- Notes: it provides a short description of the method or any additional useful notes about the method information entry.

Few examples of entries in the table of variables are shown in Figure 1a,b,c.

Biodiversity observation variable	Source	Source type	Reference for the method (sampling)	Reference for the method (analysis)
Fish (abundance, biomass, distribution)	MSFD	Legislation	WISE Marine 2020 MS report Baltic - D1-F	HELCOM Guidelines for coastal fish monitoring
Fish (abundance, biomass)	MSFD	Legislation	WISE Marine 2020 MS report Baltic - D1-F	Methodological guide for field studies and laboratory analyzes of ichthyofauna in transitional and coastal waters; GIOŚ 2014

(a)

Link to the method	Institution (that performs the monito	Geographic distribution	Unit of measure	Ecosystem	Emerging Variables (Y/N)
http://helcom.fi/Lists/Publications/Guideline	BIOR Institute of Food Safety, Animal	Baltic (LV)	n° individuals/Km2	marine	N
www.gios.gov.pl | https://helcom.fi/wp-conte	GIOS	Baltic (PL)	n° individuals/Km2	marine	N

(b)

Notes (or method short description)
Coastal fish are monitored. The monitoring addresses status of coastal fish population. Two distinct features - key fish species and abundance of functional groups are used to characterize status of fish population.
The strategy consists of 4 monitoring programs: 2 for coastal and transitional WFD waterbodies, 1 for fish of offshore shallow water areas and 1 for fish of the deep-water zone. Strategy takes into consideration regi

(c)

For the Excel sheet used to collect information about biodiversity analysis tools (e.g., Virtual Research Environments), the labels are as follow:

Figure 1. An example of two entries about biodiversity observation variables and associated monitoring methods. Information on Fish from D1 of MSFD are reported, together with the method references (a), the weblink to reach them (b), the geographic distribution and ecosystem (b), Unit of measure (b) and Notes (c).

- Tool: name of the tools, along with its type (e.g., VRE, software, toolbox, web portal or web application).

- Source: name of the source from which the information on the tool is retrieved, typically the web source providing the tool or the creator of the tool (e.g., institution, infrastructure).

- Link: web link to access the provider or the tool page.

- Brief description: a concise description of the tool's purposes and functionalities.

- Notes: any additional information or comments relevant to using or understanding the tool.

Few examples of entries in the table of variables are shown in Figure 2a,b,c.

Tool	Source	Link
Ecological Modeling Virtual Lab	LifeWatch ERIC	https://ecomodel.portal.lifewatchgreece.eu/
Belgian LifeWatch e-Lab	LifeWatch ERIC	http://www.lifewatch.be/data-services

(a)

Brief description
This vLab comprises of two online coupled models, which are parameterised and initialised for the specific conditions at a few specifically identified areas for which the required datasets exist.
This online application allows users to standardise, analyse and visualise their data, making use of web services built on top of internal and external reference databases.

(b)

Note
In an attempt to make the tool user friendly a graphic user interface (GUI) developed in the course of previous projects will be used.
One of the virtual laboratories developed by LifeWatch Belgium is the Belgian LifeWatch eLab.

(c)

Figure 2. An example of two entries about biodiversity tools. Two VRE from LifeWatch ERIC are reported, together with the link (a), a brief description (b), and Notes (c).

At the end of the process, the Excel file comprises three sheets, each dedicated to the collection of information on Sources, Variables and Tools, respectively. Additionally, a read-me sheet has been included in the file to serve as a guide during the operational phase, aiding in the interpretation and utilisation of the collected data.

2.2 Metadata collection

The retrieval of metadata about monitoring methods and tools involved sequential steps, during which various materials, such as web pages, documents, technical reports, scientific publications, and data-metadata repositories were examined. All these sources were accessed starting from the primary websites.

The main aim is to identify instances where the sampling and analysis methods for a biological group are clearly outlined. This includes determining the primary biodiversity variables considered in both quantitative and qualitative assessment. Finally, the pertinent reference is cited in the table for clarity and attribution.

Based on the assigned priorities, the retrieval process began by scrutinising the main biodiversity monitoring data workflows at the European level. These workflows stem from the reporting efforts associated with the selected directives, the MSFD, the WFD and the H&BDs. The collection of information on methodology involved a comprehensive review of official documents, guidelines, protocols, and recent reports supplied by the European Commission.

The MSFD emphasises the importance of monitoring biological variables to assess the ecological status of marine waters. Monitoring methods encompass a broad spectrum of biological elements, including plankton, benthic organisms, and fish communities. To ensure consistency across Member States (MS), standardised sampling protocols and indicators are prescribed. Each MS is mandated to inform the European Commission about the initial assessment, environmental target definition, monitoring programmes, and measure plans, finally culminating in the definition of the GES. To achieve this, each MS produces periodic reports, divided by annual ranges, specifying the monitoring for each of the directive's descriptors. These reports outline the details, methods and results, and are made available for public consultation through the official national bodies responsible for monitoring management.

For a detailed exploration of monitoring methods at the national level of each MS, the "Water Information System for Europe - Marine (WISE-Marine)" website emerged as a valuable and direct resource.

In particular, serving as a comprehensive platform for storing, managing, and disseminating marine environmental data, Wise-Marine provides access to various tools, such as dashboard and reporting, and datasets related to biological and environmental monitoring. It facilitates the integration of data from different sources and enables comparative analysis at the European level. In particular, the section dedicated to MSFD "reports and assessments" provides access to national reports either directly from individual MS or grouped by macro marine regions. The MSFD categorises marine waters of community interest into four main macro areas: Baltic Sea; Northeast Atlantic Ocean; Mediterranean Sea; Black Sea.

Information was retrieved through the "grouped by regions" option, by using the "regional overview page", each containing reports, organised within a table catalogued by descriptors (from D1 to D11), Directive's Articles (Art. num. from 8 to 11, 13-14 and 18) and two-year MSFD reporting cycle (e.g. currently available 2012; 2018/2020). Upon accessing the page dedicated to a specific descriptor, users can consult a table divided into MS, belonging to the relevant region. For each MS, listed details of the national monitoring programmes are provided. Key information includes the description of the strategy, methods, biological categories considered, spatial and temporal coverages of the monitoring, and, if available, bibliographical or website references.

The monitored MSFD descriptors considered in this task, aimed at retrieving the biological variables, were primarily selected based on their reference to biological components, encompassing animals, plants, and their habitats. One of the selected descriptors was D1 that is dedicated to marine biodiversity and that "*under the marine directive covers all marine species of birds, mammals, reptiles, fish and cephalopods found in EU waters…*". Moreover, it is stated that "*Marine biodiversity also covers all types of habitats, both pelagic and benthic. Pelagic habitats, such as habitats in the water column, need to be in a condition where their structure and functions allow species to thrive. For benthic habitats (habitats on the seabed), Member States need to look at the extent of loss and damage to the seabed*". The assessment of pelagic and benthic habitat is addressed also under D6, specifically dedicated to seabed habitat integrity. Another considered descriptor was D2, focused on non-indigenous species defined as "*…introduced by human activities are at levels that do not adversely alter the ecosystems*" and "*…species that expanded their typical geographical distribution. They become 'invasive' when they can threaten marine biodiversity*".

The remaining descriptors were excluded from the assessment, as they primarily pertain to environmental monitoring rather than focusing on biological components.

For each monitoring programme related to biological descriptors (D1 subdivided in several biological groups, D2 and D6) pertinent details were extracted from the descriptions reported by each MS. The most recent available report was chosen, i.e. the 2020 report. To ensure a systematic approach to information collection and facilitate the organisation of the worktable, biological groups were paired with the individual biological variables. As a result, each entry row in the worktable was primarily divided by Geographical Region, Ecosystem and Biological Group (e.g. Mammals, Birds, Fish etc.) and matched with the biological variables involved in monitoring for that specific group, as specified in the provided description. Among the variables, priority was given to the ones that directly refer to biodiversity. These include abundance, species/taxonomic composition, and distribution which are fundamental for understanding the qualitative aspects of biological diversity. Conversely, variables related to population dynamics (e.g., mortality and growth rate) and biological parameters for individual specimen measurements (e.g., size, age, sex) were not prioritised. This approach was pursued considering that the former are more conducive to quantitative studies of variability within a biological group, whereas the latter are primarily focused on individual characteristics rather than biodiversity assessment.

Each entry in the worktable includes at least one reference for the method for sampling and/or analysis used to determine the biological variables for that specific group. This reference may be a protocol, a guidelines document, a scientific article, or a report. In cases where the reference is not explicitly indicated, only the source and a web link are provided, allowing for easy retrieval of the information. Finally, the "Notes" section includes a concise description of the monitoring method or any supplementary comments considered as relevant.

This comprehensive approach ensures transparency and accessibility of the information, providing sufficient detail for understanding the methodologies employed in the monitoring process. It also allows for further verification and exploration of the referenced sources, contributing to the overall rigour and credibility of the performed analysis.

Figure 3 shows an example of how the information was recorded.

Biodiversity observation variable	Source	Source type	Reference for the method (sampling)	Reference for the method (analysis)
Cephalopods (distribution pattern, range, sp	MSFD	Legislation	WISE Marine 2020 MS report NE Atlantic/Baltic - D1-C	
Cephalophods (biomass, abundance)	MSFD	Legislation	WISE Marine 2020 MS report NE Atlantic - D1-C	OSPAR Guidelines on Quality Assurance for Biological Monitoring in the OSPAR Area (Agre
Fish (abundance, distribution spatial)	MSFD	Legislation	WISE Marine 2020 MS report Med. - D1-F	*Marasovic I. et al (2013)*
Fish (abundance, extent)	MSFD	Legislation	WISE Marine 2020 MS report Med. - D1-F	Orlando-Bonaca, M. et al (2013); Final report for 2013. Reports 148. Marine Biological Statio

Link to the method (if present)	Institution (that performs the monitoring)	Geographic distribution	Unit of measure	Ecosystem	Eme
https://water.europa.eu/marine/assessment-module/region	IPMA	NE Atlantic (PT)	n° individuals/Km2	marine	N
https://jadran.izor.hr/jadranski_projekt_2/MJERNE-METODE-I-OPREMA.pdf		Mediterranean (HR)	n° individuals/Km2	marine	N
https://water.europa.eu/marine/assessment-module/regional-descriptors-assessments/med/d1.4/art11/@@		Mediterranean (SI)	n° individuals/Km2	marine	N

Note
Coastal/shelf and deep-sea Cephalopods are monitored with target species in different national monitoring programmes. Monitoring of fish and cephalopods will follow internationally standardized sampling methodologies within the scope of the DCF.
The monitoring is based on some species of the categories coastal fish, pelagic shelf fish, demersal shelf fish. The method is in-situ sampling coastal/offshore.
The monitoring is based on some species of the category "Coastal fish" with in-situ sampling coastal.

Figure 3. An example of an entry about biodiversity observation variables and associated monitoring methods from WISE-Marine. Two biological groups (Cephalopods and Fish) from D1 of MSFD are reported, together with the method references (a), the link (b), the geographic distribution and ecosystem (b), Unit of measure (b) and Notes (c) with description.

While WISE served as the principal source for tracing marine biodiversity monitoring under the MSFD, the WFD has been a source of methods for the monitoring efforts of rivers, lakes, transitional and coastal waters. The WFD mandates the monitoring of biological quality elements (BQEs) as part of the ecological assessment of surface waters.

Biological monitoring methods outlined in the WFD include the assessment of phytoplankton, macrophytes, macroinvertebrates, and fish communities. Standardised sampling methodologies and quality assurance measures are integral components of monitoring programs under the WFD. Information regarding these methodologies were gathered from reports published by the Geographical Intercalibration Group of the Joint Research Centre (JRC). These reports provided insights into the methodologies employed for monitoring biological variables across the frameworks governed by WFD. The intercalibration exercise, specifically mentioned in the Annex V of the WFD, aims to harmonise the interpretation of "Good Ecological Status" across all MS. According to *Guidance on the Intercalibration Process* (EC 2005): "*The essence of intercalibration is to ensure that the high-good and the good-moderate boundaries in all Member State's assessment methods for biological quality elements correspond to comparable levels of ecosystem alteration*". The GIG proved to be a valuable reference for the national applied methodologies in the WFD monitoring framework.

The WFD reports available on the "*JRC Publications Repository*", authored by the JRC's Geographical Intercalibration Group, were analysed to identify specific methodologies recommended for monitoring biological variables in the various water bodies. This involved searching for each biological category (e.g., Fish, Benthic Invertebrate etc.), ecosystem (e.g. Transitional waters, River, Lake etc.) and geographical region (e.g. NE Atlantic, Mediterranean etc.). The most recent (i.e., 2018) technical report accessible from the repository was selected for analysis. Within each report, particular attention was given to the chapter "Description of national assessment methods". This chapter outlines individual or grouped sampling and monitoring methods for the MS participating in the intercalibration efforts. The information on sampling methods, and of analysis when specified, was extracted and reported in the worktable. The technical report was cited as the reference for this information or an alternative source was indicated when specified (e.g. protocol or scientific publication). Each WFD assessment method is often associated with the application of a biological index. From these indices, the main biological variables used in the calculation, such as abundance, biomass etc., were derived and reported.

In the context of the H&BDs, our analysis primarily focused on official documents and monitoring manuals, such as the ISPRA National Monitoring Manual for Italy. We also cross-referenced the methods for monitoring habitats and birds with those utilised in the national monitoring programs of other directives, such as the MSFD, to avoid redundancy in information.

The retrieval process also encompassed the analysis of various Research Infrastructure websites, selected Global Initiatives, EU projects/Initiatives, and sources categorised as "Other". This retrieval was exclusively conducted through accessible web portals, focusing particularly on sections dedicated to publications, technical reports, and general consultable material. One notable source within the global initiatives was the "GOOS BioEco portal" an open-access online platform currently under development. This platform serves as a repository for metadata and information concerning global ocean observations and monitoring programs related to biological and ecosystem aspects. The portal includes a comprehensive database of monitoring programs on a global scale, categorised by groups and biological variables. For each program, information is provided, which includes Standard Operating Procedures (SOPs), when available. These SOPs were consulted to enhance existing information or provide additional insights into the methods.

To facilitate the integration of methodologies at the national level, particularly those employed by national and regional agencies, project partners were engaged during the second phase of the information retrieval process. Their involvement entailed adding methodological information from national monitoring programs and their respective sources to the worktable.

Furthermore, the analysis also considered the contribution of Citizen Science activities through the European portal EU Citizen Science. This involved identifying currently active initiatives and retrieving those specifically focused on biodiversity monitoring.

Concurrently, efforts were directed towards identifying web tools that aid in biodiversity analysis. The focus was on online resources that are freely accessible or offer free downloadable software. Specifically, biodiversity web tools or VREs were selected based on their usefulness in analysing biodiversity-related data and metadata. Emphasis was placed on tools that facilitate data collection and analysis rather than those primarily focused on data visualisation, such as dashboards of graphs and interactive maps, or downloadable packages tailored for statistical analysis software.

2.3 Metadata analysis

Following the conclusion of the biodiversity monitoring methods and tools retrieval phase, the table underwent reorganisation to enable the analysis of metadata about methods and tools.

Information restructuring and category label uniformity were implemented to facilitate grouping and analysis via Pivot tables within one or more discrete categories.

We used bar plots and ring/pie charts to visualise the number of entries or percentages for each category.

To evaluate and integrate the description of each method listed in the table into our analysis, we built and employed an "Information Richness scale". This scale categorises each method according to the level of detail provided, the extent of its description, and the accessibility of information. Moreover, we evaluated whether each method adheres to International/European guidelines or standards for macro-regions. The chosen categories are: 'High', 'High-shared', 'Medium', and 'Low', as detailed in Table 2.1.

Table 2.1 Information Richness categories description, each with the respective label.

***Information Richness* category**	**Description**
High (H)	The method is clearly outlined, with comprehensive details, in the attached or referenced protocol/guidelines. Additionally, it can be readily identified within the provided protocol or in a cited publication. However, it remains uncertain or unspecified whether the method adheres to common international guidelines.
High-shared (H.s)	Similarly to the first one, the method provides clear and detailed information, readily accessible in the attached or referenced protocol/guidelines. In addition, it is explicitly linked to International/European guidelines or standards for macro-regions, such as HELCOM, OSPAR, UNEP/MAP, International commissions such as Black Sea commission or European standardised method (EN – European Normalization).
Medium (M)	The method is traceable to its source, with comprehensive yet succinct information. The sampling method can be inferred from sources such as national technical reports, sometimes only available in the national language. Adherence to regional/international guidelines remains unclear. When accessible, the website of the country monitoring program/institution is available only in the national language.
Low (L)	The reported source provides limited information on the method, which is often generic and lacks specificity, such as a single sentence or a brief definition. Sometimes, there is no indication of a precise method for analysis or sampling, but only the quantification of the biological group is mentioned (e.g., the type of index used).

Each method received a label based on one or more characteristics, categorising them as H (High), H.S. (HighShared), M (Medium), or L (Low). These labels were then analysed and summarised using Pivot tables, with the results grouped by Source, Geographic distribution, and Ecosystems.

To streamline their analysis, according to their specific characteristics and areas of application, tools were tagged based on six categories:

- Data management/analysis: tools that support a broad variety of biodiversity data management, including collection/recording (from an experiment and/or field sampling), digitalization, validation, processing, and analysis.
- Taxonomy: tools enabling species identification, specimen visualisation and classification, traits analysis and other taxonomic assessments.
- Genetics: tools applied in genomic data analysis, DNA (or eDNA) metabarcoding, and other genetic data managing for taxonomic identification.
- Indicators: tools facilitating the calculation of biodiversity indices, often applied in directives, such as WFD, using different biodiversity metrics to define the ecological quality.
- Image analysis: tools enabling digitisation of biological collection, images, and video analysis (including frame processing and taxa identification), and also virtual utilisation of natural collections.
- Sampling: tools supporting sampling design/plot and subsequent analysis.

3. Results

A first analysis was conducted on the sources from which information on biodiversity variables and tools was searched for and retrieved. The reported results reflect the frequency of appearance of each source in the Excel table.

As shown in Figure 3.1, the prevalent sources of information identified are the WFD and MSFD, representing 35.6% and 30% of the total, respectively. Furthermore, the MSFD also appears in combination with the H&BDs for monitoring activities encompassing both legislative frameworks, accounting for 13.5%. Besides, "EU Citizen Science" and PECBMS, represent approximately 6% and 3% of the total sources, respectively. All the other sources contribute less than 2% each.

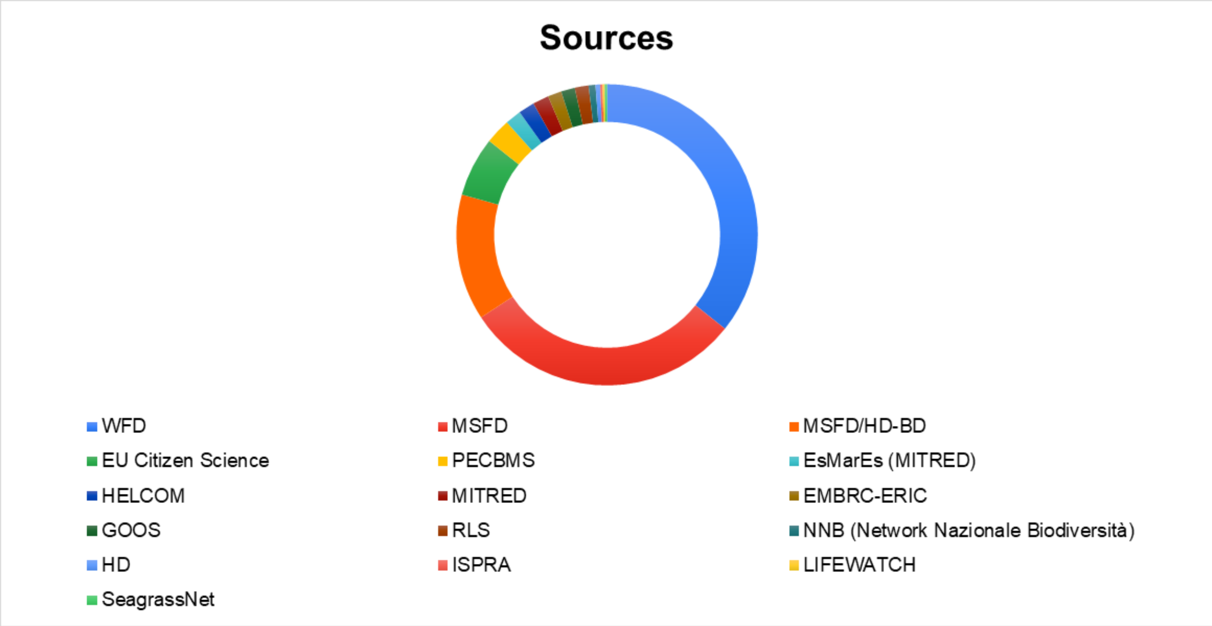


Figure 3. The ring chart illustrates the percentage distribution of the different sources.

Figure 3.2 represents the countries for which information on methods has been retrieved. Each country is labelled with the respective abbreviation, following the designated EU MS acronyms. The reported results indicate the frequency of appearance of each country within one or more entries in the table.

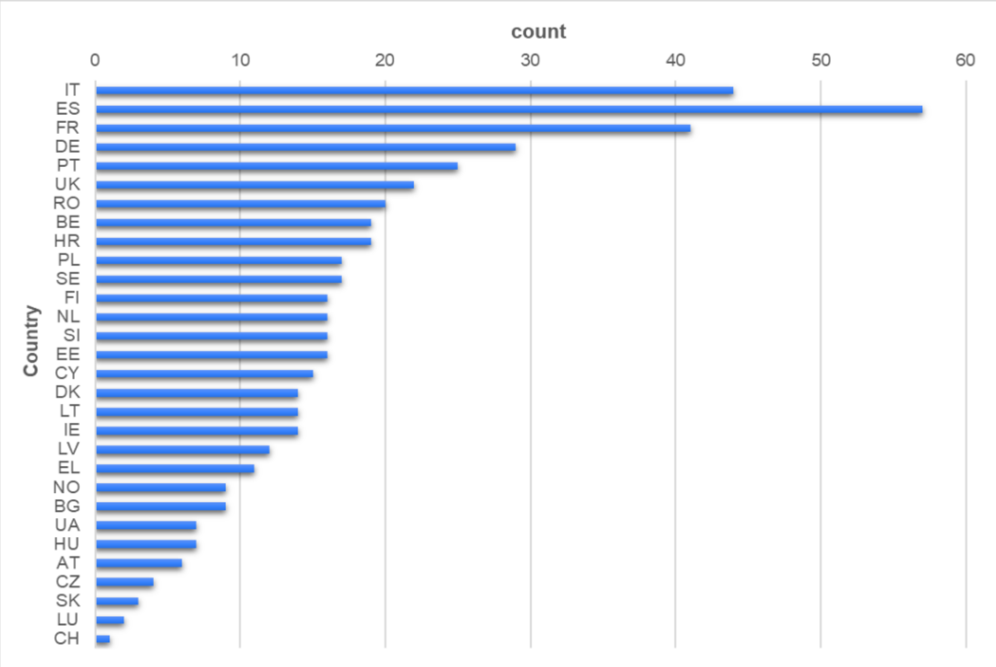


Figure 3. Occurrences of the different countries in the information collected. For Spain, the number includes all the regions within the country (Southern Coast, Balearic Islands, Cantabria, Andalusia, Catalonia region, Basque).

Furthermore, based on the description and terminologies employed by the sources, particularly the Legislations, the countries were grouped into regions for marine, terrestrial and aquatic ecosystems, within the European context (Figure 3.3).

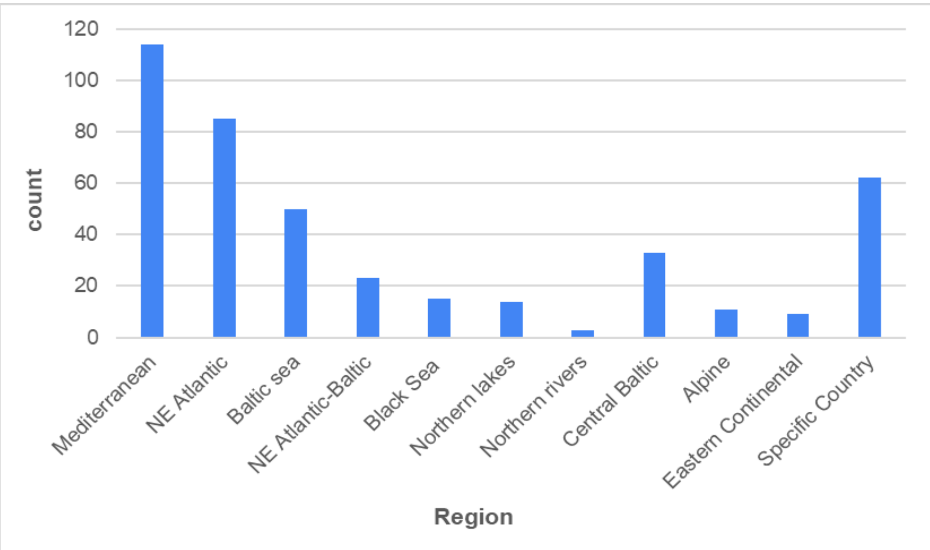
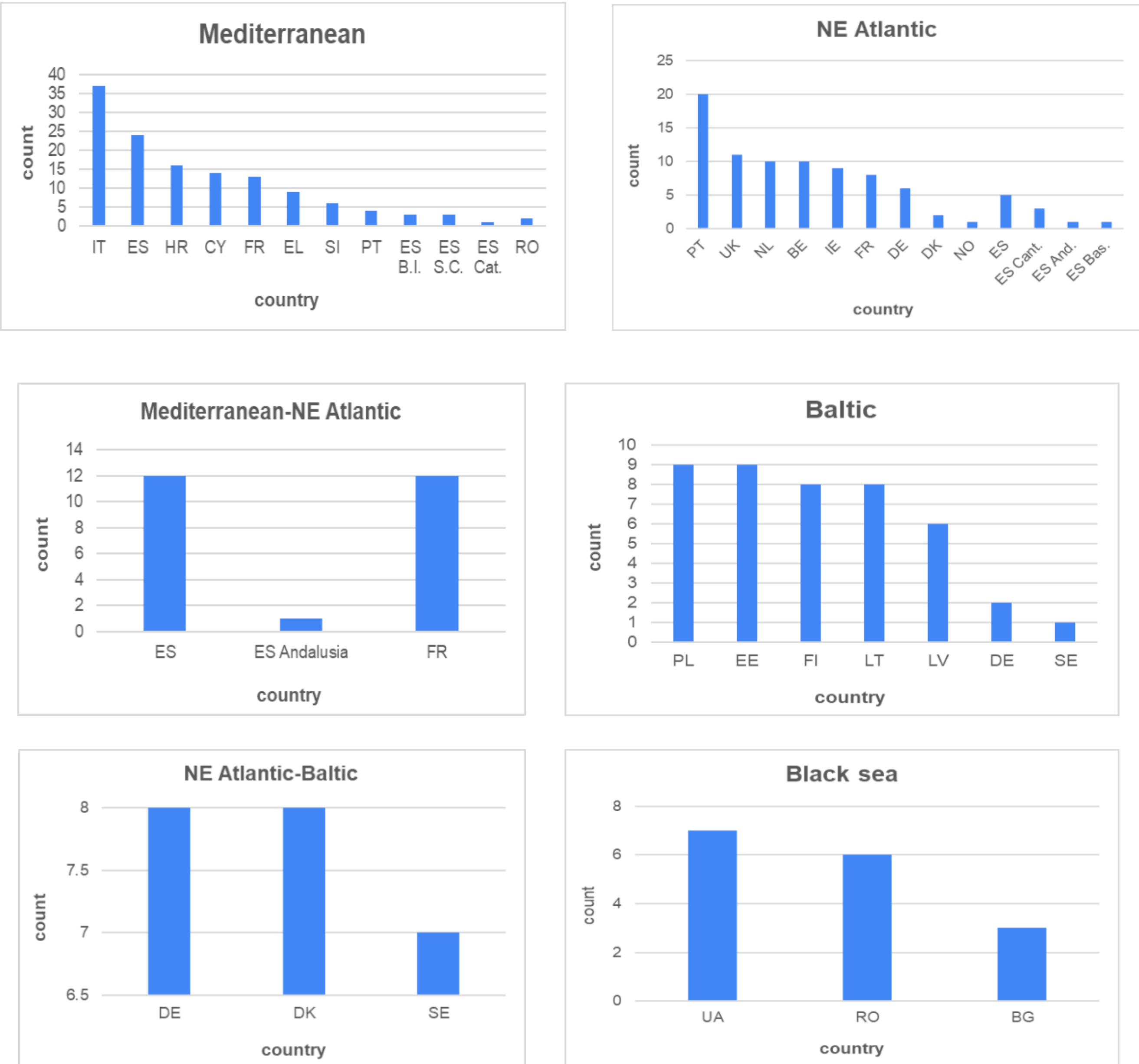


Figure 3.3. Occurrences of the different regions in the information collected. The label 'Specific Country' refers to cases where the method pertains to a single country (without region-specific details).

From the graphs above, it is evident that the most represented countries in the analysis are Italy, France, and Spain, each with more than 40 entries. This trend is also visible in Fig 3.3, where the Mediterranean region is shown to be the most represented.

In the following series of graphs (Figure 3.5), we report the distribution of countries among each region.



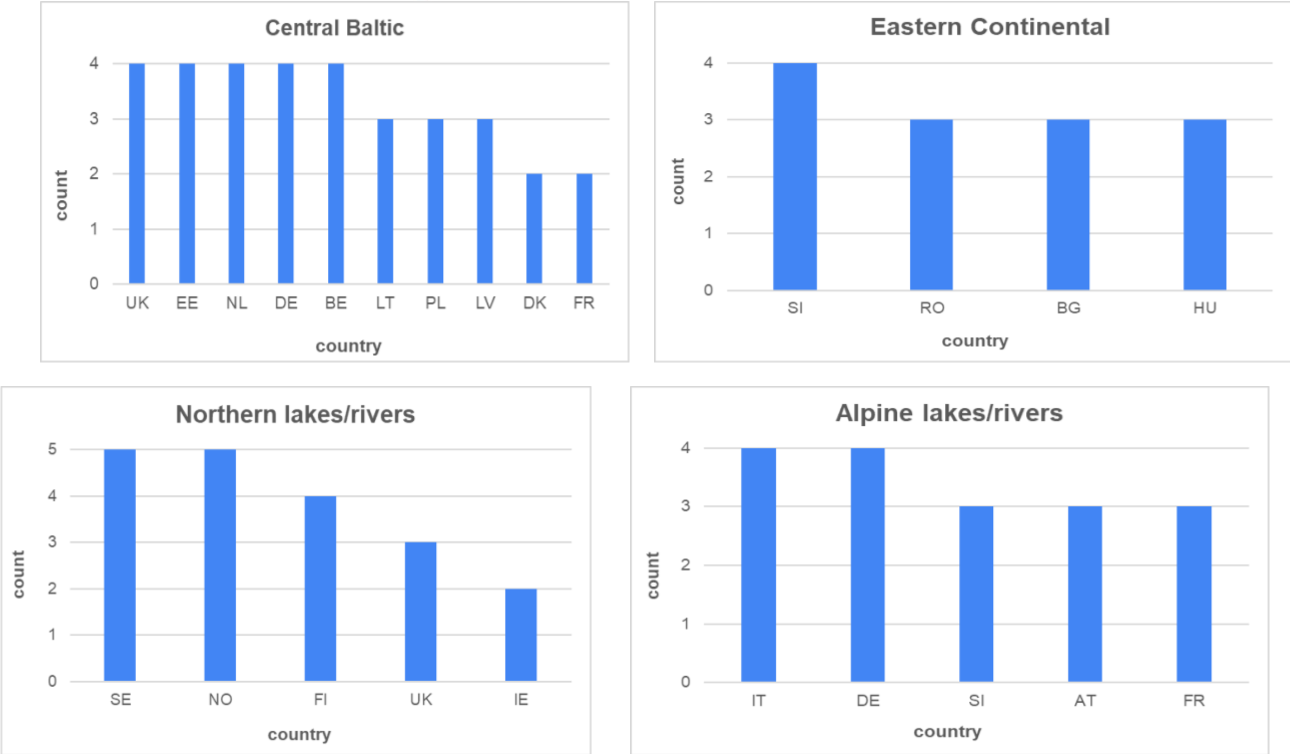


Figure 3.4. Occurrences of the different countries in the macro-regions. Note that some countries are present in two regions simultaneously, indicating that the related monitoring method is applicable by that country for both regions.

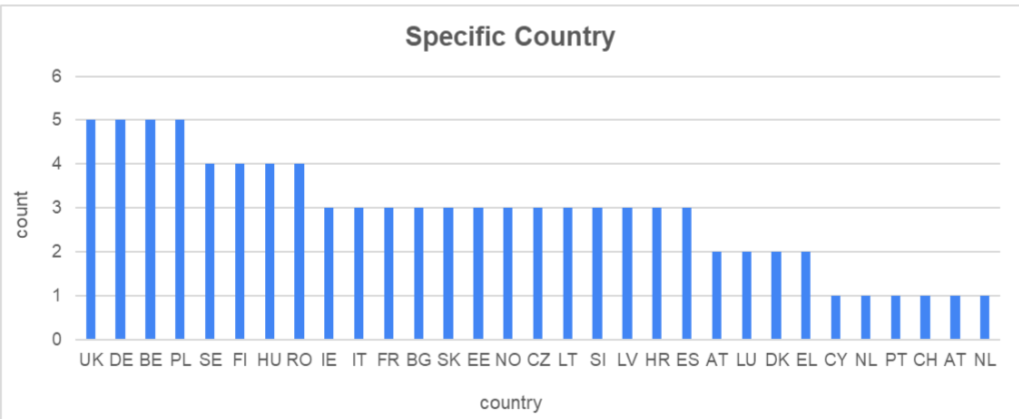


Figure 3.5. Occurrences of countries, not referred to a specific region, related to a specific monitoring method reference.

The application of methods is also examined within the context of one or more ecosystems. Figure 3.6 presents the identified ecosystems along with their respective frequency counts, representing how often each ecosystem label appears within entries in the worktable. It is noteworthy that some methods may be applicable across freshwater, transitional, and marine waters.

The results show that marine and coastal ecosystems constitute nearly half of the represented ecosystems, accounting for approximately 56%. This is followed by “lakes” at 17% and “rivers” at 10%. Transitional as well as terrestrial ecosystems appear in smaller proportions at 8% and 6%, respectively. Finally, there are several less-represented categories, each contributing less than 1% individually and just over 2% collectively. These include “multi-domain” methods, indicating methods applicable across various domains or methods applied in very specific ecosystems (e.g. Black Sea, underground river, large river).

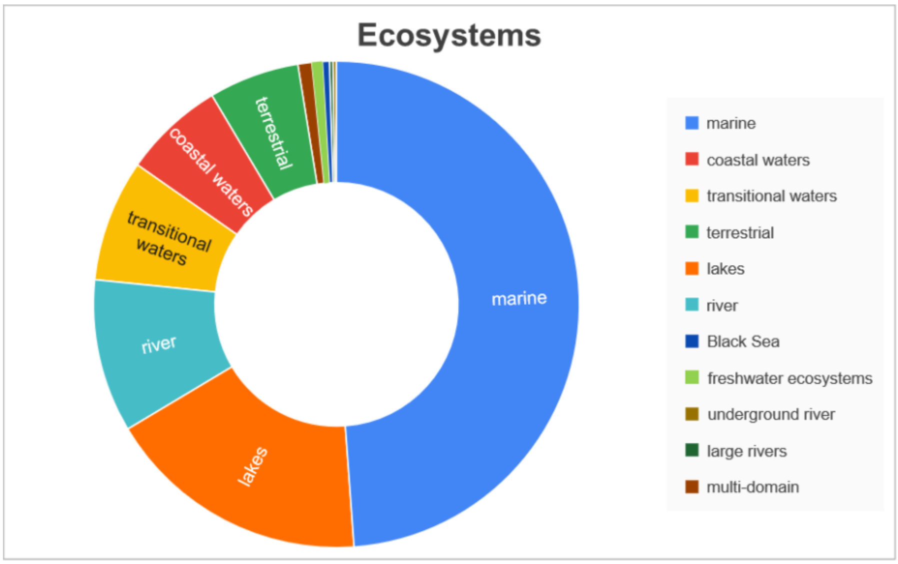


Figure 3.6. The ring chart illustrates the percentage distribution of the different ecosystems.

Furthermore, since each information pertains to one or more specific biological groups, we categorise them into “Fauna”, “Flora”, “Benthic habitat” and “other categories”.

The groups classified under the category “Fauna” result to be the most represented, with a total of 209 entries, and they are distributed across various subgroups, as shown in Figure 3.7. Particularly, “Benthic Invertebrate Fauna”, “Fish” and “Zooplankton” comprise wide faunal groups, encompassing numerous species monitored across different ecosystems. Following these, are different marine groups, such as “Marine mammals/reptiles”, “Cephalopods” and “Reef communities – Fauna’” which entail a broad spectrum of monitoring activities on different zoological groups within the reef environments. Additionally, “Seabirds”, predominantly monitored in MSFD-related activities, and “Birds”, considered separately due to their terrestrial or multi-domain context, are significant categories. “Terrestrial Mammals”, “Molluscs”, and “Amphibians” (spanning terrestrial and freshwater ecosystems), represent smaller yet significant groups.

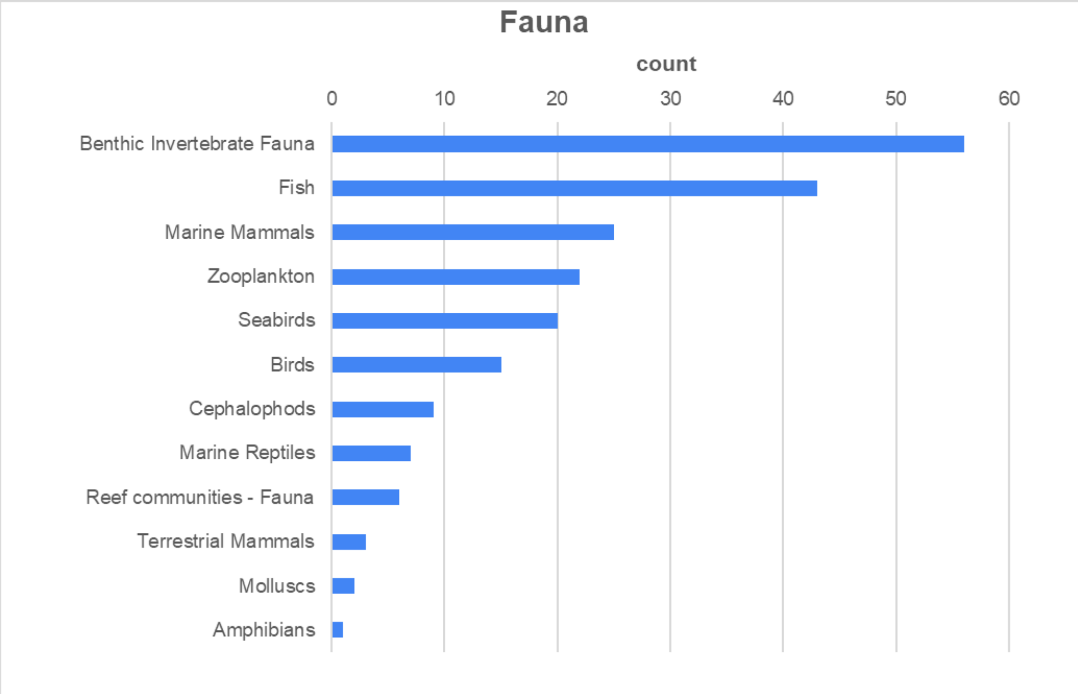


Figure 3.7. Graph illustrating the occurrences of each "Fauna" group.

Within the category "Flora" (Figure 3.8), consisting of a total of 116 entries, there is a diverse array of biological groups, with the most conspicuous being "Phytoplankton", followed by "Macrophyte", mainly comprising aquatic plants, adapted to both saltwater and freshwater environments. Also noteworthy are the "Angiosperms", encompassing various terrestrial and aquatic taxa, primarily living in marine waters, such as Seagrass, the "Phytobenthos" and the "Opportunistic Macroalgae". In addition, the "Terrestrial vegetation" category is related to endemic, allochthonous and invasive terrestrial plants.

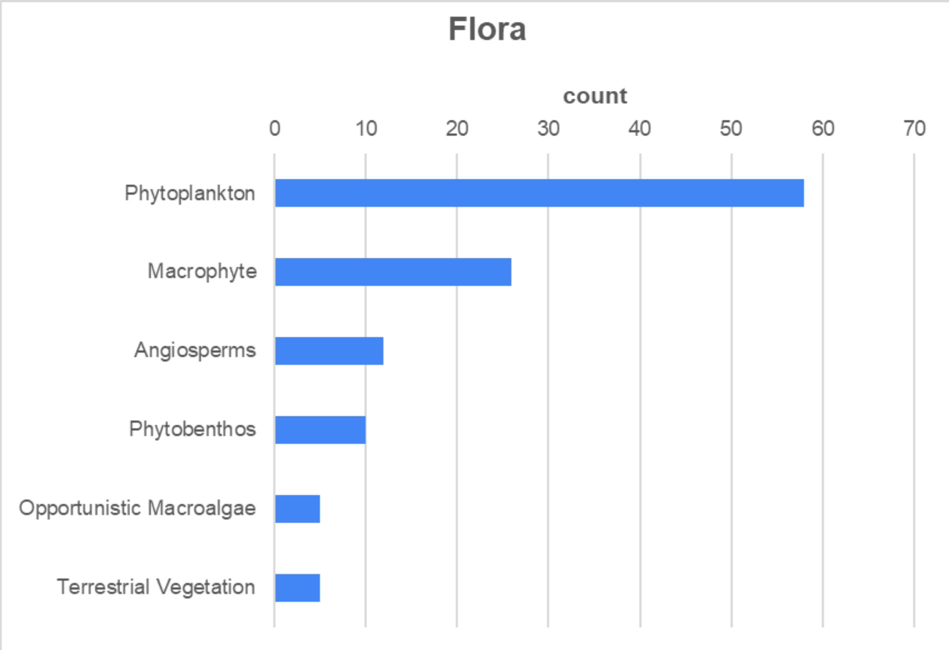


Figure 3.8. Graph illustrating the occurrences of each "Flora" group.

In Table 3.1 a detailed breakdown of the various labels categorized under "Benthic habitat" is provided, comprising a total of 52 entries that encompass both benthic fauna and flora.

Table 3.1. The table lists the results related to the category "Benthic habitats".

BENTHIC HABITATS	count
Benthic habitat - macrozoobenthos	11
Benthic habitat - soft/hard-bottom macrophytobenthos	5
Benthic habitat - macrophyte	4
Benthic habitat - Posidonia beds	3
Benthic habitat - benthic protected species	3
Benthic habitat - Angiosperms	2
Benthic habitat - opportunistic macroalgae	2
Benthic habitat - benthic communities	2
Benthic habitats	2
Benthic habitat - hard-bottom benthic invertebrates	1
Benthic habitat - soft bottom benthic macroinvertebrates	1
Benthic habitat - benthic macroinvertebrates	1
Benthic habitat - zoobenthos community	1
Benthic habitat - benthic fauna	1
Benthic habitat - meiobenthos	1
Benthic hard - bottom fauna	1
Benthic habitat - hard-bottom benthic macroalgae	1
Benthic habitat - macrophyte communities	1
Benthic habitat - phytobentos community	1
Benthic habitat - macroalgal communities	1
Benthic habitat - soft bottom benthic Angiosperms	1

Benthic habitat - Rhodolith beds	1
Benthic habitat - infralitoral rock bottom communities	1
Benthic habitat - benthic soft/hard bottom communities	1
Benthic habitat - soft-bottom community	1
Benthic habitat - reefs	1
Benthic habitat - coral beds and biocenosis of deep corals	1

The remaining categories, 25 entries in total, are listed in Table 3.2. These include "Non-indigenous or exotic species" and "Other protected species status", which pertains to protected species of particular significance within a given country. Categories such as "Pelagic habitat" and "Reef communities" encompass a wide range of monitoring activities.

Table 3.2. The table lists the results included in the "other categories" label.

OTHER CATEGORIES	count
Non-indigenous or exotic species	22
Other protected species status	1
Pelagic habitats	1
Reef communities	1

As previously specified, the information associated with each group encompassed one or more biological observation variables. The summarized results for these variables are presented in Figure 3.9. Below is a brief description of each variable, as considered in this deliverable. When available, the definition from a thematic Thesaurus is provided. (Note: we report the unity of measurement for the variables where the unit is known; for many variables there is no unit of measurement, since they are dimensionless):

- Abundance: this variable is the most frequently observed and it is the "Number of individual specimens of an animal or plant recorded within a specific area over a certain period" (https://www.eionet.europa.eu/gemet/en/concept/2437). It is typically measured as the number of individuals found per unit area (ind./Km^2 or ind./m^2).
- Species (or taxonomic) composition: this variable comprises the list of species identified during the study and/or monitoring activity, with individuals generally classified to the highest feasible taxonomic level. It is among the most recorded variables.
- Biomass: Biomass refers strictly speaking to the total weight of all the living things in an ecosystem (https://www.eionet.europa.eu/gemet/en/concept/883). It is used in some biodiversity monitoring methods to quantify sampled individuals in units of biomass (unit of weight per unit of volume (g/cm^3). For example, in macrophyte monitoring, the amount of plant biomass is measured in addition to taxonomic composition and abundance. This variable was also found to be frequently measured.
- Presence of sensitive taxa: this variable identifies species with a limited tolerance for environmental change and often referred to as "indicator species". These taxa typically

rely on specific habitat conditions and are scarce, have restricted distribution, or are particularly sensitive. As a result, they are frequently targeted and evaluated in monitoring activities to assess environmental quality.

- Distribution: it is defined as “the range occupied by a community or other group”. Within the reported methodologies, distribution is commonly referred to in general or specified as “spatial” (pertaining to a set of geographic observations), “range” (indicating the extent of the distribution), or “pattern” (describing the dispersal pattern of individual observations). Spatial units of measure are applied to quantify distribution. In the collected information, distribution emerges as one of the most frequently represented variables.
- Extent: this variable is applied in habitat monitoring to assess the average spatial extension of a group or community habitat, typically measured using spatial units.
- Specific richness: it refers to the total number of species inhabiting a specific geographical location.
- Diversity: it is the relationship between species’ evenness and richness, often measured using biodiversity indices.
- Presence: it indicates the presence of target species or species of particular interest, within the monitored ecosystem.
- Coverage: it refers to the extent to which a group or a community covers a specific habitat area. Alternatively, it may denote the coverage of a particular species within a habitat area.
- Community composition/structure: it describes the composition of a community, including the number of species and their relative abundance.
- Relative abundance within a community: it represents the ratio of abundance of one species to one or multiple other species within an ecosystem. It is also defined as “a component of biodiversity and is a measure of how common or rare a species is, relative to other species in a defined location or community” (*Hubbell*, 2001).
- Blooms: this variable is considered in some phytoplankton monitoring methods, since some species highly proliferate in specific locations. Monitoring methods may focus on measuring the frequency and intensity of these blooms.
- Incidence: it refers to species occurrence, generally determined through detection within the survey area of stationary survey devices, since some methods use stationary point-count surveys (such as camera traps), to collect presence–absence data (*Stewart et al.*, 2018). It can also be measured temporally, reflecting species' occurrence over time.

- Annual-seasonal variability: it refers to fluctuations in biomass throughout the year, particularly observed in monitoring activities of flora, it reflects the seasonal dynamics of plant communities, such as Angiosperms.

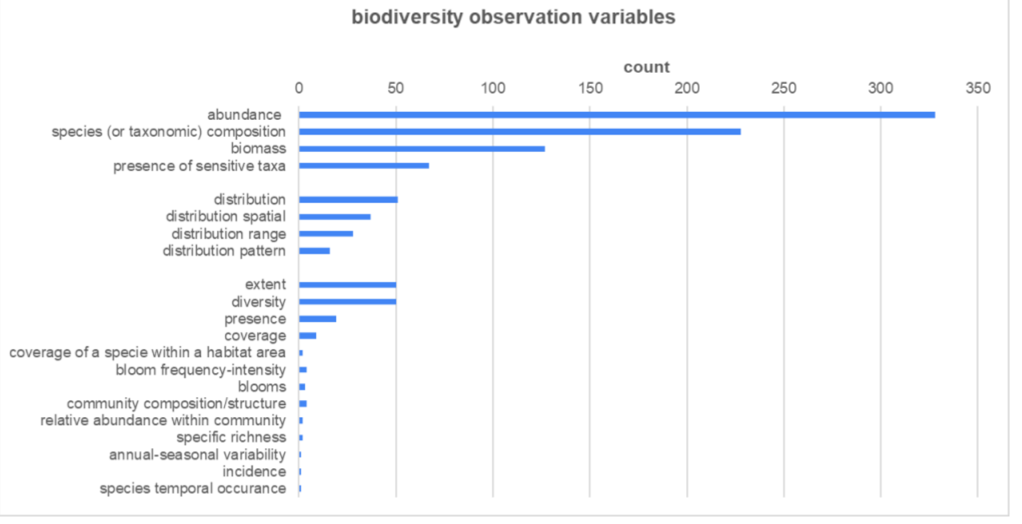


Figure 3.9. Occurrences of biodiversity observation variables in the collected information.

Figure 3.9 shows that the most represented biodiversity observation variables in the analysis are Abundance, Species (or taxonomic) composition and Biomass, each comprising over 300, 200 and 100 entries, respectively.

Figure 3.10 displays the results of the categorization based on the Information richness obtained for the 407 methods retrieved: the sections of the pie-chart are divided into M, L, and H considered collectively, and then further subdivided into H and H.S.

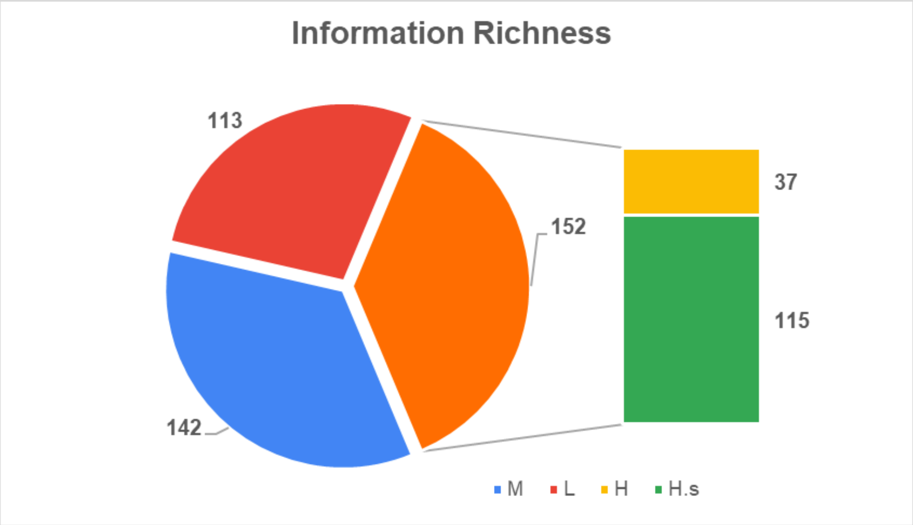


Figure 3.10. The chart displays the number of the methods in each category of Information Richness. Labels are: High (H) High-shared (H.S.), Medium (M), and Low (L).

High Information Richness accounts for 37% of the total (with 9% categorised as High and 28% as High-shared), Medium corresponds to 35%, and Low to 28%.

Examining each level category individually and comparing it with the “Sources” (Table 3.12), “Geographical distribution” (Table 3.13), and “Ecosystems” (Table 3.14) allows us to visualise how the Information richness on methods is distributed among these main elements of the retrieved information.

Information richness/Sources	count
H.s	**115**
MSFD	59
MSFD/HD	20
MSFD/HD-BD	12
PECBMS	11
HELCOM	7
EMBRC-ERIC	4
SeagrassNet	1
WFD	1
H	**37**
MSFD	21
WFD	13
MSFD/HD	2
ISPRA	1
M	**142**
WFD	54
MSFD	35
MSFD/HD	15
EsMarEs (MITRED)	7
MITRED	7
GOOS	6
RLS	6
MSFD/BD	5
EU Citizen Science	3
EMBRC-ERIC	2
HD	1
LIFEWATCH	1
L	**113**
WFD	77
EU Citizen Science	23
MSFD	7
NNB	3
HD	2
MSFD/HD-BD	1

Table 3.13 Information richness categories grouped by Regions (Geographic distribution).

Information richness/Regions	count
H	**37**
Mediterranean	11
Black Sea	8
Central-Baltic	7
NE Atlantic	7
Alpine	2
Northern	1
H.s	**115**
Baltic	43
NE Atlantic	21
EU specific state	17
NE Atlantic-Baltic	17
Mediterranean-NE Atlantic	8
Mediterranean	5
Black Sea	4
M	**142**
Mediterranean	51
NE Atlantic	33
EU specific state	21
Baltic	15
NE Atlantic-Baltic	6
Alpine	5
Black Sea	5
Northern	3
L	**113**
Mediterranean	35
EU specific state	27
Baltic	18
Northern	13
Eastern Continental	9
NE Atlantic	5
Alpine	4
BlackSea	2

Table 3.14 Information richness categories grouped by Ecosystems.

Information richness/Ecosystems	count
H.s	**115**
marine	96
terrestrial	11
marine and coastal waters	3
marine, coastal and transitional waters	2
Black Sea	1
freshwater ecosystems	1
lakes	1
H	**37**
marine	23
lakes	10
coastal and transitional waters	2
river	2
M	**142**
marine	71
lakes	18
river	16
coastal waters	11
coastal and transitional waters	10
transitional waters	9
terrestrial	2
Black Sea	1
coastal waters, large rivers	1
coastal waters, rivers, lakes and terrestrial	1
freshwater ecosystems	1
lakes and rivers	1
L	**113**
lakes	44
river	23
marine	16
transitional waters	12
terrestrial	11
multi-domain	4
freshwater ecosystems	1
terrestrial, river, lake	1
underground river	1

The last part of the information retrieval was dedicated to virtual Tools supporting biodiversity analysis, and it provided a comprehensive collection of 104 tools, covering a wide variety of fields of application across various ecosystems. Each tool has been categorised, aligning with two primary dimensions: application (i.e. for which specific aspect of biodiversity studies it can be used) and ecosystem (i.e. whether it is used for biological groups of a single ecosystem or multi-domain).

Five categories of ecosystems were considered:

- Marine
- Freshwater
- Aquatic (encompassing broad application in aquatic environments)
- Terrestrial
- Multi-domain (exhibiting versatile applicability across ecosystems)

Figure 3.11 displays a detail of the collected tools across the ecosystems of application. Notably, the 56% of the total tools show a multi-domain applicability, 23% are specific for the marine environment, and 10% for freshwaters. 7% are relevant to all aquatic ecosystems, while 5% are specific for terrestrial environments.

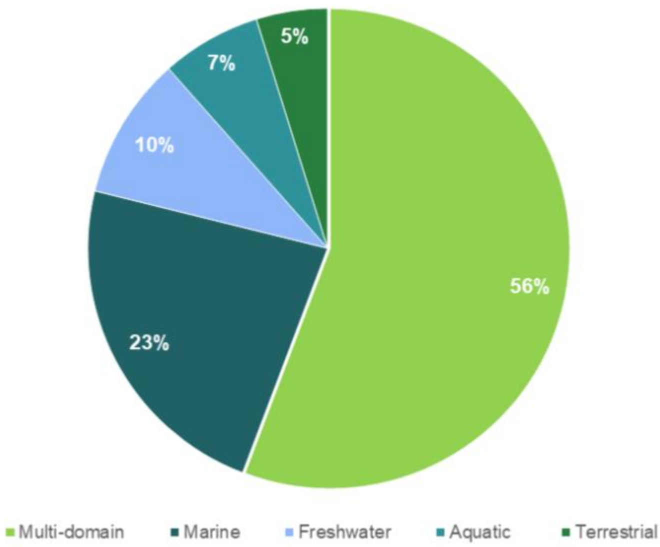


Figure 3.11. The graph illustrates the percentage distribution of the tools applications across various ecosystems

As detailed in the method section, tools were tagged based on six categories according to their specific characteristics and fields of application. Figure 3.12 shows the number of tools distributed across these application categories. Most of the tools (49%) are dedicated to Data management and analysis, followed by taxonomic application (17 %), genetics (14 %), and calculation of indicators (13%). Other applications include image analysis (8%) and sampling design/plot (3%).

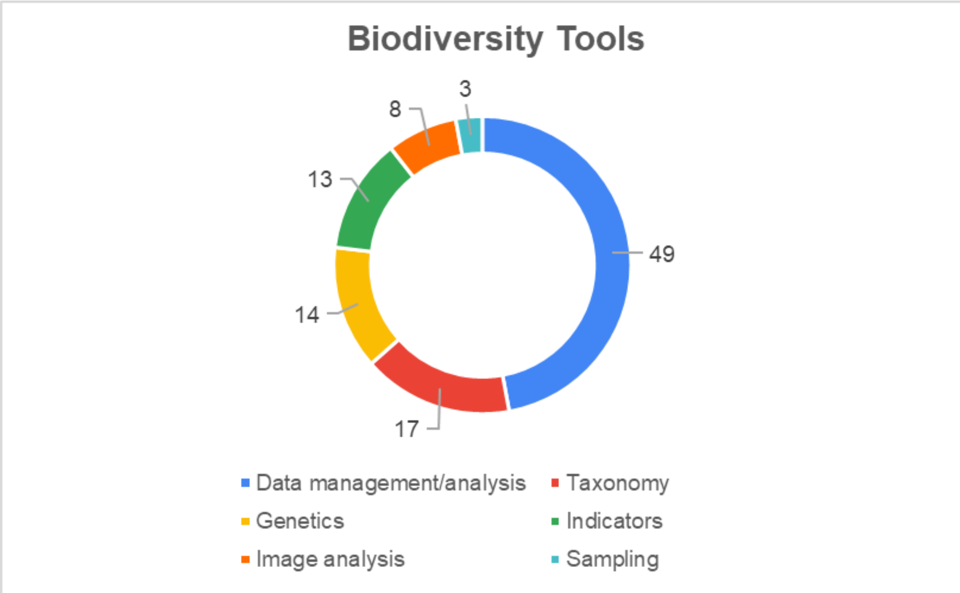


Figure 3.12. The ring chart illustrates the percentage distribution of the different tools based on six categories of application.

Table 3.11 shows in detail how the categories of application for each tool are grouped per ecosystem domain.

Table 3.11. Table shows the tools application categories for each domain.

Multi-domain	
Data management/analysis	28
Taxonomy	13
Genetics	9
Image analysis	4
Indicators	2
Sampling	2
Marine	
Data management/analysis	16
Genetics	5
Image analysis	1
Indicators	1
Sampling	1

Freshwater	
Indicators	8
Taxonomy	2
Aquatic	
Indicators	2
Data management/analysis	2
Image analysis	2
Taxonomy	1
Terrestrial	
Data management/analysis	3
Image analysis	1
Taxonomy	1

4. Discussion of differences and commonalities

This work provides an overview of biodiversity monitoring sampling and analysis methods across the land-sea continuum in Europe, outlining differences and commonalities. The sources used to gather information evolved iteratively, leading to a refinement of the initial compilation. Limitations encountered encompassed restricted access to portals, requiring login credentials, and inadequate delineation of methods and monitoring endeavours in data repositories or dashboards.

The results highlight the importance of legislative frameworks such as the MSFD and the WFD, which provide comprehensive guidance on methodology referred to biodiversity monitoring activities. These directives serve as focal points for retrieving information from individual member states. However, language barriers emerged as a notable obstacle, especially when accessing national institution portals, where information was often available only in the local language. Even when an English version existed, navigating to specific sections dedicated to reporting or methodological details posed challenges, thereby limiting accessibility across various levels of information. These challenges resonate with findings from Jessop et al. (2022), emphasising the need for improved accessibility and transparency in reporting and documentation efforts.

In the context of the MSFD, our primary information source was the WISE-Marine portal[2], which proved to be fruitful and easily accessible. This portal efficiently organises monitoring programs by country, facilitating method retrieval. Its centralised structure streamlined the whole retrieval process, with reporting tables designed to standardise monitoring data across all participating countries. Regarding the WFD, we consulted reports from the Joint Research Centre Geographical Intercalibration Group (GIG)[3], readily accessible through the official repository. The

[2] https://water.europa.eu/marine

[3] https://publications.jrc.ec.europa.eu/repository/

GIG intercalibration activities involve multiple countries within specific geographic regions or ecosystems, with a focus targeted to distinct biological groups. This approach allows comparisons of various monitoring approaches, supporting the identification of gaps and commonalities.

Obtaining information on methodologies for the H&BDs was particularly challenging. Reports available were typically tailored to specific target species or habitats for each country, lacking a standardised format for biodiversity variables and groups. The H&BDs address primarily the conservation of target species and habitats, with monitoring parameters mainly related to their conservation status. These parameters include quantitative aspects, such as range, area, population size, as well as qualitative criteria related to structure and functions, along with forecasts for the future ('future prospects' parameter), as outlined by the European Commission (2016). Notably, guidance on monitoring these species and habitats is not provided. Only guidelines for reporting of the necessary information for assessing sites' state were delivered (DG Environment, 2017; Manea et al., 2021). However, our information retrieval process did non comprehensively address H&BDs, since they often rely on expert opinions to assess the conservation status of species and habitats, and they integrate various monitoring programs and species data without standardised procedures (Morán-Ordóñez et al., 2023). This lack of standardisation can make it challenging to understand the data flows, criteria, and methods employed for data collection and integration at local and sub-national levels.

Initiatives like PECBMS, adopted by various countries, fulfil the objectives of the BD simultaneously. This convergence was beneficial in enabling the identification and understanding of monitoring methods across different legislative frameworks.

However, from our research it also emerged a degree of heterogeneity in the accessibility and reporting practices of information, even within well-established frameworks like the MSFD and WFD:

- Within the MSFD framework, there exist discrepancies in how each country reports its monitoring efforts. Many national programs are still in progress or in the process of implementation, resulting in incomplete (or lacking) details on methodologies. Some reports only specify the target group of the monitoring, while others indicate a projected full implementation year, such as by 2024. Moreover, several countries conduct monitoring for a single descriptor (and its associated biological group) through separate national programs with distinct objectives. For instance, for Descriptor 1, fish fauna is monitored through various national programs focused on coastal monitoring, offshore monitoring, recreational fishing, etc., rather than through a unified program. Additionally, the presentation of information within the reports lacks consistency or systematic organisation across countries.

- In some cases in WFD, countries may be excluded from participation in intercalibration exercises, with reasons outlined in the relevant documents. For instance, some countries, initially engaged in an intercalibration process, postponed their participation or withdrew and then developed their own methods. This exclusion raises concerns regarding methodological uniformity across participating and non-participating countries, especially when not all countries within a geographical macro-region contribute to technical reports.

These challenges are compounded by the fact that the MSFD and WFD, despite outlining comprehensive monitoring requirements, do not provide MS with specific threshold values or baselines for assessing the level of Good Environmental Status (GEnS) and Good Ecological Status (GEcS), respectively (Manea et al., 2021). This absence of guidance may result in divergent approaches adopted by each country.

Within the context of the ESFRI Research Infrastructures (RIs) considered in this deliverable, the availability and detail of extracted information are contingent on the implementation status and developmental stage of the RI. Notably, those already established as ERICs tend to offer more comprehensive information on the services provided and the monitoring methods employed. For example, LifeWatch ERIC and Elixir ERIC have provided detailed information on biodiversity analysis tools. Conversely, eLTER-RI, dedicated to long-term ecological research, is currently in its preparatory phase. Once operational, it will encompass terrestrial, freshwater, and transitional water sites, facilitating the acquisition of standard observations (SOs) across 250 LTER Europe sites. However, given that eLTER is still in the process of drafting methods and protocols for SOs acquisition, detailed information on these is not yet available.

The "GOOS BioEco Metadata Portal" and the Italian "National Biodiversity Network" (NNB) are still in the development phase, which limits the completeness of the information they provide. Additionally, the Citizen Science framework emerges as a valuable way for accessing alternative biodiversity monitoring approaches. Projects sourced from the "EU Citizen Science portal" were included, documenting the potential of Citizen Science initiatives to contribute significantly to biodiversity monitoring.

A noteworthy observation concerns the overlap in information among various sources such as national institutions (e.g., ISPRA, MITRED), international organisations (e.g., HELCOM), and other initiatives. While these sources offer valuable insights into biodiversity monitoring methods, there is often a convergence of methodological information with the Directives. When analysing these sources collectively, it becomes evident that discrepancies in information between and within sources can lead to varying degrees of fragmentation.

Additionally, other sources were evaluated, but did not contain the necessary methodological information. In some case, while potentially useful, the information was fragmentary and considered insufficient to supplement the agreed-upon list. These sources were therefore excluded from the final list. Data repositories such as the ones listed in the Table 1 of the MARCO-BOLO deliverable D6.1 (Stakeholder profiling report), while valuable sources of datasets, remain fragmentary in terms of information on methodologies, as in general they lack a standardized approach for reporting such information in a specific metadata field.

In the paragraph below, we summarise the key aspects obtained from this analysis.

4.1 Geographic and Ecosystem distribution

An analysis of the results reveals that the Mediterranean, North-East Atlantic, and Baltic regions were the most frequently represented in the retrieved data. When examining individual countries, Spain emerges as the most represented, followed by Italy, France, and Germany.

The fragmentation observed in the results primarily stems from the content sourced from the most readily accessible platforms. Notably, the categorization prescribed in the Directives becomes more evident, as monitoring reports typically classify countries into macro- or sub-regions, facilitating the organisation of information by country and macro-region and enabling comparisons. However, despite this categorization, gaps in geographical distribution were still encountered within the directives. Some countries are not consistently included in reports pertaining to specific biological groups and ecosystems within a given region and year, further contributing to fragmentation in the data.

Some countries, such as Spain or Germany, report information for two regions, such as the Mediterranean and North-East Atlantic (for Spain), and the North-East Atlantic and Baltic (for Germany). However, this distinction is not always specified, making it necessary to merge the information. In the case of Spain, there is an additional layer of fragmentation as information is often reported by sub-regions according to specific monitoring programmes (e.g., Cantabria, Andalusia). This confirms that some programmes appear to be nested within broader national programmes and regional frameworks (Jessop et al., 2022). We also observed a bias towards the Mediterranean countries compared to the Eastern ones, these latter being less represented. Northern regions generally exhibit better representation, with monitoring programs more prevalent in the North Sea and Baltic Sea. Conversely, Southern and Eastern European waters tend to be less monitored for biodiversity, as also emerged from the study of Jessop et al. (2022).

Furthermore, conducting such a study within the framework of the EU directives highlights the challenges associated in considering non-EU countries and accessing information about them. This obstacle hindered the possibility of tracing monitoring methods along the land-sea continuum across Europe, thereby exacerbating geographical disparities.

In general, the marine ecosystems are the most represented, largely stemming from the MSFD, indicative of extensive monitoring activities in this domain. Following are continental aquatic ecosystems, including lakes and rivers, as well as coastal and transitional waters, with substantial contribution from the WFD. In contrast, the terrestrial domain is less described and represented, alongside a few other minor eco-domains, indicating a notable imbalance in monitoring focus and data availability across different ecosystems.

4.2 Biological groups and monitored variables

In this study, faunal groups emerged as predominant, with marine ecosystems making significant contributions across these groups. "Benthic invertebrates" and "Fish" were the most extensively monitored, followed by "Flora," particularly "Phytoplankton" and "Macrophytes." Benthic habitats encompassed both faunal and floral groups, with a notable focus on "macrozoobenthos" and "macrophytobenthos." Additionally, "non-indigenous species" were treated as a distinct category and often subjected to separate monitoring efforts. Minor categories included "other protected species status," albeit with comparatively less specific information.

Our findings align with existing literature, indicating that phytoplankton, zooplankton, benthic invertebrates, fish, birds, and mammals are among the most extensively monitored taxa (Jessop et al., 2022). Similarly, our study corroborates the focus of freshwater monitoring on phytoplankton, macroalgae, macrophytes, phytobenthos, benthic invertebrates, and fish (Santana et al., 2023). However, we observed a general absence of EU-wide monitoring initiatives for terrestrial ecosystems, particularly for certain terrestrial biological groups. These groups are likely monitored more extensively at the national and local levels, as previously noted by Morán-Ordóñez et al. (2023).

The inconsistency in terminologies across different sources posed a significant challenge in our study, affecting the aggregation of biological groups under the same category. For example, terms like "Pelagic habitat" and "Benthic habitat" lacked uniformity in referring to offshore marine waters monitoring. Different programs utilised diverse semantics to describe habitat types (e.g., hard/soft-bottom habitat versus benthic habitat) and biological groups (e.g., macrophyte or macrophyte communities; benthic fauna or bottom fauna; Angiosperms or Posidonia beds). This lack of semantic standardisation resulted in fragmentation of the results.

The most used variables for monitored groups were abundance, species composition, and biomass. Distribution was also present but with different specifications (e.g., spatial, range, pattern), leading to ambiguity when not explicitly defined. Additionally, the absence of standardised terminology for variables has the potential to influence the interpretation of methodologies, resulting in a misalignment of the analysed information.

4.3 Monitoring methods

Compiling information on monitoring methods posed significant challenges due to differences in terminology and reference types. This led to fragmentation, especially influenced by biases in reference sources and differences among biological groups.

To address the heterogeneity of information on methods, an Information Richness rating scale was employed to assess the level of detail. This scale categorises each method according to the extent of its description, the level of detail provided, and the accessibility of information. Moreover, we evaluated whether each method adheres to International/European guidelines or standards for macro-regions. The chosen categories were: 'High', 'High-shared', 'Medium', and 'Low'. By analysing each category with respect to Sources, Geographical distribution, and Ecosystems, we can highlight the following points:

• In the "High" and "High-shared" categories, which are predominantly found within the MSFD, methods are extensively described and often shared, particularly with the H&BD and in regional international organisations like HELCOM, as well as frameworks such as PECBMS. However, in the context of the WFD, while methods are typically well described, they are less commonly shared. The Baltic and North-East Atlantic regions are more frequently represented in this category.

Regarding ecosystems, marine environments demonstrate greater sharing of well-described methods compared to freshwater environments. While detailed descriptions are available for freshwater ecosystems, especially for lakes, methods are not as commonly shared in this domain.

• The category Medium comprises sources from both the MSFD and the WFD, with the latter being more represented. Significant contributions to this category come from national networks (e.g., MITRED) and international initiatives (e.g., GOOS, RLS). The Mediterranean region is the most represented, followed by the North-East Atlantic and specific countries. Ecosystems in this category encompass not only marine environments but also fresh, coastal, and transitional waters.

• In the category Low, the main sources include the WFD and Citizen Science initiatives. The Mediterranean region and individual countries are the most represented, particularly associated with freshwater ecosystems, such as lakes and rivers.

Overall, the accessibility of sources significantly influences the comprehensiveness of monitoring methods. Marine ecosystems, governed by the MSFD, tend to have more detailed and widely shared methods compared to freshwater ecosystems.

PECBMS exemplifies effective monitoring for birds, with accessible protocols across multiple domains.

In contrast, the WFD often falls into the "Low” category of information richness, with concise descriptions, mainly focusing on biological indexes. While Citizen Science offers potential for expanded coverage of biodiversity monitoring, it often lacks detailed method descriptions. Language barriers in national networks hinder information access, as highlighted also by Jessop et al. (2022). Northern regions generally exhibit higher information richness, as already described by Morán-Ordóñez et al. (2023), who highlighted the fragmented biodiversity data in European marine waters, particularly from Southern and Eastern regions.

Given the extent and variety of the gathered information, and recognizing the unique characteristics of each biological group within an ecosystem, in Table 4.1 we provide - as significant example - a detailed list of the methods gathered, within the marine ecosystem, for the biological group "Fish", which is among the most extensively monitored across Europe (Jessop et al., 2022). The brief descriptions provided highlight discrepancies among methods used for monitoring fish in the marine ecosystem. Despite the existence of shared guidelines among countries at a regional level, these guidelines were not always explicitly referenced in the descriptions of methods. This lack of explicit reference to shared guidelines may contribute to variability in how monitoring methods are implemented and interpreted across different regions and countries.

The methods employed for fish monitoring exhibit considerable heterogeneity, encompassing techniques such as acoustic surveys, visual census via scuba divers or ROVs, photogrammetry, and videos. These methods vary depending on the type of monitoring program and whether it focuses on coastal or offshore areas. In Mediterranean coastal monitoring, visual census techniques are particularly prevalent. Additionally, cephalopods are often included in surveys conducted under the MSFD. Despite this diversity in monitoring techniques, trawl surveys remain the predominant method for fish surveys (Jessop et al., 2022). Conversely, there is a greater uniformity in the methods of analysis, typically involving taxonomic recognition and quantification of individuals expressed as abundance. While there is alignment in the Baltic Sea and NE Atlantic regions, gaps persist in the Mediterranean region, despite some methodological commonalities among countries. Although there is partial regional agreement and detailed information is available, some inconsistencies impede comparison and harmonisation of methods across different regions.

Some examples of critical issues may include:

- In the Mediterranean area, Slovenia appears in the WISE - MSFD report without specifying a method for fishing monitoring, only referring to target categories and relying on a national by-catch monitoring program.
- In the Mediterranean-NE Atlantic area, Spain provided detailed method descriptions, including reference to a scientific paper. However, it was unclear whether these methods followed a shared protocol. Additionally, there was diversity in the descriptions of the sources, which mentioned MSFD and the National Network, MITRED - EsMarEs.

Table 4.1. Methods of sampling and analysis for the biological group Fish in the 'marine' ecosystem.

Biodiversity Observation Variables	Source	Geographic Distribution	Ecosystem	Method sampling	Method analysis
Abundance, Biomass, spatial and range Distribution	MSFD	Mediterranean (ES)	marine	- Non-intrusive methods such as scuba visual surveys, carried out at a fixed depth range between 5 and 35 metres, with intervals of 5 metres (for coastal fish). - Fish and cephalopod populations are directly identified through visual means, using photogrammetry and video technology, including photogrammetric sleds, Remotely Operated Vehicles (ROV), and landers.	The quantification method involves conducting 3 replicates of 50 x 5 m line transects (covering a total area of 250 m²). Information obtained from each transect and captured in a comprehensive list of fish species. For each species data on density, length, and weight documented. Spatial variation is accounted for through hierarchical and nested sampling techniques.
Abundance	MSFD	Mediterranean (FR)	marine	Sampling of coastal and offshore areas is conducted in situ using: bottom trawls employing various gear types, such as GOV and beam trawls, to capture the fish, including elasmobranch, and cephalopod community.	Species identification, numbers of individuals by size class (primarily length). Species infrequently encountered may be documented simply as present, without length or weight measurements.
Abundance	MSFD	Mediterranean (IT)	marine	Underwater visual censuses are conducted using the transect technique, in unprotected and	N.A. (in the report is not specified)

				protected sites, covering rocky bottoms at two distinct depth intervals.	
Abundance, Biomass, Distribution pattern-range	MSFD	Mediterranean (CY)	marine	A bottom trawl made of four panels serves the as sampling gear), deployed within a depth stratified sampling scheme. Positions within each depth stratum, ranging from the surface to 800 meters, are randomly selected for sampling. The monitoring is mainly focused on the category "Demersal-shelf fish".	Species identification sheets for selected families and species include an alpha-numerical code for both family and species, along with valid scientific names and synonyms still in use. Additionally, data collection for each species will include the total weight and the number of individuals.
Abundance, spatial Distribution	MSFD	Mediterranean (HR)	marine	In-situ sampling of coastal and offshore areas involve the use of a scientific bottom trawl net. During sampling, the ship maintains a constant speed of 3 nautical miles per hour at all stations, with each tow lasting for a duration of 30 minutes.	On the deck of the ship all individuals are identified to the highest possible taxonomic level, possibly to the species level. Specimens requiring further determination are separated and stored in formalin solution for further analysis. Species encountered at each station are also photographed to maintain a visual record. The abundance of individual species at all stations is expressed as the number of individuals per km2 (N km^{-2}; abundance index) and as wet mass per km2 (kg km^{-2}; biomass index), using the catchability coefficient, q=1.

					Whenever possible, the total bycatch is analysed. At stations where the amount of bycatch was very abundant, a subsampling method is used.
Abundance, Extent	MSFD	Mediterranean (SI)	marine	N.A.; only the sentence appears in the report: “The category monitored is "Coastal fish" with in-situ sampling coastal (the Coastal Fish Monitoring Programme refers to the criteria element Inadvertent by-catch of endangered species of birds, mammals, reptiles, fish and cephalopods not exploited for commercial purposes)	N.A.

Abundance, Distribution, Species composition	EsMarEs (MITRED)	Mediterranean (ES)	marine	Sampling is conducted using non-intrusive methods, such as scuba visual surveys. Quantification is achieved through 3 replicates of 50 x 5 m (250 m^2) line transects. Additionally, three replicates are carried out also to ensure adequate sampling of cryptic species. Spatial variation is accounted for through hierarchical and nested sampling.	Data collected from each transect is compiled into a complete list of fish species. For each species, associated density, length, and weight measurements are recorded, to obtain biomass derived from length conversion calculations. Spatial variation is e addressed by hierarchical and nested sampling methodologies.
Abundance, Distribution, Species composition	EU Citizen Science	Mediterranean	marine	Citizen observations of Mediterranean elasmobranchs entail documenting individual sightings through photographs and recording detailed observations.	N.A.
Abundance /Biomass, Distribution range, Extent	MSFD	NE Atlantic (NL)	marine	A standard bottom trawl, equipped with Grand Overture Vertical (GOV) gear type, employs multiple trawls according to the principles of ‘stratified random sampling’.	All catches from valid hauls are thoroughly sorted, if feasible. Fish and shellfish species are identified to the lowest taxonomic level achievable. For larger catches, a subset of species or size categories may be selected and properly sampled based on their abundance.

Abundance, Biomass, Distribution range-spatial	MSFD	NE Atlantic (ES)	marine	Sampling relies on non-intrusive methods like scuba diving visual census. Along each transect, the diver swim one way at constant speed, approximately 4 meters per minute, identifying and recording the number and size of each encountered fish.	The quantification method entails conducting 3 replicates of linear transects of 50 x 5 meters (250 m^2). Fish wet mass is estimated from size data by means of length-weight relationships derived from the available literature.
Abundance, Biomass	MSFD	NE Atlantic (PT)	marine	Monitoring is conducted through several methods: underwater coastal visual censuses, using diving, pelagic bottom trawls with various gears including GOV and Beam, and through auction sampling. The coastal zone is also covered by a campaign designed specifically for (non-rocky) habitats occurring at depths <50m.	The mass of fish and elasmobranch at different length values is estimated from the number of individuals within each size class using length-weight relationships, specific for each species (from national data or extracted from www.fishbase.org).

Abundance, Biomass, Distribution range	HELCOM	Baltic sea	marine	The common monitoring strategy in fisheries independent surveys involves tracking changes over time (years) at fixed stations. The focus is on relative abundance of different segments of the coastal fish community in each monitoring area. Monitoring is generally performed using passive gears, such as gillnets or fyke nets, but active gears, such as trawls, are also used in some areas. The monitoring areas often serve as reference points where the direct impact of human activities is relatively minimal. The primary goal of this monitoring is to reflect large-scale changes in the Baltic marine environment. -HELCOM guidelines (H.g.)	All fish are identified to species and their length and weight are directly measured during the monitoring activities. Environmental parameters are also measured directly in connection with the monitoring. Raw data are used for calculating catch per unit of effort (CPUE), serving as the basic unit in the data analysis and indicator-based assessments. -HELCOM guidelines (H.g.)
Abundance, Biomass, spatial Distribution range-pattern, Extent	MSFD	NE Atlantic-Baltic (DK)	marine	HELCOM guidelines (H.g.)*	HELCOM guidelines (H.g.)*
Abundance /Biomass, spatial Distribution	MSFD	NE Atlantic-Baltic (DE)	marine	(H.g.)*	(H.g.)*
Abundance, Biomass, Distribution range	MSFD	Baltic (FI)	marine	(H.g.)*	(H.g.)*
Abundance, Biomass, Distribution range-pattern	MSFD	Baltic (LT)	marine	(H.g.)*	(H.g.)*
Abundance, Biomass, Distribution	MSFD	Baltic (LV)	marine	(H.g.)*	(H.g.)*

Abundance, Biomass	MSFD	Baltic (PL)	marine	(H.g.)*	(H.g.)*
Abundance, Biomass, Distribution range	MSFD	Baltic (SE)	marine	(H.g.)*	(H.g.)*
Abundance, Biomass, spatial Distribution	MSFD	Baltic (EE)	marine	For monitoring offshore fish species, the hydro-acoustic surveys and scientific trawls are carried out. Data on all coastal fish species are collected annually in discrete monitoring areas, as part of the national fisheries data collection program. [1]	Based on the collected material, biological analyses are performed, and the age of the individuals is determined.
Abundance, Biomass, Distribution	GOOS	NE Atlantic (IE)	marine	Trawl fishing stratified survey	All fish and invertebrate species are sorted and weighed. Biological data are collected for the species identified.
Abundance, Biomass, Distribution	GOOS	NE Atlantic (IE)	marine	Acoustic Survey	Age stratified relative stock abundance estimates within the survey area are calculated using acoustic data and biological data from trawl sampling.

[1] The member state declares to follow HELCOM guidelines, but the methodology is quoted according to a national and ICES report.

* (H.g.): 'HELCOM guidelines'; N.A.: 'Not Available' (the method is not specified in the report)

4.4 Tools

Accessing information on tools for biodiversity analysis proved to be scattered across various sources. While tools from sources like "LifeWatch" and "Elixir.biotools" were readily available, others required searching across different locations, being many tools embedded within individual research projects or national monitoring programs.

Our findings also reveal some overlap among tools for biodiversity data analysis and management. For instance, the "Elixir.biotools" section predominantly features tools for genetics data analysis and management. Conversely, other application categories like image analysis and sampling support are less frequent in this source. In contrast, LifeWatch provides a wider array of applications, including an easily accessible section dedicated to VREs.

In terms of domains of application, tools for index calculation are more prevalent in freshwater environments. Tools with multi-domain functionality are abundant, guaranteeing versatility, while certain tools respond to specific needs, such as taxonomic traits of marine plankton. It's important to recap our definition of tools, focusing on VREs supporting biodiversity analysis. This definition excludes web-based software unless integrated into VREs. For example, tools offering dashboards for visualising biodiversity data or code packages for data analysis software were not considered unless part of VREs like R packages. While the information provided for the tools is generally concise for retrieval and reporting, it may not always offer a comprehensive understanding of their functionality. The analysed tools are generally accessible and freely available, often accompanied by user guides. However, some tools may require specialised knowledge and complementary external software for optimal use.

5. Final recommendations

This study offers a valid approach to assess the status of biodiversity monitoring methods across the land-sea continuum in Europe. The results provide valuable insights and can serve as foundational knowledge for enhancing the existing methodological framework in biodiversity monitoring. While this analysis focuses on European monitoring networks, its findings can be adaptable to various scales, including regional, national, and specific ecosystem levels. This adaptability facilitates an evaluation of methods in other contexts, thus contributing to a broader understanding of biodiversity monitoring practices.

Accessibility and data availability continue to pose significant challenges, restricting access to a broader audience beyond institutions conducting the monitoring. Additionally, fragmentation in the location and reporting of information enhances misinterpretation and hinders efforts towards harmonisation. Addressing these issues is essential for advancing biodiversity monitoring efforts and ensuring the availability of comprehensive and accessible data for informed decision-making.

Here after, we outline some recommendations for future actions for improving biodiversity monitoring in Europe:

- **information convergence points**: WISE-Marine serves as a model for information convergence in MSFD monitoring across diverse regions and countries, focusing on a specific domain. Developing similar portals for other domains could be beneficial. Additionally, a centralised portal for accessing all tools for biodiversity analysis could serve as a valuable resource;

- **semantic harmonisation:** to address the inconsistency in terminology for observation variables, a potential solution could involve using standardised semantic labels, such as controlled vocabularies and thesauri, which unequivocally identify the variables used to analyse the monitored group;
- **methods harmonisation:** to have agreed and broadly adopted methods across ecosystems could lead to better shared biodiversity observations. For the marine realm a valuable example could be the Ocean Best Practices System (OBPS)[4], jointly sponsored by IODE and GOOS Programmes; moreover, to better integrate data generated using different protocols, standardized metadata describing protocols could be developed and linked to associated datasets in data repositories;
- **collaboration**: encourage collaboration among monitoring networks, research institutions, and governmental bodies can facilitate the sharing of best practices, methodologies, and resource;
- **accessibility**: improving accessibility and availability of information to a broader range of stakeholders, including researchers, policymakers, and the public, is crucial for fostering transparency, accountability, and informed decision-making in biodiversity conservation and management;

These recommendations partly align with those proposed by the Europa Biodiversity Observation Network (EuropaBON), which suggests five clusters of solutions to improve the collection and uptake of policy-relevant biodiversity data. These overall solutions include:

- enhancing coordination and collaboration of monitoring efforts, to streamline data collection and sharing processes;
- increasing data standardisation, by combining different Essential Variables frameworks (EBVs, EESVs and EOVs), to ensure consistency and comparability of data across different monitoring initiatives;
- leveraging modelling efforts and new technologies, to enhance data analysis and interpretation;
- enabling additional, consistent, and long-term financial resources to support monitoring efforts, ensuring their sustainability and continuity;
- expanding capacity building through new exchange knowledge platforms, and embracing citizen science initiatives, to engage the public in biodiversity monitoring and conservation efforts.

The creation of a European Biodiversity Monitoring Coordination Centre, as also proposed by EuropaBON, would undoubtedly be an asset in advancing the collection, analysis, reporting, and political uptake of biodiversity data in all European countries. This coordinated approach can

[4] https://www.oceanbestpractices.org/

significantly enhance the effectiveness and impact of biodiversity monitoring efforts in Europe, ensuring the inclusion of the different expertise and information, comprehensive of all the relevant eco-domains.

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https://www.embrc.eu/

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https://bioeco.goosocean.org/

- HELCOM 'Baltic Marine Environment Protection Commission' (Helsinki Commission)

https://helcom.fi/

-ISPRA 'Italian Institute for Environmental Protection and Research'

https://www.isprambiente.gov.it/en?set_language=en

-JRC Publications Repository

https://publications.jrc.ec.europa.eu/repository/

- LifeWatch ERIC

https://www.lifewatch.eu/

- Ministerio de Transición Ecológica y el Reto Demográfico (MITERD) - Estrategias marinas

https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/estrategias-marinas/eemm_2dociclo_fase4.html

-National Biodiversity Network (IT)

https://www.nnb.isprambiente.it/en

-WISE-Marine Information System for Europe

https://water.europa.eu/marine

- Pan-European Common Bird Monitoring Scheme

https://pecbms.info/

-Reef Life Survey

https://reeflifesurvey.com/

-SeagrassNet

https://www.seagrassnet.org/

Appendix

Annex 1

See here for the table containing all the retrieved information:

https://docs.google.com/spreadsheets/d/1z4ivcTQ1uTPqcT4eAkbXVEGzJh3J770qps4xYmb6mlY/edit?usp=sharing

MARCO-BOLO

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