D1.2 Biodiversity Specific Geospatial Reporting Indicators - Preliminary Framework (interim)

Funded by
the European Union

Document Identification			
Related WP	WP1	**Document reference**	D1.2
Status	Final	**Submissions date**	30/12/2025
Related deliverables	-	**Dissemination Level**	PU
Lead Author	Mayte Toscano (OGC)	**Version**	0.2
Co-Authors	Rob Atkinson (OGC) Arne Jørgen Berre (SINTEF) Laura Slaughter (SINTEF) Volker Hoffmann (SINTEF)	**Reviewers**	Bob O'Hara (NTNU) Kristin Böttcher (SYKE) Tomas Mildorf (UWB)
Keywords	Biodiversity, Standardization, Interoperability, Indicators, Geospatial	**Website**	http://bioclima.net/

This document is issued within the frame and for the purpose of the BioClima project. This project has received funding from the European Union's Horizon-RIA Framework Programme under Grant Agreement No. 101181408. The opinions expressed and arguments employed herein do not necessarily reflect the official views of the European Commission.

Document History			
Version	**Date**	**Change editors**	**Changes**
0.1	01/10/2025	Mayte Toscano (OG	Initial Draft
0.2	19/11/2025	Bob O'Hara Kristin Böttcher	revision
0.3	15/12 2025	Arne J. Berre, Laura Slaughter, Volke Hoffman (SINTEF)	Input on Policies, Projects and Ethics
1.0	22/12/2025	Mayte Toscano (OGC)	Final version

Table of Contents

List of Tables

List of Figures

List of Acronyms

Acronym	Definition
AI	Artificial Intelligence
API	Application Programming Interface
BD	Biodiversity Data
CBD	Convention on Biological Diversity
CARE	Collective Benefit, Authority to Control, Responsibility, Ethics
CBD COP	Conference of the Parties to the Convention on Biological Diversity
DSS	Decision Support System
EBV	Essential Biodiversity Variable
ECV	Essential Climate Variable
EO	Earth Observations
EOSC	European Open Science Cloud
ESG	Environmental, Social and Governance
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
FAIR-R	FAIR – Ready for Artificial Intelligence
GAIA-X	European federated data infrastructure initiative for secure and sovereign data sharing
GBF	Global Biodiversity Framework
GEOSS	Global Earth Observation System of Systems
GEOBON	Group on Earth Observations Biodiversity Observation Network
GIS	Geographic Information System
ISO	International Organization for Standardization
KPI	Key Performance Indicator
OGC	Open Geospatial Consortium
OSPD	Open Science Persistence Demonstrator
QA/QC	Quality Assurance / Quality Control
RAINBOW	OGC Registry for Semantic Alignment and Interoperability Profiles
SDG	Sustainable Development Goal
TDWG	Biodiversity Information Standards (Taxonomic Database Working Group)
TNFD	Taskforce on Nature-related Financial Disclosures
UNEP-WCMC	United Nations Environment Programme – World Conservation Monitoring Centre
W3C	World Wide Web Consortium
WMO	World Meteorological Organization
WP	Work Package

1 Executive Summary

Deliverable D1.2, *Biodiversity-Specific Geospatial Reporting Indicators*, contributes to **WP1 – Integrated Observations for Climate and Biodiversity**, which establishes the foundation for **data integration, standardisation, and interoperability** across all BioClima activities. WP1 acts as the project's central data and standards hub, ensuring that biodiversity and climate observations—ranging from in situ and citizen science data to satellite and AI-derived information—can be consistently harmonised, validated, and reused across Europe and China.

This deliverable defines the preliminary framework for **geospatial reporting indicators** that support the calculation and harmonisation of **Essential Biodiversity Variables (EBVs)** and **Essential Climate Variables (ECVs)**.

It outlines how open, standardised data protocols—based on Open Geospatial Consortium **(OGC), ISO/TC 211**, Biodiversity Information Standards- Taxonomic Database Working Group (TDWG), and World Wide Web Consortium **(W3C)** standards—can underpin the integration of multi-source environmental information into policy-relevant indicators and evidence-based decision-making.

Building on the project's emphasis on **data interoperability and federation**, D1.2 applies the **FAIR**, **CARE**, and **FAIR-R (AI-ready)** principles to ensure that BioClima data are not only technically accessible but also **ethically governed**, **machine-actionable**, and **sustainably reusable**. The framework integrates advanced data access mechanisms (e.g. **OGC API – Features, Coverages, and EDR**) with validation environments such as **OGC RAINBOW** and the **Data Exchange Tool**, establishing a transparent and reproducible basis for environmental data exchange.

BioClima's approach directly supports the **EU–China cooperation on improving monitoring for integrated climate and biodiversity approaches**, as described in the Horizon Europe call **HORIZON-CL6-2024-CLIMATE-01-7**.
Through shared standards, federated infrastructures, and aligned governance models, the project contributes to a joint EU–China observation and demonstration platform that connects European initiatives (e.g. **Green Deal Data Space**, **Destination Earth**, **European Open Science Cloud-EOSC**) with the **Chinese SDG Big Data Platform**.

The outcomes of D1.2 will enable downstream activities:

- **WP2**, which builds on these indicators to analyse spatial biodiversity–climate interactions;
- **WP3**, which uses harmonised and FAIR-R datasets to train AI-enhanced analytics models; and
- **WP5**, which disseminates best practices and fosters EU–China collaboration through communication and training.

In summary, D1.2 translates the objectives of WP1 into a practical roadmap for sustainable and interoperable biodiversity and climate monitoring. By connecting scientific observation, standardisation, and sustainability governance, BioClima contributes to a trusted and open environmental data infrastructure—supporting global policy frameworks such as the **Kunming–Montreal Global Biodiversity Framework**, the **EU Biodiversity Strategy 2030**, and the **European Green Deal**.

2 Introduction

2.1 Purpose of the document

The purpose of this document is to establish a **preliminary framework for biodiversity-specific geospatial reporting indicators**, conceived as an initial step towards the standardisation of observation systems related to biodiversity and climate change.

This deliverable has been developed within the framework of **Work Package 1 (WP1)** of the **BioClima** project, and it is directly linked to **Task 1.1 "Standards for observational systems of biodiversity and climate change"**, which aims to describe applicable standards for terrestrial ecosystem observation systems and ensure that the data generated comply with the **FAIR principles** (Findable, Accessible, Interoperable, and Reusable).

The document introduces an **initial concept of geospatial reporting indicators**, understood as a structured set of spatial and thematic metrics designed to assess, communicate, and compare information on the state and dynamics of biodiversity and its interactions with climate. These indicators are intended to serve as a methodological foundation for **policy and disclosure frameworks** such as the **Taskforce on Nature-related Financial Disclosures (TNFD)**, **Environmental, Social and Governance (ESG) reporting**, and the **Sustainable Development Goals (SDGs)**.

In addition, the document identifies the **data harmonisation requirements** needed to ensure interoperability among different systems and data sources. Harmonisation is addressed across three complementary levels:

- **Syntactic**, referring to data formats and structures;
- **Structural**, referring to conceptual models and information schemas; and
- **Semantic**, focusing on ontologies, vocabularies, and RDF models that guarantee a shared understanding across disciplines and platforms.

In addition, semantic technology standards will be used to provide a ubiquitous capability for multi-lingual terminology support.

The proposed approach acknowledges the diversity of data sources —including *in situ* observations, remote sensing, citizen science, and modelling— and promotes their integration within a **standardised and open ecosystem**. To this end, it builds upon the work of international standardisation bodies such as the **Open Geospatial Consortium (OGC)**, **TDWG (Biodiversity Information Standards)**, **ISO**, **W3C**, and **Global Earth Observation System of Systems (GEOSS)**, encouraging convergence between the biodiversity, climate, and geoinformation communities.

Alongside the FAIR principles, the document also incorporates the **CARE principles** (*Collective Benefit, Authority to Control, Responsibility, and Ethics*), which guide the responsible and equitable use of data related to Indigenous Peoples, local communities, and traditional knowledge. These principles complement FAIR by introducing an **ethical, social, and governance dimension** to biodiversity data management, emphasising the need to ensure collective benefit, respect data authority, promote responsibility in data use, and guarantee that all observation and reporting practices are carried out under principles of fairness and cultural respect.

In this way, the document addresses not only the **technical and semantic interoperability**, but also the **social and ethical interoperability** required for the fair and sustainable use of environmental data.

Furthermore, this deliverable serves as a **cross-cutting reference** within the BioClima project, providing the conceptual and technical foundations that guide interactions between the different work packages. Specifically:

- It contributes to **WP2** by providing the methodological basis for the development of biodiversity and climate indicators;
- It supports **WP3** by defining the FAIR/CARE data management and interoperability conditions required for the integration of data derived from artificial intelligence and citizen science; and
- It facilitates **WP5** by offering a coherent conceptual framework for dissemination, training, and communication activities.

Overall, **Deliverable D1.2** lays the groundwork for the development of an **observation and reporting ecosystem for biodiversity and climate change** aligned with the **FAIR and CARE principles**, international standards, and European policies on sustainability, transparency, and open science.

2.2 Relation to other project work

This document is part of Work Package 1 (WP1) of the BioClima project, whose overall objective is to establish the conceptual and technical foundations for the observation, standardisation and interoperability of data on biodiversity and climate change. In particular, **D1.2** is closely linked to the results of **Tasks 1.1 and 1.2**, which are aimed at developing standards, methodologies and indicator frameworks to ensure the quality and compatibility of the data generated in the different components of the project.

Deliverable D1.2 is directly related to other work packages, serving as a link between technical standardisation and the practical application of geospatial indicators.

Its role within the project is twofold: on the one hand, it provides the **methodological and regulatory basis** that guides the design of indicators in WP2; and on the other, it offers the **interoperability and FAIR data management references** that underpin the technological integration and dissemination work carried out in WP3 and WP5, respectively. Specifically:

- **WP2 – Indicators and assessment**: The preliminary framework defined in this document feeds into the definition of **geospatial indicators of biodiversity and climate**, contributing to their alignment with international standards (OGC, TDWG, GEOSS) and with policy and financial frameworks such as **TNFD** or the **SDGs**.
- **WP3 – Artificial Intelligence and Citizen Science**: The interoperability specifications and FAIR data recommendations included in this document guide the integration of **new data sources**, including citizen observations and information flows processed using artificial intelligence, ensuring their compatibility with standardised observation systems.
- **WP5 – Dissemination, Training and Communication**: D1.2 provides common content and terminology for **training and dissemination** activities, facilitating the transfer of knowledge on geospatial standards, indicators and FAIR practices to international stakeholders and open science platforms (e.g. **GEO Knowledge Hub**).

In this way, document **D1.2** is not only a stand-alone technical product, but also a **linking element** between the different components of the BioClima project. Its function is to ensure consistency between methodological, technological and communication developments, contributing to an integrated approach to the **observation, reporting and sustainable management of biodiversity and climate change**.

2.3 Structure of the document

The document is structured to provide a coherent narrative that connects the conceptual, technical, and policy aspects of biodiversity and climate data interoperability. It begins with an overview of the objectives, scope, and expected outcomes of Deliverable D1.2, followed by an explanation of its purpose, context within the project, and the key principles that guide BioClima's approach to standardisation.

Subsequent sections explore the international and European policy frameworks that shape biodiversity and climate reporting and describe BioClima's role within global standardisation initiatives such as the OGC, TDWG, ISO, and W3C.

The central part of the document focuses on the development of the standardised ecosystem for observation systems and the identification of relevant standards supporting interoperability.

Finally, the document presents the work plan for the upcoming period and concludes with a summary of the main findings and recommendations, highlighting how the results of WP1 will feed into the following stages of the BioClima project.

2.4 Glossary adopted in this document

The terminology used throughout this deliverable follows recognised international standards and project-specific conventions. Key terms include:

- **FAIR principles** – Guidelines ensuring that data are *Findable, Accessible, Interoperable,* and *Reusable*.
- **CARE principles** – A complementary framework promoting *Collective Benefit, Authority to Control, Responsibility,* and *Ethics* in data governance.
- **FAIR-R** – Extension of FAIR principles integrating *AI readiness* and responsible data use in artificial intelligence applications.
- **EBVs (Essential Biodiversity Variables)** – Core variables for biodiversity monitoring as defined by GEO BON and the CBD framework.
- **ECVs (Essential Climate Variables)** – Key physical, chemical, or biological variables describing the Earth's climate system, coordinated by the WMO.
- **OGC (Open Geospatial Consortium)** – International organisation developing open standards for geospatial and location data.
- **TDWG (Biodiversity Information Standards)** – Global community developing standards for the management and exchange of biodiversity data.
- **RAINBOW** – OGC semantic registry and validation environment used for managing interoperability profiles.
- **Data Exchange Tool** – OGC interoperability tool for validating and transforming datasets according to standardised profiles.
- **OSPD (Open Science Persistence Demonstrator)** – Framework for documenting and sharing reproducible workflows following FAIR and open science practices.

This glossary ensures consistency across the deliverable and alignment with terminology used in other BioClima work packages and international initiatives.

3 Guiding Principles

3.1 FAIR Principles

The **FAIR principles** —*Findable, Accessible, Interoperable and Reusable*— are a set of internationally accepted guidelines for the **responsible, efficient and sustainable management of scientific data**. Their aim is to ensure that data produced in observation systems can be found, used and combined by different users, institutions and technologies, contributing to a more transparent, reproducible and useful information ecosystem for research and policy-making.

From the perspective of the **OGC**—the primary body responsible for developing open standards for geospatial data—the FAIR principles are interpreted and applied specifically to meet the needs of infrastructures (variously known as **Spatial Data Infrastructures (SDI)**, Data Spaces and Digital Twins), **interoperability between systems** and the promotion of an **environment of open and collaborative standards**.

The adoption of the FAIR principles by the OGC strengthens the global geospatial data ecosystem by ensuring that data is:

- **Findable**, through interoperable catalogues and metadata;
- **Accessible**, through standardised interfaces and APIs;
- **Interoperable and Usable,** across different platforms, domains and applications;
- **Reusable**, thanks to clear licensing, traceability, and data documentation.

The essential components of each of the FAIR principles, as understood and promoted within the OGC framework, are detailed below:

3.1.1 Findable (F)

Data must be easily findable by both people and machines.

The OGC promotes the use of **standardised metadata** and **interoperable catalogue services**, such as **OGC Catalogue Services,** which can support extended semantic interoperability through integration of**GeoDCAT** and other ontology profiles, which enable the search, identification and retrieval of datasets and services through portals and search engines.

Key elements:

- Use of **unique and persistent identifiers** (e.g. URIs) that ensure traceability and unambiguous referencing of resources.
- Inclusion in metadata of detailed spatial and temporal information, formats, coordinate reference systems, resolution levels and data managers.
- Publication in interoperable catalogues that enable federation and automated discovery of resources at regional, national or global level.
- Comprehensive mapping of schema and content to a common standards-based semantic model.

3.1.2 Accessible (A)

Data and services must be **easily and securely retrievable** using standardised and open communication protocols.

For example, OGC provides a consolidated set of **web services and APIs** that facilitate structured and controlled access to geospatial data.

Key elements:

- Use of OGC services such as **WMS (Web Map Service)**, **WFS (Web Feature Service)**, **WCS (Web Coverage Service)** and the new **OGC API Standards** (e.g. *OGC API – Features*, *Tiles*, *Coverages*), which ensure technical interoperability between data providers and consumers.
- Use of **open and universally implementable protocols**, such as HTTP or HTTPS, to maximise accessibility and compatibility.
- Definition of **authentication and authorisation mechanisms** where necessary, maintaining a preference for **open access** and the principle of "as open as possible, as restricted as necessary".
- Semantic definitions of parameters and parameter ranges to enable generation of suitable data access queries

3.1.3 Interoperable (I)

Data must be **compatible and combinable** with other data sets and services through the use of **open and shared vocabularies, ontologies, and standards**.

Interoperability is a central pillar of the Bioclima's work and is achieved through the design of consistent, standardised information models that facilitate integration across disciplines and applications.

Key elements:

- Application of **OGC standards** that define consistent formats and structures for the exchange of geospatial information.
- **Alignment with other international standardisation bodies** such as **ISO (International Organisation for Standardisation)**, **W3C (World Wide Web Consortium)** and **IETF (Internet Engineering Task Force)**, promoting compatibility between technological frameworks.
- Enhanced interpretability and processing automation through support for **Linked Data** and **Semantic Web** technologies using standards such as **OGC GeoSPARQL**, which enable spatial data to be connected to other domains of knowledge through semantically rich representations.

3.1.4 Reusable (R)

Data must be sufficiently **described, documented and licensed** to be reused in different contexts, disciplines and applications.

The principle of reuse implies not only technical access, but also **clarity in the conditions of use and the quality of the data**, guaranteeing its scientific, operational and social value.

Key elements:

- Inclusion of **rich metadata** detailing the provenance of the data, its quality, methods of acquisition and conditions of use.
- Explicit information on **licences for use**, preferably based on open and standardised frameworks such as **Creative Commons**, which facilitate responsible redistribution and reuse.
- Use of **flexible and documented data models** that support multiple applications, transformations and combinations, ensuring the long-term sustainability of the digital resource.
- Modular inclusion of additional aspects of metadata such as licence and data quality to assist in evaluation and re-use decisions.

Taken together, the FAIR principles, as implemented in the OGC ecosystem, provide a solid framework for ensuring that geospatial data on biodiversity and climate change are **findable, accessible, interoperable and reusable**.

Their adoption within BioClima is an essential step towards the harmonisation of standards, open data and interoperability between scientific domains, enabling more effective integration between terrestrial observation, remote sensing, citizen science and environmental modelling.

3.1.5 From FAIR to FAIR-R: 'AI-ready' data

In recent years, the international debate on data management has evolved into a new phase that seeks to connect FAIR principles with the ethical and responsible development of artificial intelligence. In this context, researcher Stefaan G. Verhulst[1], co-founder of the GovLab (New York University), has proposed the concept of a 'fourth wave of open data'[2], in which public and scientific data must not only be accessible and interoperable, but also 'AI-ready.'

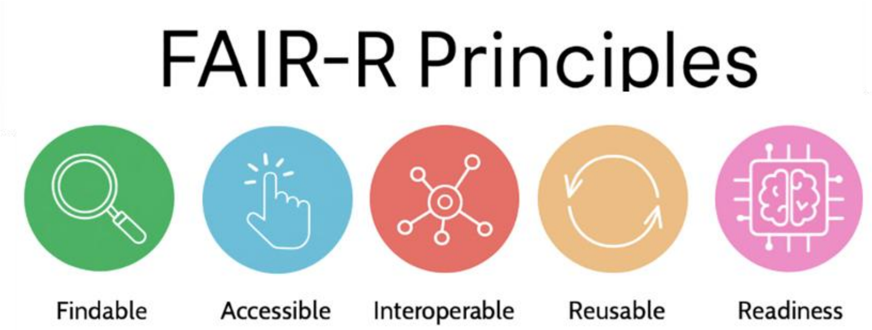

Figure 1.- FAIR-R principles

This vision is embodied in the **FAIR-R** (*FAIR + Readiness for AI*) framework, which extends the FAIR principles with a fifth dimension focused on the **readiness, quality and responsibility of data used in artificial intelligence**. The approach has recently been adopted and promoted by the **Open Data Portal of the Regional Government of Andalusia** as a benchmark in the transition towards a model of **intelligent open data** capable of feeding AI systems in a secure, transparent and socially valuable manner[2].

The main components of the FAIR-R framework include:

[1] Verhulst, S. G. (2025). A Fourth Wave of Open Data? Combining Open Data and AI creatively for Social Impact.

[2] Verhulst, S. G. (2025). Moving Toward the FAIR-R Principles: Advancing AI-Ready Data.

- **Comprehensive labelling, annotation and semantic enrichment** of data.
- **Complete documentation of the provenance and lineage of datasets**, ensuring transparency and traceability.
- **Use of homogeneous standards, formats and metadata**, facilitating the training of unbiased AI models.
- **Adequate coverage and quality** to avoid exclusions or lack of representativeness.
- **Clear and specific licences for AI uses**, regulating model training and preventing misuse.

Adopting the FAIR-R approach offers substantial benefits: it improves the accuracy and efficiency of AI models, facilitates the generation of useful knowledge for public policy (e.g., in health, biodiversity, or climate change), and promotes more ethical, inclusive artificial intelligence that serves society.

Consequently, **FAIR-R does not replace FAIR**, but rather complements it, integrating the technological and ethical dimensions required by the 'fourth wave of *Open Data*'. Its application to the field of biodiversity and climate change represents an opportunity to ensure that the data generated by BioClima is FAIR, CARE and AI-Ready, and can feed into observation systems and predictive models based on artificial intelligence in a responsible manner and with a positive impact on society.

3.2 CARE principles

The **CARE principles** —*Collective Benefit, Authority to Control, Responsibility, and Ethics*— complement the FAIR principles by introducing a **social, ethical, and governance dimension** into data management. While the FAIR framework focuses on technical interoperability and openness, CARE addresses the **human and community conditions** surrounding the use and reuse of information, particularly in contexts where data reflect knowledge, practices, or resources from **Indigenous Peoples, local communities, or vulnerable groups**.

Within the **BioClima** project, adopting the CARE principles is essential to ensure that geospatial, ecological, and social data used for biodiversity and climate change observation are handled in an **equitable, responsible, and collectively beneficial** manner, strengthening the legitimacy and acceptance of data infrastructures in the territories where they are applied. The four principles are outlined below.

3.2.1 Collective Benefit (C)

The principle of **Collective Benefit** states that the production, use, and circulation of data should **contribute to collective well-being** and generate **shared social, environmental, and economic value**. Data should not be considered merely as a technical or scientific resource but also as a **common good** that can strengthen resilience, governance, and environmental justice.

In the context of BioClima, this means that observation, modelling, and indicator-generation activities should:

- Promote **tangible benefits** for the communities and regions involved, such as improved ecosystem management, climate adaptation, or local capacity building.
- Ensure that analytical results and indicators are **accessible and understandable** to all relevant stakeholders, including local authorities, civil society organisations, and citizens.
- Foster **open science with social impact**, so that data serve not only research purposes but also **evidence-based sustainable decision-making**.

Thus, the principle of collective benefit turns FAIR and FAIR-R data into tools for **public action and territorial equity**.

3.2.2 Authority to Control (A)

The principle of **Authority to Control** recognises the right of communities, institutions, or legitimate actors to **decide over the access, use, interpretation, and redistribution of their data**. In the field of biodiversity, this is particularly relevant when data include information about **biological resources, traditional territories, or local ecological knowledge**.

Applied to BioClima, this principle means that:

- Communities and entities providing data must **retain sovereignty over their information**, setting clear conditions for its use.
- Data agreements and metadata should include **mechanisms for informed consent and traceability**, ensuring that control remains in the hands of those who generate or steward the data.
- A **participatory data governance model** should be promoted, integrating local, scientific, and administrative actors in decision-making processes regarding data use and dissemination.

Authority over data does not oppose openness; it **contextualises and regulates** it, ensuring a balance between **access and informational self-determination**.

3.2.3 Responsibility (R)

The principle of **Responsibility** establishes that all actors who collect, process, or disseminate data must act **ethically, transparently, and accountably**, ensuring that data use **does not cause harm or inequality**.
Responsibility implies recognising the potential impacts of data, especially when reused for public policies, financial decisions, or artificial intelligence systems.

In the context of BioClima, this principle requires that:

- **Data quality and governance protocols** are implemented to ensure accuracy, reliability, and traceability.
- **Proactive risk management practices** are adopted, including anonymisation, privacy protection, and ethical impact assessments. For example, certain tasks need to be performed to protect endangered species, which may involve reducing spatial accuracy or simply not entering the data into a database.
- Outcomes derived from data use are **verifiable and auditable**, preventing misinterpretations or misuse.

This principle directly complements the FAIR-R approach, ensuring that data preparation for AI and geospatial analysis is carried out **responsibly and with accountability**.

3.2.4 Ethics (E)

The principle of **Ethics** serves as a transversal foundation for the previous ones, requiring that data handling be conducted in accordance with **values of respect, equity, transparency, and justice**. Ethics in data implies **recognising the cultural and ecological contexts** in which data are produced and ensuring that their use does not harm individuals, communities, or ecosystems.

Within BioClima, the ethical dimension translates into:

- Integrating **ethical evaluation throughout the entire data lifecycle**, from collection to publication and reuse.
- Avoiding data extraction without reciprocity or acknowledgment of sources, particularly in areas with traditional ecological knowledge.
- Promoting **transparency and traceability in decision-making** derived from geospatial data or indicators.
- Encouraging training in **data ethics and responsible interoperability**, both among project partners and within the activities of the BioClima Academy.

The principle of ethics reinforces the idea that data openness and reuse must be guided by **trust, scientific integrity, and respect for human and environmental values**.

Taken together, the CARE principles expand the reach of FAIR and FAIR-R by placing **people, communities, and ecosystems** at the centre of data governance. Their application within the BioClima project ensures that the geospatial indicators and observation infrastructures developed are **not only technically interoperable but also socially and ethically sustainable**.

3.2.5 Ethical aspects related to Biodiversity

The BioClima project will align ethical strategies with those of other projects on BioDiversity – such as DTO-BioFlow[3] and BioDT on ethical topica areas as the following:

<u>Human participation and personal data protection</u> in EU & non-EU countries: the involvement of stakeholders and end-users, including civil society, implies human participation and the protection of personal data, in both EU and non-EU countries.

<u>The use of Artificial Intelligence (AI)/Machine Learning (ML) methodologies</u>, or digital models development particularly in decision-making tools must be robust. The system must guarantee human oversight, define uncertainty and ensure transparency about the limitation of the tool, explicability, and avoid bias.

<u>The use and integration of genetic data and its respective compliance with the Nagoya Protocol</u> regarding biodiversity beyond national jurisdiction or with other relevant international/European conventions must meet the requirements designed with respect to access and benefit sharing. The Nagoya Protocol is a global agreement under the Convention on Biological Diversity (CBD) that ensures the fair and equitable sharing of benefits from using genetic resources (like plants, animals, microbes) and associated traditional knowledge, by regulating access and setting rules for benefit sharing (Access and Benefit Sharing, ABS). Adopted in Nagoya, Japan, in 2010, it provides a transparent legal framework for countries and researchers, requiring prior informed consent (PIC) and mutually agreed terms (MAT) for access, leading to monetary (royalties) or non-monetary (tech transfer) benefits for the source country, thereby supporting biodiversity.

<u>The use and integration of genetic data and its respective compliance with CITES</u> when species are identified as endangered.   CITES (Convention on International Trade in Endangered Species of Wild

[3] Biodiversity Data for Digital Twins of the Ocean | DTO-BIOFLOW

Fauna and Flora) is a global treaty regulating international trade in over 40,900 wild animals and plants, ensuring it's legal, sustainable, and doesn't threaten species' survival, thereby conserving biodiversity by controlling trade in everything from live pets to timber and derived products

The tagging of different species which requires ethics approval and the integration of data collected from tagged animals for which the data provider must confirm that an ethics approval has been obtained.

Informed and responsible social media use – misinformation and disinformation.

The BioClima project will regularly revisit the adherence to these ethical principles in the context of the regular update of the BioClima data management plan.

4 Policy Frameworks

Policy frameworks define the **regulatory and strategic environment** in which data standards, geospatial indicators, and environmental information infrastructures acquire operational relevance. They establish global priorities for biodiversity and climate action, guiding observation, monitoring, and reporting efforts toward common and measurable objectives.

The interoperability promoted by **BioClima** is grounded in the need to **align geospatial standards with international policy frameworks**, ensuring that FAIR–CARE–FAIR-R data are not only technically valid but also **relevant for decision-making, compliance, and accountability**.

4.1 Global Policy Frameworks

At the international level, several policy frameworks provide the foundation for the collection, management, and use of biodiversity and climate data:

- **Convention on Biological Diversity (CBD)** and the **Kunming–Montreal Global Biodiversity Framework (GBF, 2022)** establish a global system of indicators to measure progress towards conservation and sustainable-use targets. The GBF promotes the development of **Essential Biodiversity Variables (EBVs)** and the harmonisation of national reporting mechanisms.

  URL: https://www.cbd.int/gbf/

- The **United Nations Sustainable Development Goals (SDGs)** of the **2030 Agenda** provide a universal framework linking biodiversity, climate, and socio-economic development. Indicators such as **15.1.1**, **15.5.1**, and **14.5.1** rely on interoperable geospatial data and directly contribute to BioClima's objectives.

  URL: https://sdgs.un.org/goals

- The **Group on Earth Observations (GEO)** and the **(GEOSS)** promote the use of **open standards (OGC, ISO, W3C)** to integrate environmental data within interoperable global platforms.

  URL https://earthobservations.org/geoss.php

- The **Taskforce on Nature-related Financial Disclosures (TNFD)** provides a framework for organisations to identify, manage, and disclose their nature-related risks and opportunities. The integration of open and standardised geospatial data is essential to ensure **transparency, comparability, and traceability** in corporate sustainability reporting.

  URL https://tnfd.global/

4.2 European Policy Frameworks

Within Europe, biodiversity and climate data interoperability are driven by a coherent set of environmental and digital policies:

- The **EU Biodiversity Strategy 2030** and the **European Green Deal** reaffirm the EU's commitment to restoring ecosystems, halting biodiversity loss, and fostering the use of open data to support evidence-based decision-making.

  URL https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

- The **INSPIRE Directive (Infrastructure for Spatial Information in Europe)** provides the legal framework for spatial-data interoperability across the EU, built on **OGC** and **ISO** standards. INSPIRE serves as a key reference for the publication, discovery, and use of environmental data.

  URL https://inspire.ec.europa.eu/

- The **Data Governance Act (DGA)** and the development of the **Green Deal Data Space** aim to create an open, ethical, and secure data ecosystem in which environmental and biodiversity data can be shared and reused across sectors, countries, and institutions.

  URL: https://digital-strategy.ec.europa.eu/en/policies/data-governance-act

- **AI Act:** The proposal aims to categorise AI systems into different risk levels based on their potential impact on safety, fundamental rights, and societal values. The highest level of scrutiny and regulation was expected to be applied to high-risk AI systems. Providers of AI systems were expected to provide clear information about the capabilities, limitations, and intended purposes of their AI technology. Additionally, they may be required to provide explanations for AI-generated decisions.

  URL: https://artificialintelligenceact.eu/

- **Interoperability Act:** The Interoperable Europe Act is a cornerstone of the European Union's policy to substantially reinforce cooperation around interoperability among public administrations in the EU. The proposed Act sets up a new cooperation framework on interoperability between EU Member States and EU institutions. In this framework, Member States, the Commission, the Committee of the Regions as well as the European Economic and Social Committee (CoR and ECOSOC) agree on joint priorities and work together on common interoperability solutions. This enhanced cooperation helps design and implement policies in which digital aspects are considered from the start.

  URL: https://ec.europa.eu/commission/presscorner/detail/%20en/ip_22_6907

- **Data Act:** The Data ACT of February 2022 proposes measures for a FAIR and innovative data economy. Today, the Commission proposes new rules on who can use and access data generated in the EU across all economic sectors. The Data Act will ensure fairness in the digital environment, stimulate a competitive data market, open opportunities for data-driven innovation and make data more accessible for all. It will lead to new, innovative services and more competitive prices for aftermarket services and repairs of connected objects. This last horizontal building block of the Commission's data strategy will play a key role in the digital transformation, in line with the 2030 digital objectives.

  URL: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1113

- The **EU Sustainable Finance Strategy** and the **EU Taxonomy for Sustainable Activities** establish mechanisms for integrating biodiversity and environmental criteria into financial markets, linking ecological indicators with **ESG (Environmental, Social & Governance)** frameworks.

Aligning BioClima's outcomes with global and European policy frameworks is essential to ensure their **relevance, adoption, and long-term impact**. The geospatial indicators developed within the project directly contribute to the monitoring system of the **Kunming–Montreal Global Biodiversity Framework (GBF)** and to the reporting mechanisms of the **Sustainable Development Goals (SDGs)**.

Through the application of the **FAIR–CARE–FAIR-R principles**, BioClima facilitates the integration of biodiversity and climate data into emerging **European Data Spaces** and into **sustainability disclosure frameworks**, such as the **Taskforce on Nature-related Financial Disclosures (TNFD)** and the future **ESG DWG**.

By adopting **OGC**, **TDWG**, and **ISO** standards, the project ensures that its outputs are **interoperable, reusable, and ethically governed**, serving the needs of public administrations, research institutions, and private actors alike. In doing so, BioClima acts as a **bridge between scientific observation, technological innovation, and global environmental policy**, contributing not only to technical standardisation but also to the **implementation of international biodiversity and climate commitments**.

5 European projects and Initiatives

A number of European projects and initiatives include climate and biodiversity as supported domains for data sets and models.

5.1 Destination Earth

Destination Earth (DestinE) is a major European Union-led initiative to build a high-precision digital replica of the Earth system —a digital twin — that integrates observations, models, simulations and analytics to monitor, simulate and predict environmental change and human impacts. DestinE is a cornerstone of the **European Commission's Green Deal and Digital Strategy**, providing critical digital infrastructure to support data-driven environmental policy and decision-making.

DestinE's Forest Biodiversity use case illustrates how different aspects of forest management can affect our natural environment in the changing climate. This use case demonstrated a system providing **temporal trajectories of forest ecosystems** in terms of their carbon stock and suitability as wildlife habitats. The project opened up the capabilities of the **Destination Earth (DestinE) Data Lake** services, demonstrating how they can be used for multi-purpose large-scale environmental monitoring and modeling.

URL: https://destination-earth.eu/use-cases/forest-biodiversity/

BioClima's use cases for remote sensing biodiversity monitoring produce datasets that could be integrated into Destination Earth models and tools. DestinE's Data Lake supports access to numerous data stores, especially Earth observations, and these overlap with BioClima's remote sensing biodiversity monitoring data. Satellite imagery is used to observe habitat changes, vegetation indices, and species distributions, all of which are relevant to DestinE.

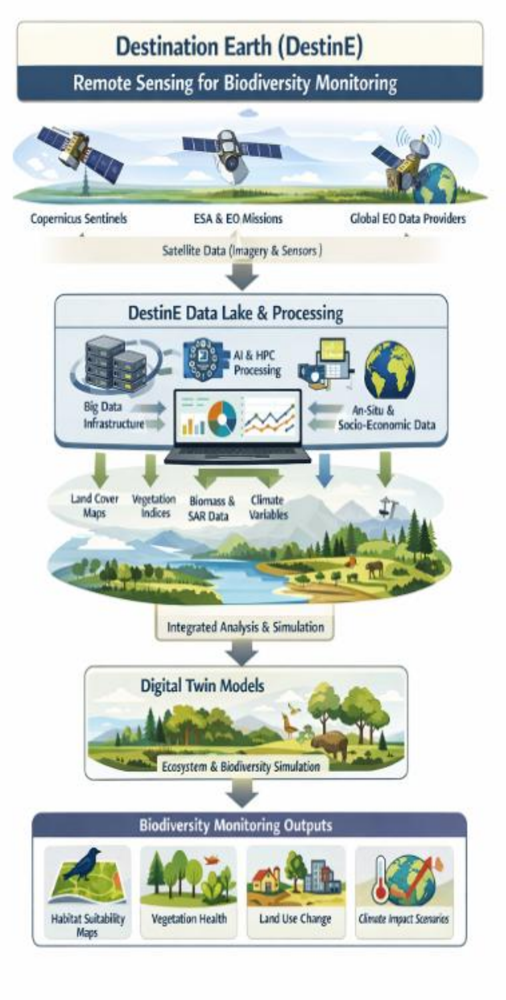

Figure 2.- The flow of remote sensing data for biodiversity monitoring in DestinE.

5.2 European Data Spaces

European data spaces are federated ecosystems (not single databases) that enable trusted data sharing across countries and sectors while respecting EU rules on privacy, sovereignty, and intellectual property. Some of the key features of data spaces are clear governance and access rules, common standards and metadata, interoperable infrastructures, and support for cross-domain use. The relevant data spaces for BioClima are: (1) Green Deal Data Space, (2) Earth Observation (EO)Space Data Ecosystem, and (3) Agriculture Data Space.

Remote sensing biodiversity data exists but is scattered across platforms in inconsistent formats and metadata, making it difficult to combine with in situ observations. European data spaces can be relevant for BioClima, enabling discovery and data access, exposing data through standardized interfaces. A biodiversity researcher can combine sentinel imagery, habitat maps, and species observations without negotiating separate access agreements for each source. Integrated data improves biodiversity models and supports building Essential Biodiversity Variables (EBVs).

URL: https://digital-strategy.ec.europa.eu/en/policies/data-spaces
URL: https://www.greatproject.eu
URL: https://www.greendealdata.eu
URL: https://dataspace.copernicus.eu
URL: https://agridataspace-csa.eu

5.3 SAGE Use Cases (Green Deal Data Space for a Sustainable Green Europe)

The SAGE project is establishing a fully operational **Green Deal Data Space (GDDS)**, building on the **GDDS GREAT** project's results, to enhance the accessibility and utilization of green and environmental data across the EU. It aligns with core pillars of the **European Green Deal** — including zero pollution, climate adaptation, biodiversity conservation, and circular economy action — by integrating high-value datasets and demonstrating practical, data-driven services and solutions through 10 pilot use cases.

The NECST use case is one of several strategic actions within the SAGE framework, specifically focusing on biodiversity conservation. The primary goal of the NECST use case is to provide a decision support tool that makes the **trade-offs involved in managing natural resources** more transparent. Ecosystem services often have complex relationships; increasing one service (e.g., food production via intensive agriculture) can decrease another (e.g., water quality or biodiversity).

By leveraging the **Green Deal Data Space (GDDS)** to integrate diverse data sources — including environmental, biodiversity, and geospatial datasets — with AI-based models and socioeconomic information, **NECST aims to support evidence-based sustainability assessments** for land use and natural capital planning. This use case is highly relevant to remote sensing–based biodiversity monitoring, demonstrating how Earth observation data can be operationally integrated with biodiversity, ecosystem service, and socioeconomic information within an interoperable data space.

Through the **Green Deal Data Space**, SAGE enables harmonised access to satellite-derived products such as land cover, vegetation condition, habitat extent, and environmental pressures, which are essential inputs for biodiversity indicators and ecosystem assessments. NECST builds directly on these capabilities by combining remote sensing–derived spatial layers with AI-driven models to quantify trade-offs between land use, economic activities, and ecosystem services, making biodiversity change observable, comparable, and decision-relevant at scale.

URL: https://www.greendealdata.eu/about/use-cases/ecosystem/

5.4 EOSC

The **European Open Science Cloud or EOSC,** is a European initiative to create a federated, trusted environment for sharing, accessing, and reusing research data, tools, and services across disciplines and countries. It is relevant to BioClima in how it enables FAIR data practices, cross-disciplinary integration, and reproducible science.

EOSC enables hosting interoperable datasets from different disciplines, provides shared metadata and semantic standards, and supports cross-domain data discovery. It allows researchers to publish data, codes, and workflows, run analyses, and share benchmark datasets and models. BioClima remote sensing is the source of observations while ecologists working in the use cases supply the models. EOSC can supply an environment to connect, test, and validate models.

URL: https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/our-digital-future/open-science/european-open-science-cloud-eosc_en

The **EOSC Node Data Terra** serves as a French national research e-infrastructure within the European Open Science Cloud (EOSC) that federates high-quality, FAIR, multi-domain Earth system data — including land surfaces, atmosphere, oceans, solid Earth, and biodiversity — together with tools for cross-domain data analysis, virtual research environments, and interoperable workflows that connect researchers and stakeholders with satellite observations and in-situ measurements across disciplines. Data Terra underpins European data ecosystems that support projects such as the Nature and Ecosystem Services Trade-offs (NECST) use case in the Green Deal Data Space (GDDS).

URL: https://www.data-terra.org/eosc/

5.5 BioDT

BioDT is an EU-funded Horizon Europe project whose goal is to **design and prototype a Biodiversity Digital Twin** for Europe. The project combines observations, models, and simulations to allow users to monitor, understand, and forecast biodiversity change.
The project is currently working towards integration into DestinE infrastructure. BioDTs biodiversity digital twins rely on spatial data (including remote sensing) for dynamic ecological modeling, which, when integrated with DestinE, enhance biodiversity monitoring, forecasting, and decision-making. BioDT and DestinEs remote sensing for biodiversity monitoring systems are standard ecological remote sensing approaches (e.g., satellite EO, EBV derivation, AI-enabled species mapping) used internationally to monitor biodiversity change.

URL: https://biodt.eu/synergies/destine

BioDT has results that are relevant to BioClima through its efforts in combining high-resolution satellite imagery (land cover, temperature) with ground data. Together with the DestinE integration, these projects provide BioClima with the following foundational infrastructure for large-scale biodiversity monitoring and forecasting:

- DestinE’s use cases (notably the Forest Biodiversity use case) show concrete methods for producing habitat suitability, carbon/biomass maps, and species-related indicators from EO + models. These act as **blueprints** for remote-sensing biodiversity monitoring.
- Both DestinE and BioDT focus on fusing satellite observations with process and statistical ecological models (species distribution, forest growth), improving how remote sensing is used to drive forecasts and scenario testing.
- By combining long satellite time series with DestinE’s computing infrastructure and BioDT modelling, both initiatives support **robust detection** of habitat change, phenology shifts, and long-term biodiversity trends across large regions.
- The projects emphasize **fusing field data (species occurrences, plot inventories) with satellite products** to improve model calibration/validation and to scale local biodiversity information to regional/global extents.

- User eXchange events and the BioDT ↔ DestinE synergy pages show **active community engagement** that spreads best practices for EO-based biodiversity monitoring and pulls user needs into platform development.
- BioDT prototypes tie **remote sensing outputs directly to policy-relevant questions** (e.g., forest management, biodiversity indicators), showing how EO products can inform regulation and reporting

5.6 GBIF and links to GeoBON and EuropaBON

GBIF, GEOBON, and EuropaBON are interconnected, but play different, **complementary roles** in the biodiversity data and monitoring ecosystem. Their links are mainly about data flow, standards, and coordination, not governance or ownership.

GBIF's role is primarily data infrastructure and access, with standardized biodiversity data publishing (Darwin Core).

GEOBON (Group on Earth Observations Biodiversity Observation Network) is an international coordination network of researchers dedicated to improving the acquisition, and delivery of biodiversity information at the global, regional, and national levels. The group coordinates global biodiversity monitoring, defines Essential Biodiversity Variables (EBVs), Integrates in situ and remote sensing observations, and supports global biodiversity assessments (CBD, IPBES).

URL: https://portal.geobon.org/datasets

EuropaBON is the European regional BON, aligned with GEO BON but the goals are to outline European biodiversity monitoring needs, harmonization across EU Member States, and supporting EU policy (Biodiversity Strategy, Nature Restoration Law). **The European Biodiversity Observation Coordination Centre (EBOCC)**, is the newly funded extension of the EuropaBON project. EuropaBON has defined 84 EBVs (incl. Metrics, spatial and temporal resolutions). The project has identified gaps related to monitoring community composition, ecosystem structure, and ecosystem functions where remote sensing can help.

At the European level, the new European Biodiversity Observation Coordination Center (EBOCC) aims to harmonise monitoring efforts and establish a shared framework. Its goals include delivering policy-relevant data on key Essential Biodiversity Variables (EBVs), promoting a FAIR (Findable, Accessible, Interoperable, Reusable) data approach, and making better use of existing information.

URL: https://www.europabon.org

BioClima must relate to all three organizations. GBIF provides Darwin Core and data infrastructure. GEO BON defines the global biodiversity monitoring framework. EuropaBON applies that framework in Europe and supports policy.

BioClima will also follow and harmonise with the developments by the preparatory Action project for EU Biodiversity Observation Coordination Centre (EBOCC).

The project will pilot and test the **biodiversity observation coordination centre and monitoring framework** on the basis of the EuropaBON proposal. In this way, the contract will contribute to better availability, coherence and accessibility of biodiversity data in support of the EU biodiversity policy implementation at national, EU and global level, and support a coherent, structured and cost-effective EU approach to systematic biodiversity observation. This will streamline biodiversity data flows and reduce administrative burden in Member States with regard to biodiversity monitoring and reporting.

Biodiversa+ partners (project described in section 5.7 of this report) developed the concept of **National Biodiversity Monitoring Coordination Centres (NBMCCs)**, a flexible national model aligned with the **EBOCC**. These centres would supply monitoring data and national perspectives, while receiving support in implementation, funding, and EU reporting. **Thematic Hubs** complement the system as transnational expert networks that foster collaboration, harmonise protocols, build capacity, and deliver European-level analysis.

The **EBOCC pilot project** will contribute to improving the availability, accessibility, and coherence of biodiversity data at national, EU, and global levels. It aims to reduce the reporting burden on Member States by streamlining biodiversity data flows and integrating existing monitoring efforts into a structured, cost-effective European framework. Ultimately, the EBOCC will support the implementation of the EU Biodiversity Strategy for 2030 and the European Green Deal.

Building on the work of the EuropaBON consortium, the EBOCC is envisioned as a central coordination hub. It will address existing data gaps, harmonise biodiversity data collection, and foster collaboration among national and international monitoring initiatives. Its core objective is to deliver timely and policy-relevant biodiversity information especially Essential Biodiversity Variables (EBVs) to support evidence-based decision-making.

5.7 Biodiversa+

Biodiversa+ is the European Biodiversity Partnership that supports excellent research on biodiversity with an impact on policy and society. Co-developed and launched in 2021 by BiodivERsA and the European Commission as part of the **EU Biodiversity Strategy for 2030**, it contributes to the ambition that by 2030, nature in Europe is on a path to recovery, and by 2050, people are living in harmony with nature. Some specific needs that are addressed are: harmonized biodiversity monitoring, improved use of Earth Observation (EO) data, and knowledge on drivers of ecosystem change.

The vision of Biodiversa+ is that **EO should be routine elements** for biodiversity monitoring, remote sensing biodiversity data products should be easily available (via Copernicus), and these data support measuring of Essential Biodiversity Variables (EBVs). By 2040, ground and space observations will be integrated into models to support decision-making and forecast changes, **CHIME** and other hyperspectral satellites help to monitor e.g. functional traits and vegetation conditions.

Biodiversa+ funded ~33+ transnational projects that directly target transnational terrestrial biodiversity observation (acoustics, radar, eDNA, soil/soil fauna, fungi, forest plots, grasslands, ponds, etc.). Their deliverables (standard protocols, harmonised datasets, EBV prototypes) provide necessary inputs that EuropaBON needs to build a Europe-scale monitoring system. Two relevant remote sensing projects that were funded are **Habitat pilot** and **MAMBO**. Habitat pilot **evaluates the ability of different RS-based approaches** to provide accurate, scalable data on the distribution of habitat types, their condition, and structural and other qualitative changes, both seasonal and long-term. MAMBO **develops, tests and implements enabling tools** for monitoring conservation status and ecological requirements of species and habitats for which knowledge gaps still exist.

URL: https://www.biodiversa.eu
URL: https://www.biodiversa.eu/biodiversity-monitoring/pilots/habitat-pilot/

URL: https://www.mambo-project.eu

Biodiversa+ outputs are being routed into EOSC (for FAIR data & workflows), the European data spaces / Copernicus ecosystem (for combined EO + in-situ products), and into digital twin efforts(BioDT / Destination Earth) for modelling, scenario analysis and policy-relevant products.

One outcome has been a **list of recommendations** for the use of remote sensing in biodiversity monitoring. These recommendations for the use of satellite data are: ground truth data, harmonized protocols, time series, collaboration of experts, open algorithms and more analysis-ready data products, preparation for novel sensors, and integration of observation data with models to detect change and to provide knowledge for a sustainable future.

5.8 FOCAL

Fostering Open and interoperable Climate data and services for Adaptation and mitigation **(FOCAL)** is a Horizon Europe project aimed at improving access to, interoperability of, and uptake of climate data and services to support climate adaptation and mitigation policies. The project focuses on strengthening the link between climate science, data infrastructures, and decision-making by promoting FAIR and interoperable climate information across European and international contexts.

FOCAL develops common frameworks, tools, and best practices to integrate heterogeneous climate data sources—such as Earth observation, in situ measurements, and model outputs—into policy-relevant climate services. Particular emphasis is placed on usability, trust, and reproducibility of climate information, enabling public authorities and stakeholders to better assess climate risks and support evidence-based adaptation strategies.

URL: https://www.focal-euproject.eu/

5.9 BMD

Biodiversity Monitoring and Decision Support (BMD) is a European project focused on advancing biodiversity monitoring through the integration of heterogeneous data sources and decision-support tools. The project aims to enhance the capacity of public authorities and environmental stakeholders to monitor biodiversity change and support conservation actions using interoperable, standardised data.

BMD promotes the use of Earth observation, in situ data, and modelling approaches within a coherent monitoring framework aligned with European biodiversity policies. By improving data harmonisation, accessibility, and analytical workflows, BMD contributes to more consistent biodiversity assessments and supports policy-relevant indicators at local, national, and European levels.

URL: https://bmd-project.eu/about

5.10 OBSGESSION

Observations for Sustainable Environmental Governance through Integrated and Open Systems **(OBSGESSION)** focuses on strengthening environmental governance through integrated, open, and interoperable observation systems. The project addresses the fragmentation of environmental data by promoting common standards, shared workflows, and interoperable digital infrastructures that support cross-domain environmental analysis.

The project brings together geospatial technologies, open standards, and governance frameworks to enable better use of observation data in policy, planning, and sustainability reporting. OBSGESSION emphasises transparency, data quality, and reproducibility, supporting evidence-based decision-making across environmental domains such as climate, biodiversity, and land use.

URL: https://obsgession.eu/

5.11 CLIMOS – Climate Impacts and Mitigation through Open Science

CLIMOS is a research and innovation project dedicated to improving the assessment of climate impacts and mitigation pathways through open science and interoperable data infrastructures. The project focuses on combining climate observations, models, and socio-environmental data to support climate risk assessment and long-term sustainability planning.

By promoting FAIR data principles and open standards, CLIMOS enhances the accessibility and reuse of climate-related datasets and analytical workflows. Its results support policymakers, researchers, and practitioners in understanding climate dynamics and designing effective mitigation and adaptation strategies grounded in transparent and reproducible scientific evidence.

URL: https://climos-project.eu/

6 Geospatial Indicators for the Global Biodiversity Framework (GBF)

The **Kunming–Montreal Global Biodiversity Framework (GBF)**, adopted under the Convention on Biological Diversity (CBD) in 2022, establishes a set of **long-term goals and targets for 2030** aimed at halting and reversing biodiversity loss, while ensuring the sustainable use of ecosystems and the fair and equitable sharing of benefits derived from biological resources.

To support its implementation, monitoring, and review, the GBF includes a **structured system of indicators** designed to enable regular, coherent, and comparable reporting at national, regional, and global levels. This indicator system plays a central role in translating the policy commitments of the global framework into measurable evidence that can inform decision-making, policy evaluation, and accountability.

The **official GBF indicator system**, maintained by the CBD Secretariat and publicly accessible through the platform: https://www.gbf-indicators.org/, organises indicators into several categories, including **headline indicators**, **component indicators**, and **complementary indicators**, all of which are aligned with the specific goals and targets of the framework. This tiered structure allows for different levels of analytical depth and supports flexibility in implementation, taking into account varying national capacities and data availability.

Figure 3.- Goals and targets of the Kunming–Montreal Global Biodiversity Framework (GBF) (Source: Nature Positive).

Increasingly, GBF indicators rely on **spatially and temporally explicit data** derived from a wide range of sources, including in situ observations, Earth observation and remote sensing products, environmental and climate models, and official statistics. This growing reliance on georeferenced information highlights the importance of **geospatial data infrastructures, interoperability, and standardised methodologies** as key enablers for a robust, transparent, and reproducible monitoring of progress towards the objectives of the Global Biodiversity Framework.

6.1 State of the art: GBF indicators and geospatial dimension

From a technical and methodological point of view, monitoring the **Global Biodiversity Framework (GBF)** highlights a number of key challenges related to the integration, interoperability and effective use of geospatial information. These challenges reflect the complexity inherent in monitoring biodiversity at multiple scales and in diverse institutional contexts, as well as the need to translate heterogeneous scientific observations into comparable and politically relevant reporting indicators.

- Firstly, a significant proportion of GBF indicators require **explicit spatial referencing**. This is particularly evident in indicators aimed at assessing changes in the **extent, structure and condition of ecosystems**, **ecological connectivity**, the **distribution and abundance of species**, or **anthropogenic pressures** arising from land use, climate change or other human activities. In these cases, the geospatial dimension is not an accessory attribute, but an essential component of the indicator itself, as it determines both its interpretation and its aggregation at different reporting scales.

- Secondly, there is a direct dependence on **Essential Biodiversity Variables (EBVs)** and, to a lesser extent, **Essential Climate Variables (ECVs)** as an intermediate layer between observation data and GBF indicators. EBVs and ECVs make it possible to structure and standardise information from multiple sources — including in situ observations, remote sensing, models and citizen science — reducing the complexity of primary data and facilitating its integration into coherent reporting frameworks. However, the operationalisation of these variables still requires explicit methodological decisions on spatial scales, units of analysis and aggregation methods.
- A third relevant challenge is the **heterogeneity in the practical implementation of indicators** across regions and countries. Differences in technical capabilities, data availability, institutional frameworks, and monitoring traditions give rise to a wide variety of approaches in terms of spatial scales, geographical reference units, and calculation methodologies. This diversity, while partly unavoidable, hinders **international comparability** and highlights the need for common frameworks that allow results to be aligned without imposing rigid solutions.

In this context, **geospatial indicators** play a central role as a **translation mechanism** between observational data and GBF reporting requirements. By explicitly articulating the relationship between observational variables (EBVs/ECVs), geographical units and aggregation processes, geospatial indicators make it possible to generate reproducible and comparable results, while maintaining traceability to the source data. This approach is equally relevant for other international reporting frameworks, such as the **Sustainable Development Goals (SDGs)**, the **Taskforce on Nature-related Financial Disclosures (TNFD)**, and the statistical systems of the **United Nations and Eurostat**, which share similar requirements in terms of spatial consistency, methodological transparency, and reuse of results.

6.2 Geospatial indicators as an integrative framework

From the perspective adopted in BioClima, **geospatial indicators** should not be understood solely as final reporting metrics, but rather as an **integrative framework** that allows information from heterogeneous observation systems to be organised, related and translated into coherent and comparable results for the monitoring of public policies.

In this approach, geospatial indicators are conceived as a combination of **two fundamental elements**.

First, a **coherent hierarchy of geographical units**, which defines the reference areas on which the analysis and reporting are carried out. These units may include, among others, sampling plots, protected areas, river basins, biogeographical regions, administrative units or regular spatial grids. The explicit definition of these units and their hierarchical relationships is essential to ensure the spatial consistency of the analyses, enable the multiscale aggregation of results, and ensure traceability between local, national, regional, and international levels.

Secondly, geospatial indicators are based on the **association of standardised observational variables** — mainly **Essential Biodiversity Variables (EBVs)** and, where appropriate, **Essential Climate Variables (ECVs)** — with these geographical units. This association allows observation data to be linked in a structured way to analysis and reporting processes, ensuring the **comparability, reproducibility and reusability** of results. By relying on widely recognised essential variables, this approach reduces dependence on ad hoc indicators and promotes alignment with established scientific and policy frameworks.

One of the main benefits of this integrative framework is that it allows for the clear decoupling of different levels of information flow, differentiating between:

- **primary observation data**, from diverse sources such as remote sensing, in situ sensors, ecological inventories, models, or citizen science;
- essential variables (EBVs and ECVs), which act as an intermediate layer of standardisation and complexity reduction;
- and reporting indicators, which respond to the specific requirements of the Global Biodiversity Framework and other policy and regulatory frameworks.

This decoupling facilitates the independent evolution of each level—for example, the incorporation of new data sources or the updating of methodologies—without compromising the overall consistency of the indicator system.

At the same time, the approach of geospatial indicators as an integrating framework facilitates alignment with the reporting systems of the United Nations and Eurostat, which require consistent spatial aggregations, clear definitions of units of analysis, and transparent and reproducible methodologies. By making explicit the relationship between geographical units, essential variables and final indicators, this approach provides a solid basis for ensuring consistency between scientific biodiversity monitoring and formal statistical and policy reporting processes.

In the context of BioClima, this conceptualisation of geospatial indicators reinforces the project's role as a facilitator of interoperability between data, variables and indicators, and justifies the emphasis placed on defining methodological and technical frameworks that can be reused and scaled up in later phases of the project.

6.3 Relevance for BioClima and future work

The conceptualisation of **geospatial indicators as an integrative framework**, presented in this section, is highly relevant to BioClima, as it provides the **conceptual and methodological framework** necessary to coherently address the integration of biodiversity and climate in international reporting contexts.

At this stage of the project, **no applied analysis or implementation of specific indicators has yet been carried out**. The work carried out has deliberately focused on defining the principles, structures and methodological requirements that must be met in order for geospatial indicators to be developed in a consistent, reproducible manner that is aligned with frameworks such as the Global Biodiversity Framework (GBF), the SDGs or the United Nations and Eurostat reporting systems.

In particular, this deliverable establishes:

- a common understanding of geospatial indicators as the result of combining **spatial hierarchies** and **essential variables (EBVs and ECVs)**;
- a clear separation between **observation data**, **intermediate variables** and **reporting indicators**, avoiding premature couplings;
- and the **interoperability requirements** necessary to ensure traceability, comparability and long-term reuse.

This positioning allows BioClima's case studies to be used in later phases (to be included in deliverable D.1.3) as **validation and demonstration environments**, without anticipating methodological decisions that require greater technical maturity and consensus among stakeholders. In this way, BioClima avoids defining closed solutions at an early stage and reduces the risk of subsequent redefinitions.

Looking ahead to future work, the framework presented will serve as a basis for:

- the progressive development of **concrete examples of geospatial indicators** in WP2;
- the technical validation of data flows, semantic profiles and spatial hierarchies;
- and operational alignment with reporting and dissemination processes in WP3 and WP5.

This progressive approach ensures that the indicators developed in BioClima are based on solid methodological foundations, are interoperable and scalable, and can be coherently integrated into data ecosystems and public policy frameworks at European and international level.

7 Engaging in Global Standardisation

Global standardisation is a cornerstone for ensuring the **interoperability, comparability, and sustainability of biodiversity and climate change data**. In a context where environmental information is generated from multiple sources —including *in situ* observations, remote sensing, sensors, citizen science, and modelling— the adoption of open standards enables the **integration, validation, and reuse of data in a consistent way at the international level**.

Ensuring interoperability across biodiversity and climate observation systems requires engagement not with a single family of standards, but with the entire ecosystem of international standardisation bodies that shape environmental data exchange. While OGC standards play an important role — particularly for geospatial interfaces and APIs— they are only one component of a broader landscape that includes TDWG biodiversity standards, ISO/TC 211 geospatial information models, W3C Semantic Web specifications, and IETF web communication protocols.

For BioClima, the central challenge is therefore **not how to apply OGC standards in isolation**, but how to ensure that **all relevant standards can work together coherently** across domains, infrastructures, and policy contexts. This requires active participation in multiple SDO communities, alignment of conceptual models, and the development of semantic bridges that enable biodiversity, climate, geospatial, and AI-derived data to integrate seamlessly.

Accordingly, this chapter describes:

- how OGC contributes to the geospatial and API dimensions of interoperability,
- how TDWG provides the semantic backbone for biodiversity information,
- how ISO, W3C, and IETF ensure compatibility of data models, metadata, web architectures, and communication protocols, and
- how BioClima contributes to *cross-standard* alignment rather than adopting a single technical framework.

This cross-domain perspective reflects the true ambition of WP1: **enabling interoperability across diverse and heterogeneous standards ecosystems**, ensuring that biodiversity and climate indicators can be integrated, compared, and reused within scientific, operational, and policy-driven workflows.

7.1 Functioning of OGC Working Groups

The **Open Geospatial Consortium (OGC)** develops its standards through a formal, open, and community-driven process. This model aims to ensure **transparency, interoperability, and consensus**, actively involving experts from public institutions, private companies, universities, and international organisations. In this process, **working groups** play a central role, as they are the spaces where technical needs are discussed, specifications are developed, and standards are reviewed to support the global geospatial data ecosystem.

The OGC working groups are structured into two main categories: **Standards Working Groups (SWG)** and **Domain Working Groups (DWG)**. Both are complementary and essential for the development and implementation of OGC open standards. In general terms, DWGs function as spaces for reflection and requirements analysis ("*think tanks*"), while SWGs act as engineering teams responsible for the design and maintenance of standards ("*engineering teams*").

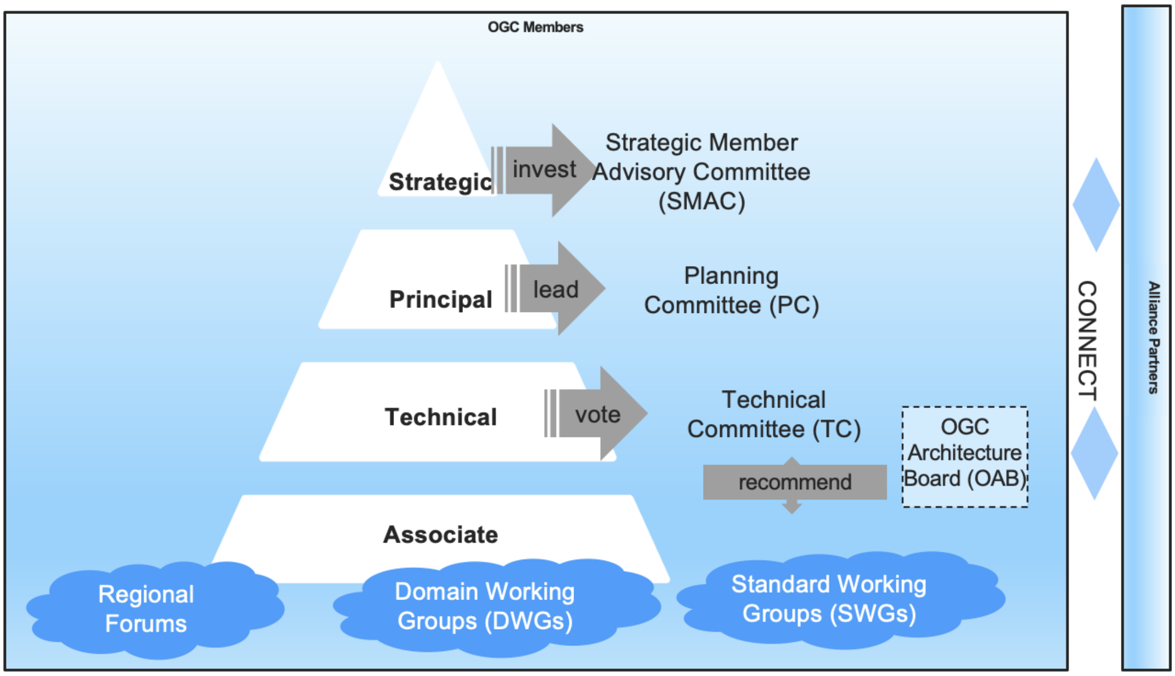

Figure 4.- OGC membership structure

7.1.1 Standards Working Groups (SWG)

SWGs are formal OGC groups responsible for **developing new standards or revising existing ones**, ensuring that they remain up to date and meet the evolving needs of the geospatial community. Their work covers the entire lifecycle of standards, from **creation and technical specification** to **validation, maintenance, and periodic review**.

SWGs produce detailed specifications that define data structures, interfaces, service models, and interoperability protocols. They also organise **testbeds and interoperability experiments** that make it possible to validate implementations and demonstrate the applicability of standards before their formal approval.

Participation in these groups requires active OGC membership and compliance with the organisation's intellectual property policies, since the results of their work directly influence the formulation of official OGC standards.

Examples of relevant normative working groups include:

- **GeoPackage SWG**, responsible for maintaining the compact and portable *GeoPackage* geospatial data format.
- **Environmental Data Retrieval (EDR) API SWG**, which develops a standardised interface for the efficient retrieval of environmental data.
- **Geospatial Reporting Indicators SWG**, focused on developing standards for geospatial data products aimed at reporting sustainability, biodiversity, and climate change indicators, including *EBVs*.

7.1.2 Domain Working Groups (DWG)

DWGs are thematic working groups that provide an open and collaborative forum for knowledge exchange among OGC members and other stakeholders. Unlike SWGs, DWGs do not produce formal standards but rather **document use cases, best practices, and gap analyses** that inform and guide the development of new standards.

Their main function is to promote **cross-domain dialogue**, connecting technical, scientific, and policy communities to address complex challenges through interoperability. Participation in DWGs is open to all OGC members, encouraging a diversity of perspectives and collaboration among public, private, and academic sectors.

Among the DWGs most relevant to biodiversity and climate change are:

Table 1.- OGC Working Groups Relevant to BioClima

Working Group	Description	Relevance to BioClima
Citizen Science DWG	Supports the citizen science community by promoting and facilitating the interoperability of citizen-generated data. It collaborates with other OGC groups to increase the impact and reuse of biodiversity and environmental observations.	Enables the integration of participatory data and local observations into BioClima's monitoring systems, strengthening the link between citizen science, biodiversity, and climate resilience.
Climate Resilience DWG	Provides a forum for defining interoperability requirements, reviewing specifications, and developing best practices that support climate adaptation and resilience efforts.	This is the group with which BioClima holds **monthly coordination meetings**. It supports project alignment with the global climate resilience community and facilitates connections with other OGC working groups.
Data Quality DWG	Works to establish an interoperable framework for measuring, documenting, and assessing geospatial data quality.	Ensures that biodiversity and climate indicators are based on accurate, reliable, and traceable data — a key aspect for scientific and policy credibility.
Hydrology DWG	Develops and maintains standards for describing, modelling, and exchanging hydrological data. These are essential for managing aquatic and terrestrial ecosystems.	Relevant for monitoring water cycle variables, river and wetland ecosystems, and hydrological processes that underpin biodiversity and climate assessments.
Geospatial Reporting Indicators SWG	Develops standards for geospatial data products supporting international reporting mechanisms, such as **Land Degradation Neutrality (LDN)** and the **(SDGs**. Includes work on **EBVs**.	Directly aligned with BioClima's objective to define **geospatial biodiversity indicators** and integrate them into policy and financial reporting frameworks such as **TNFD** and **ESG**.
Analysis Ready Data (ARD) SWG	Develops a standard defining and publishing **Analysis Ready Data (ARD)** that can be integrated and used with minimal pre-processing. Expands the ARD concept beyond satellite data to all geospatial domains.	Strengthens the project's **FAIR-R strategy**, enabling biodiversity and climate datasets to be prepared for advanced analytics and AI applications while ensuring interoperability and efficiency.
Environmental Data Retrieval (EDR) API SWG	Develops the **OGC API – Environmental Data Retrieval (EDR)** standard, providing a uniform and efficient interface to access spatio-temporal environmental data via	Facilitates the implementation of interoperable environmental data services within the BioClima ecosystem, improving accessibility and

	queries based on location, area, or trajectory.	exchange of climate, hydrological, and biodiversity data.
ESG DWG (to be founded)	A planned OGC working group focused on the intersection between **Environmental, Social, and Governance (ESG)** reporting and geospatial standards. Its goal is to connect the technical OGC ecosystem with corporate sustainability frameworks.	Once established, it will play a key role in linking BioClima's outcomes to financial and sustainability reporting systems, supporting the integration of geospatial indicators into **TNFD** and **ESG** frameworks.

In the context of **BioClima**, a regular collaboration has been established[4] with the **Climate Resilience Domain Working Group (DWG)** of the OGC. A **monthly coordination meeting** has been initiated to align BioClima's activities with ongoing discussions and developments within the Climate Resilience community. This group will provide **continuous support throughout the project's implementation**, helping to connect BioClima with other relevant OGC working groups and ensuring that the project's results are consistent with the broader geospatial standardisation ecosystem.

7.1.3 Synergy between SWGs and DWGs

The interaction between **Domain Working Groups** and **Standards Working Groups** is essential within the OGC standardisation process. DWGs **identify needs, gaps, and opportunities** in the use of geospatial data, while SWGs **translate those needs into technical specifications**. This continuous feedback cycle ensures that OGC standards are **scientifically relevant, technically sound, and applicable in multiple contexts**.

In the context of international standardisation, this dynamic defines a policy of active participation in **Standard Development Organisations (SDOs)** based on four complementary lines of action:

1. **Providing feedback** to SDOs on the improvement or extension of existing standards.
2. **Initiating the development of new standards** when gaps or emerging needs are identified.
3. **Developing best practices** for the consistent use of consolidated standards.
4. **Creating domain-specific implementation guides** tailored to the project's thematic scope (in the case of BioClima, biodiversity and climate change).

Within the OGC, these principles materialise through ongoing collaboration between SWGs and DWGs, which makes it possible to combine **strategic and sectoral vision** with **technical formalisation**. DWGs generate knowledge and consensus on shared needs, while SWGs translate that knowledge into open standards that facilitate global interoperability.

For **BioClima**, this structure offers an ideal cooperation framework in which the project can **contribute use cases, technical requirements, and recommendations** derived from its experience in geospatial observation, indicators, and environmental policy. Active participation in these groups ensures that project results are integrated into international standardisation processes, guaranteeing the **scalability, interoperability, and sustainability** of standards in the fields of biodiversity and climate.

7.1.4 Standards Development Process

The Open Geospatial Consortium (OGC) ensures that its standards are developed through a transparent, inclusive, and consensus-based process. Understanding this process is essential to contextualise how BioClima can contribute to the evolution of geospatial standards for biodiversity

[4] https://bioclima.net/news/bioclima-meets-with-ogc-climate-resilience-working-group/

and climate observation. The following section provides an overview of the main phases that guide the formal development, review, and maintenance of OGC standards.

7.1.4.1 Idea and Community Need

A need for a new geospatial reporting indicator related to biodiversity often originates from various sources, including discussions and findings within domain-specific working groups, outcomes and requirements identified through innovation program projects, or direct requests and identified gaps highlighted by external partners and stakeholders. This identified need can stem from several factors, such as recognized deficiencies or limitations in currently available geospatial standards that hinder effective biodiversity monitoring and reporting, the emergence of new technological advancements that offer opportunities for more accurate or efficient data collection and analysis for biodiversity assessments, or specific demands and information requirements articulated by stakeholders involved in conservation efforts, policy-making, or sustainable development initiatives.

7.1.4.2 The Standards Working Group (SWG)

To address unmet needs, requirements are directed to an existing SWG or a new one is created. Forming a new SWG starts with a charter proposal defining the SWG's scope (geospatial domain), purpose (goals and problem to solve), expected deliverables (outputs like standards), and IPR considerations (ownership and usage). The proposal is reviewed and voted on by OGC members. Approval leads to the SWG's formal creation and work according to the charter.

7.1.4.3 Development of the Candidate Standard

Upon establishment, the Standards Working Group (SWG) begins its core technical work to create a robust standard. This includes:

1. **Specification Drafting**: Defining scope and objectives, identifying requirements (functionalities, data structures, interfaces, protocols), developing conceptual models, specifying technical details (data formats, encoding, APIs, conformance), and documenting design rationale.
2. **Meetings and Reviews**: Holding internal SWG meetings, community review periods, and review workshops/teleconferences. Recording and addressing all feedback transparently.
3. **Collaboration with Other Working Groups**: Ensuring harmonization and interoperability, leveraging expertise, avoiding duplication, and holding joint meetings.

The development process is iterative, incorporating feedback from the OGC community (mailing lists, reviews) and practical implementation/testing in testbeds to refine the standard before finalization.

7.1.4.4 Public Review (Request for Comment – RFC)

Upon SWG consensus, a candidate standard is released as a Request for Comment (RFC) for public review (minimum 30 days). This solicits feedback from industry, academia, other standards bodies, and interested parties to ensure robustness and clarity. The originating SWG carefully reviews all feedback, incorporates changes as appropriate, or provides rationale for non-implementation. This iterative process strengthens the final standard for the geospatial community.

7.1.4.5 Voting and Approval

The revised standard is formally submitted to the OGC Technical Committee (TC) and Planning Committee (PC) for review and vote. Committee member approval signifies its adoption as an official OGC Implementation Standard, establishing recognized practices within the geospatial domain.

7.1.4.6 Publication and Maintenance

Upon approval, the standard will be published on the OGC website and enter a continuous maintenance phase. During this phase, the standard will be reviewed and potentially updated by the originating Standards Working Group or via revision requests from the OGC community or external stakeholders. This maintenance process ensures the standard remains current and relevant, supporting its long-term usability.

7.2 Other Strategic Collaborations and Synergies

The geospatial standardisation ecosystem extends beyond the internal work of the **Open Geospatial Consortium (OGC)** and relies on **continuous collaboration with other international organisations** dedicated to standardisation, biodiversity, and sustainability. These partnerships are fundamental to ensuring the **coherence, compatibility, and global adoption** of developed standards, avoiding duplication of efforts and fostering convergence across different scientific and technological domains.

Within the **BioClima** project, synergies with other communities of practice —such as **TDWG (Biodiversity Information Standards)**, **ISO**, **W3C**, and **IETF**, as well as with policy and financial frameworks like the **Taskforce on Nature-related Financial Disclosures (TNFD)** and the emerging **ESG DWG**— are essential to ensure that geospatial biodiversity and climate indicators can be integrated into **international monitoring, reporting, and decision-making mechanisms**.

These collaborations reinforce BioClima's role as a **bridge between open science, standardisation, and global sustainability policies**, contributing to a more interoperable, ethical, and collectively beneficial data infrastructure.

7.2.1 Collaboration with TDWG (Biodiversity Information Standards)

Coordination between OGC and TDWG in data models, ontologies, and interoperable publication of biodiversity information.

Historically known as the *Taxonomic Databases Working Group*, today's **Biodiversity Information Standards (TDWG)** is a non-profit, scientific, and educational association that fosters **international collaboration among creators, managers, and users of biodiversity information**. Its mission is to promote the **broad and effective dissemination and sharing of biodiversity knowledge**, ensuring that data about the world's biological heritage are interoperable, accessible, and reusable across disciplines and systems.

The **Open Geospatial Consortium (OGC)** collaborates closely with TDWG to develop **joint standards and data models** that enhance the dissemination, accessibility, and integration of biodiversity information. This partnership aims to align geospatial and biodiversity data communities, promoting the **use of interoperable vocabularies, ontologies, and metadata frameworks** that enable cross-domain understanding and semantic consistency.

Within **BioClima**, this collaboration is particularly relevant for the **harmonisation of geospatial and biodiversity data models**, especially in the definition of **geospatial reporting indicators** and the management of **EBVs**. By leveraging both OGC and TDWG standards —such as **Darwin Core**, **its Humboldt Extension** (which is especially relevant for monitoring data), **Audubon Core**, and **OGC API specifications**— BioClima contributes to improving **data interoperability, traceability, and alignment** between biodiversity monitoring frameworks and policy-driven reporting mechanisms (e.g., *SDGs*, *TNFD*, *G BF*).

This joint OGC–TDWG approach strengthens the foundation for a **shared technical language between biodiversity science and geospatial technology**, supporting the creation of an open, FAIR, and ethically managed ecosystem of biodiversity data.

7.2.2 Coordination with Other Standardisation Bodies (ISO, W3C, IETF)

The **Open Geospatial Consortium (OGC)** maintains close coordination with other international standardisation bodies to ensure that geospatial standards are **technically compatible, semantically consistent, and globally applicable**. This collaboration avoids fragmentation across domains and reinforces the interoperability between geospatial data, web technologies, and information infrastructures.

Among these organisations, the **International Organization for Standardization (ISO)**, the **World Wide Web Consortium (W3C)**, and the **Internet Engineering Task Force (IETF)** play particularly relevant and complementary roles:

- **ISO** provides the overarching framework for geospatial information through the **ISO 19100 series**, which defines models for metadata, services, reference systems, and data quality. The alignment between OGC and ISO is formalised through the **ISO/TC 211** collaboration, ensuring that OGC standards (e.g., *WMS*, *WFS*, *GeoPackage*, *OGC API – Features*) are consistent with the ISO standards ecosystem.
- **W3C** governs the standards for the **Semantic Web and Linked Data**, including **RDF (Resource Description Framework)**, **OWL (Web Ontology Language)**, and **SPARQL**. OGC actively collaborates with W3C to integrate geospatial concepts into web semantics, exemplified by the **GeoSPARQL** and **SSN/SOSA** ontologies, which enable spatial reasoning and semantic interoperability across datasets.
- **IETF** defines the **core internet protocols and communication frameworks** that underpin data exchange (e.g., HTTP, TCP/IP, URIs, and JSON). Its standards provide the foundational layer upon which OGC APIs are designed and implemented, ensuring open, scalable, and secure data access on the web.

In the context of **BioClima**, coordination with these organisations is essential to guarantee that biodiversity and climate indicators are:

- **Technically interoperable**, through shared data models and encoding standards (ISO/OGC alignment);
- **Semantically interoperable**, through the use of common ontologies and vocabularies (W3C integration); and
- **Accessible and scalable**, through standardised web-based APIs and protocols (IETF foundations).

By building upon the interoperability synergies among ISO, W3C, IETF, and OGC, **BioClima contributes to a unified digital ecosystem** where geospatial, environmental, and biodiversity data can be connected, reused, and trusted across scientific, policy, and operational domains.

7.2.3 Synergies with TNFD and ESG DWG

In recent years, the growing emphasis on **environmental, social, and governance (ESG)** reporting and the global deployment of sustainability disclosure frameworks have highlighted the critical role of **geospatial data** in assessing nature-related dependencies, risks, and impacts. The **Taskforce on Nature-related Financial Disclosures (TNFD)** has been instrumental in developing a global framework that guides organisations in identifying, managing, and reporting their nature-related financial risks and opportunities.

The **Open Geospatial Consortium (OGC)** plays a strategic role in enabling this transformation by promoting the use of **open, interoperable geospatial standards** to support **data-driven ESG and TNFD reporting**. In this context, the planned establishment of the **ESG Domain Working Group (DWG)** within OGC represents an important step towards formalising collaboration between the geospatial and sustainability communities. This future working group will serve as a **platform for aligning geospatial data practices with corporate sustainability reporting needs**, fostering cross-sector dialogue and technical convergence.

The **BioClima** project directly contributes to this vision by developing a **framework of geospatial biodiversity and climate indicators** aligned with existing global sustainability frameworks such as the **SDGs** and the **TNFD disclosure recommendations**. By applying OGC standards and FAIR/CARE data principles, BioClima helps ensure that biodiversity-related data and indicators can be **integrated, traceable, and verifiable** within ESG and financial reporting systems.

Furthermore, the project promotes the adoption of **FAIR-R (AI-ready) principles**, ensuring that open environmental data can also feed responsibly into analytical and artificial intelligence models that support ESG assessments. This approach strengthens the link between **scientific observation and sustainability governance**, making BioClima a bridge between the geospatial standardisation community and the global financial and policy ecosystems driving the green transition.

Through its synergies with **TNFD** and the forthcoming **ESG DWG**, BioClima contributes to establishing a **trusted, transparent, and interoperable foundation** for nature-based and climate-related reporting across sectors, supporting a more sustainable and accountable digital economy.

7.3 BioClima's Contribution to Global Standardisation

The **BioClima** project plays a key role as a **bridge between scientific research, technical standardisation, and public policy**, helping to connect knowledge generation with the definition of open standards and their practical implementation within international sustainability frameworks.

Through its active participation in the working groups and forums of the **OGC**, as well as in global initiatives such as **GEO** and **GEOSS**, BioClima contributes to strengthening international governance of environmental data. The project promotes a **coordinated and aligned approach** with the priorities of the European and global geospatial communities.

Its contribution can be described across three complementary dimensions:

1. **Data Harmonisation:** BioClima promotes the integration of data from *in situ* observations, remote sensing, modelling, and citizen science, ensuring their technical and semantic interoperability through **OGC**, **TDWG**, and **ISO** standards.
2. **Interoperable Indicators:** The project develops a preliminary framework of geospatial indicators for biodiversity and climate change, based on the **FAIR** and **CARE** principles, enabling their use within reporting and disclosure frameworks such as the **SDGs**, **TNFD**, and the forthcoming **ESG DWG** standards.
3. **Adoption of FAIR–CARE–FAIR-R Principles:** BioClima promotes a comprehensive vision of interoperability that combines **data openness (FAIR)**, **ethical and social responsibility (CARE)**, and **AI-readiness (FAIR-R)**. This convergence reinforces the quality, transparency, and social value of environmental data.

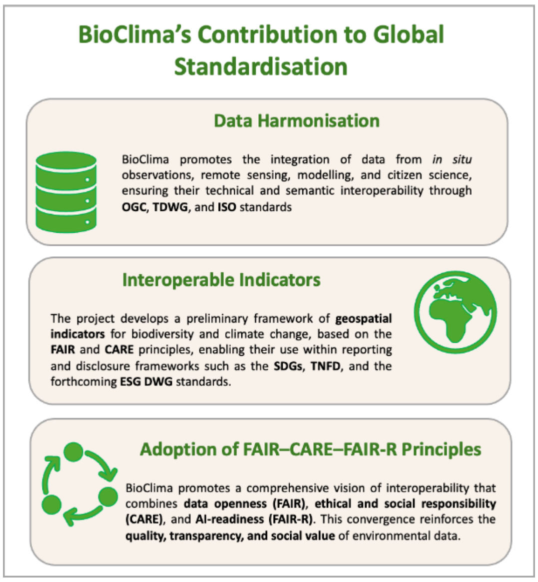

Figure 5.- BioClima's Contribution to Global Standardisation

Overall, BioClima's participation in global standardisation processes helps to **link scientific innovation with sustainability policy**, contributing to a more interoperable, ethical, and impact-oriented data infrastructure. The project strengthens Europe's leadership in the development of open standards for Earth observation and evidence-based decision-making.

8 ESG Reporting Requirements

ESG reporting standards are evolving to place **greater emphasis on biodiversity and ecosystem health**. This reflects a growing recognition of the critical role that biodiversity plays in maintaining ecosystem services, supporting economic activities, and contributing to overall societal well-being.

Integrating **biodiversity-specific indicators** into ESG frameworks is essential for organisations to transparently communicate their **impacts and dependencies on nature**, enabling stakeholders to assess their environmental performance and sustainability efforts.

Currently, several **international frameworks and initiatives** are emerging to integrate biodiversity into ESG reporting. Among them, the **TNFD** stands out, aiming to develop a framework that enables organisations to identify, manage, and disclose nature-related risks and opportunities. In parallel, **sector-specific guidelines and metrics** are being developed to reflect the distinct impacts and dependencies of different industries on biodiversity.

The inclusion of **biodiversity-specific geospatial reporting indicators** within ESG standards provides significant advantages. Geospatial data allow for **visualising and quantifying the extent and condition of ecosystems**, tracking changes over time, and assessing the **location-specific impacts** of organisational activities. This enhances the **accuracy, reliability, and comparability** of biodiversity-related disclosures.

Examples of potential geospatial indicators include:

- **Habitat extent and condition:** Metrics on the area, quality, and connectivity of key habitats within and around an organisation's operational footprint, such as mapping and monitoring changes in forest cover, wetlands, grasslands, and other critical ecosystems.
- **Species presence and abundance:** Data on the distribution and population trends of species, especially those that are endangered, threatened, or of high conservation value. Geospatial tools can track species occurrences and monitor the effectiveness of conservation measures.
- **Ecosystem service provision:** Indicators that quantify the benefits ecosystems provide, such as **carbon sequestration**, **water purification**, **pollination**, and **flood regulation**. Geospatial analysis helps map and value these services and assess the impact of human activities on their delivery.
- **Land use change and impact:** Monitoring changes in land cover and use associated with organisational activities, including **deforestation**, **habitat fragmentation**, and **conversion of natural areas**. Geospatial data provide detailed information on the location and extent of these changes.
- **Protected area coverage:** Assessing the overlap between an organisation's operations and protected areas, as well as its contribution to their management and conservation.

The development and adoption of biodiversity-specific geospatial indicators within ESG frameworks face several challenges, including **data availability and quality**, the **lack of standardised methodologies and metrics**, and the **capacity of organisations** to collect, analyse, and report geospatial data effectively. However, ongoing advances in **remote sensing, GIS technologies, and data analytics** are improving the feasibility and precision of biodiversity assessments.

Moving forward, it is essential for ESG reporting standards to further integrate **robust and standardised biodiversity-specific geospatial indicators**. This will enable organisations to better understand and manage their impacts and dependencies on nature, enhance transparency and accountability, and contribute to global biodiversity conservation and sustainable development efforts. The **preliminary framework** presented in this document aims to provide a foundation for the development and implementation of such indicators.

8.1 European Sustainability Reporting Standards (ESRS)

The **European Sustainability Reporting Standards (ESRS)** aim to establish a **comprehensive and standardised framework** for companies to report on their sustainability-related impacts, risks, and opportunities.

These standards cover a broad range of environmental, social, and governance (ESG) topics, providing investors and other stakeholders with **comparable and verifiable information**. The ESRS are being developed to **enhance transparency and accountability**, driving more sustainable business practices across Europe.

8.2 International Sustainability Standards Board (ISSB)

The **International Sustainability Standards Board (ISSB)** is a global body created to develop and maintain a **comprehensive set of high-quality, understandable, and comparable sustainability disclosure standards**. These standards aim to provide investors and stakeholders with **decision-useful information** about companies' sustainability-related risks and opportunities.

The ISSB's work spans a wide range of ESG topics, including **climate-related disclosures**, and is progressively expanding to address **biodiversity and natural capital**. The inclusion of **biodiversity-specific geospatial indicators** within the ISSB framework reflects a growing recognition of the fundamental role of nature and biodiversity in **corporate sustainability and financial performance**.

This development suggests that companies will increasingly be expected to **disclose spatially referenced data** about their biodiversity impacts and dependencies, enabling more **precise and location-specific assessments** of their environmental footprint. This shift towards **geospatial reporting** aligns with emerging approaches in **environmental accounting and natural capital valuation**, which emphasise the importance of geographic context in assessing sustainability risks and opportunities.

8.3 Global Reporting Initiative (GRI)

The **Global Reporting Initiative (GRI)** is a pioneering international organisation that has developed some of the most widely used **sustainability reporting frameworks**. These frameworks provide a standardised structure and set of indicators for organisations to report on a broad range of ESG topics, promoting **transparency and comparability** in sustainability performance.

Within its comprehensive suite of standards, GRI addresses environmental dimensions, including **biodiversity**. The **preliminary framework for biodiversity-specific geospatial reporting indicators** presented in this document seeks to **build upon and complement existing GRI standards**, offering more **detailed and spatially explicit guidance** for organisations to report on their **impacts and dependencies on biodiversity**.

Integrating geospatial information enhances the **relevance and accuracy** of biodiversity reporting, enabling stakeholders to better understand the **location-specific context** of an organisation's interactions with ecosystems and species. By aligning with and expanding upon GRI's established principles, this framework seeks to **strengthen the measurement and disclosure of biodiversity-related information**, contributing to global efforts in **biodiversity conservation and sustainable development**.

9 Existing and Emerging Standards Relevant to BioClima

The development of open standards and interoperable frameworks represents one of the fundamental pillars of the **BioClima** project, aimed at improving the observation, analysis, and reporting of geospatial indicators on biodiversity and climate change. To achieve this, the project builds upon both **established international standards** and the **proposal of new specifications** designed to address emerging challenges in interoperability, data quality, and alignment with the **FAIR–CARE–FAIR-R** principles.

Existing standards provide a robust foundation for the **integration of environmental and biological data**, including models and protocols developed by international organisations such as the **OGC**, the **World Meteorological Organization (WMO)**, **ISO**, **NASA Earth Science Data Systems (ESDS)**, and **TDWG (Biodiversity Information Standards)**. These frameworks ensure technical, semantic, and operational compatibility across diverse observation systems.

However, the growing demand for **geospatial biodiversity reporting**, the rise of **data spaces**, and the increasing role of **artificial intelligence** in environmental management call for the development of **new standards and extensions**. These should facilitate transparent information exchange across scientific, technical, and policy domains, while ensuring the **ethical, reproducible, and responsible use of data**.

In this context, **BioClima** acts as an **interoperability laboratory**, integrating best practices in observation systems, metadata, ontologies, and quality protocols to contribute to the development of **proposed standards** that support global biodiversity and climate monitoring.

9.1 Existing Standards and Observational Systems for Biodiversity and Climate Change

The development of interoperable and FAIR-compliant geospatial indicators for biodiversity and climate change requires a **solid foundation of existing international standards and data models**, together with a **forward-looking approach** to address emerging gaps in interoperability, semantics, and ethical data management.

The **BioClima** project builds upon this existing ecosystem of standards to enhance the integration of **biodiversity observation systems** and **climate change monitoring frameworks**, ensuring alignment with global initiatives such as **GEO**, **GEOSS**, and the **Open Geospatial Consortium (OGC)**.

This chapter presents an overview of the **current landscape of relevant standards**—covering observational systems, biodiversity data management, and climate monitoring—and identifies the **areas where new standards or extensions are needed** to support interoperable geospatial reporting indicators.
It also highlights the importance of **data quality, ethical governance, and privacy protocols** as cross-cutting enablers for trustworthy environmental data.

By combining established frameworks (e.g., OGC SWE, ISO 19115, TDWG Darwin Core, NASA ESDS, WMO protocols) with proposed new developments such as **geospatial reporting standards**, **AI-ready FAIR-R metadata**, and **semantic bridges between biodiversity and climate domains**, BioClima contributes to shaping the **next generation of interoperable standards** that will underpin evidence-based sustainability reporting and policy-making.

Within this context, **observational systems for environmental and climate monitoring** play a foundational role. They are governed by a set of **international standards that ensure data consistency, comparability, and interoperability** across spatial, temporal, and institutional boundaries. These standards not only facilitate the integration of diverse observation networks but also provide the backbone for linking **biodiversity and climate monitoring frameworks** within a unified geospatial infrastructure.

9.1.1 Standards for Spatial and Aerial/UAV Observation Systems

Environmental and climate observation activities in WP1 rely on international standards that ensure data consistency, comparability, and interoperability across spatial, temporal, and institutional boundaries. While these standards primarily support spatial and aerial/UAV observation workflows, any standard listed here that does not directly relate to these platforms is included because it plays a key role in interoperability across observation systems. These include:

- **Sensor Web Enablement (SWE)** – A suite of OGC standards enabling the discovery, access, and control of sensors and sensor data over the web. SWE includes *Sensor Observation Service (SOS)*, *Sensor Model Language (SensorML)*,*Observations and Measurements (O&M) and the* Semantic Sensor Network Ontology (SOSA/SSN)
- **NASA Earth Science Data Systems (ESDS) Standards** – Provide guidelines for data interoperability, metadata documentation, and open data access across NASA's Earth science missions, ensuring global usability of satellite and in situ data.
- **ISO 19115 Geographic Information – Metadata** – Establishes the structure and content for describing geospatial datasets and services, ensuring discoverability and traceability of observational data.
- **WMO Standards** – Define protocols for climate and atmospheric observations, including the *WMO Integrated Global Observing System (WIGOS)* and *WMO Information System (WIS)*, ensuring data comparability among national meteorological agencies.

These standards collectively enable **multi-source integration** and provide the foundation for linking climate and biodiversity observations into common analytical frameworks. Together, these standards support the integration of multiple observation platforms and establish the foundations needed to combine climate and biodiversity observations within common analytical and reporting frameworks.

9.1.2 ESA Climate Change Initiative ECVs

The **ESA Climate Change Initiative (CCI)** programme is one of Europe's most important long-term efforts to monitor and understand climate change and its impacts on biodiversity, land, and coastal systems. It was originally launched in in 2008. to produce reliable, consistent, and scientifically accurate data covering the 27 Essential Climate Variables (ECVs) as defined by the Global Climate Observing System (GCOS). Individual CCIs do not rely on single satellites, but combine data from multiple ESA and non-ESA missions. Data is harmonized across different sensors and time-periods, and biases are corrected to ensure consistency. Partners include the European Commision, ESA, and EUMETSET, ESA, and a large number of institutes and universities. The table below lists the CCIs that are directly related to terrestrial and coastal biodiversity.

/// TABLE WITH RELEVANT CCIs ///

As they are based on historical data and aim to establish a validated record, CCIs are inherently backward facing. The ambition for a global snapshot that supports forward-looking modelling is covered by Destination Earth (DestinE) which aims for high-resolution Digital Twin of the Earth system [DestinE]. This twin should support global now-casting and forecasting of the Earth system state. In this context, data from CCIs take the role validated initial conditions and calibrators for forward-looking models. Core partners in DestinE are the European Commission, ESA, and ECMWF.

In the biodiversity context, establishing a baseline link between Earth Observation products and biodiversity metrics can be supported by CCI data while forwarding-looking and nowcasting approaches should – once developed – be related to DestinE components.

URL: https://climate.esa.int/en/about-us-new/climate-change-initiative/Climate-Change-Initiative/

URL: https://climate.esa.int/en/about-us-new/climate-change-initiative/essential-climate-variables/how-cci-ecvs-are-generated/

URL: https://destination-earth.eu/destination-earth/destines-components/

9.1.3 Biodiversity Data Standards

Biodiversity information is managed through a diverse ecosystem of **standards, ontologies, and controlled vocabularies** coordinated primarily by **TDWG (Biodiversity Information Standards)** and complementary international initiatives. These frameworks ensure that biological, ecological, and taxonomic data can be **shared, reused, and semantically integrated** across platforms, supporting interoperability under the **FAIR** and **CARE** principles.

Table 2.- Biodiversity Data Standards

Core Biodiversity and Ecological Standards		
Standard / Model	**Description**	**Link**
Darwin Core (DwC)	A TDWG standard defining a glossary of terms for sharing biodiversity data, widely adopted by **GBIF**, **OBIS**, and other global repositories.	https://dwc.tdwg.org/
Humboldt Extension	A TDWG extension to Darwin Core for representing biodiversity monitoring data, including abundance, sampling design, and effort.	https://eco.tdwg.org/
GBIF New Data Model	A revised data architecture under development by the **Global Biodiversity Information Facility (GBIF)** to better handle event-based and monitoring data.	https://www.gbif.org/new-data-model
Ecological Metadata Language (EML)	A widely used metadata specification for documenting ecological datasets, supporting transparency and reproducibility.	—
IUCN Habitat Classification Scheme	A controlled vocabulary for classifying habitat types, enabling consistent	—

	reporting on ecosystem extent and condition.	
Taxonomy and Nomenclature Standards		
Authority	**System Description**	
Catalogue of Life (CoL)	Provides an authoritative, comprehensive index of species names and taxonomic hierarchies.	
ITIS (Integrated Taxonomic Information System)	Offers a consistent reference for species taxonomy across scientific and governmental institutions.	
GBIF Backbone Taxonomy	Serves as a harmonised reference for scientific names, ensuring consistency across biodiversity datasets. https://www.gbif.org/new-data-model	
Ontologies and Measurement Vocabularies		
Ontology / Framework	**Description**	**Link**
OBO Foundry Ontologies	A family of interoperable biological ontologies (e.g., **Environment Ontology**, **Population and Community Ontology**) supporting semantic integration.	List of OBO Ontologies
QUDT (Quantities, Units, Dimensions, and Data Types)	Defines standard units and quantities for scientific measurement, ensuring data compatibility.	—
Genomics Standards Consortium (MIxS)	Establishes *Minimum Information about any (x) Sequence* metadata requirements for genomic and metagenomic datasets.	—
Data Integration and Publication Tools		
Tool	**Model Description**	**Link**
TDWG RDF Models	Semantic Web representations of Darwin Core and Audubon Core that enable linked data and ontology-based applications.	https://dwc.tdwg.org/rdf/
GBIF Integrated Publishing Toolkit (IPT)	An open-source platform for publishing and sharing biodiversity datasets compliant with **DwC** and **EML** standards.	https://www.gbif.org/ipt

These biodiversity data standards and ontologies provide the **semantic and structural foundation** for integrating biological observations with **geospatial frameworks**. Their adoption within BioClima supports the development of **interoperable biodiversity indicators**, aligned with **OGC**, **ISO**, and **TDWG** standards, and compliant with the **FAIR–CARE–FAIR-R** principles.

Together, they enable **harmonised, ethically managed, and AI-ready biodiversity data**, essential for reliable climate and ecosystem reporting.

9.1.4 Standards for Climate Change Observation

Climate change monitoring relies on a combination of **geospatial, sensor, and environmental observation standards** that ensure interoperability and long-term comparability of datasets. The most relevant include:

- **OGC Sensor Web Enablement (SWE)** – For real-time environmental sensing and integration of distributed observation networks.
- **NASA Earth Science Data Systems (ESDS)** – For cross-mission interoperability and open data exchange.
- **ISO 19115** – For metadata documentation ensuring traceability and harmonisation of climate datasets.
- **WMO Standards** – For calibration, measurement, and data-sharing protocols related to meteorology, hydrology, and climatology.

Together, these standards underpin global initiatives such as **GEOSS**, **Copernicus**, and **GOOS**, enabling cross-domain use of climate data for impact analysis, forecasting, and policy reporting.

9.1.5 Data Quality, Privacy, and Ethical Protocols

Beyond technical interoperability, observation systems must ensure that data collection and use comply with **ethical, privacy, and quality standards**.

- **Data Quality and Assurance:** Standards such as ISO 19157 define methods for evaluating positional, temporal, and thematic accuracy. Quality assurance protocols also derive from WMO and TDWG best practices.
- **Ethical and Privacy Frameworks:** The **General Data Protection Regulation (GDPR)** establishes rules for the ethical use and protection of personal data within the EU, including data collected through citizen science.
- **FAIR and CARE Principles:** Complementary to technical standards, these principles ensure that data are not only interoperable but also **accessible, reusable, and ethically managed**, considering both machine-readability and human rights implications.

9.1.6 Towards Standard Integration for Biodiversity and Climate

The integration of biodiversity and climate observation standards is essential for the development of **comprehensive geospatial indicators**. Emerging frameworks such as **Living Data 2025** advocate for the convergence of **biological, climatic, and socio-environmental data** within open and interoperable infrastructures.
This alignment will facilitate cross-domain analyses, improve policy-relevant monitoring, and enable progress towards global sustainability targets such as the **SDGs**, **CBD GBF**, and **Paris Agreement**.

9.2 Proposed Standards

While many mature standards exist for geospatial, environmental, and biodiversity data, there are still **critical gaps** that limit full interoperability between biodiversity and climate observation systems. The BioClima project contributes to identifying these needs and proposing new **standardisation pathways** that extend or complement existing frameworks.

Key areas for the development of new or extended standards include:

1. **Geospatial Reporting Indicators for Biodiversity and Climate Change**: Development of OGC-compliant standards for **spatially explicit indicators** supporting global frameworks such as the **SDGs**, **TNFD**, and **ESG**. This may include the creation of an **OGC Geospatial Reporting Indicators Standard (SWG)** or an extension of existing OGC APIs to enable structured reporting on biodiversity metrics.

2. **Semantic Interoperability between TDWG and OGC Models**: Definition of **crosswalks and semantic mappings** between biodiversity data models (e.g., *Darwin Core*, *Humboldt Extension*, *GBIF Data Model*) and OGC geospatial schemas (e.g., *Observations & Measurements*, *OGC API – Features*). This would enable seamless integration of ecological data into geospatial infrastructures and data spaces

3. **AI-Ready FAIR-R Metadata Profiles**: Introduction of metadata extensions supporting **FAIR-R principles**, ensuring that datasets are not only Findable, Accessible, Interoperable, and Reusable, but also **ready for responsible artificial intelligence applications**. This involves the inclusion of fields describing data provenance, lineage, uncertainty, and ethical constraints for automated use.

4. **Integrated Quality and Provenance Frameworks**: Proposal of interoperable quality assessment models aligning ISO 19157 with TDWG and WMO best practices. This would enhance confidence in multi-source datasets used for biodiversity and climate reporting.

5. **Ethical and Privacy Protocols for Citizen Science and Indigenous Data**: Expansion of CARE principles and GDPR-aligned mechanisms to manage consent, attribution, and sensitive ecological data, particularly in the context of community-driven or participatory monitoring.

The proposed standards outlined above aim to **bridge the gap between existing biodiversity and climate data frameworks**, enhancing the **FAIR–CARE–FAIR-R compliance** of future reporting systems. Through its participation in **OGC**, **TDWG**, and **GEO** standardisation activities, **BioClima** contributes to defining these new specifications and validating their implementation through real-world use cases and policy applications.

10 Standardised ecosystem for observational systems of biodiversity and climate change

A **standardised ecosystem** for biodiversity and climate observation is essential to ensure that data generated by different observation systems—ranging from *in situ* sensors to satellite imagery and citizen-science contributions—can be meaningfully combined, analysed, and reused across spatial and temporal scales. Such an ecosystem does not depend on a single universal data model, but on the **progressive harmonisation and optimisation of interoperability** across data, processes, and semantics.

The establishment of this ecosystem is a **cornerstone for environmental governance**, as the world increasingly relies on data-driven decision-making to monitor progress towards global policy targets such as the **Kunming–Montreal Global Biodiversity Framework (CBD, 2022)**, the **Sustainable Development Goals (UN, 2015)**, and the **Paris Agreement on Climate Change (UNFCCC, 2016)**. Fragmented, inconsistent, or inaccessible data impede the development of reliable indicators, whereas **interoperable and standardised observation systems** enable transparent and reproducible assessments of ecosystem change.

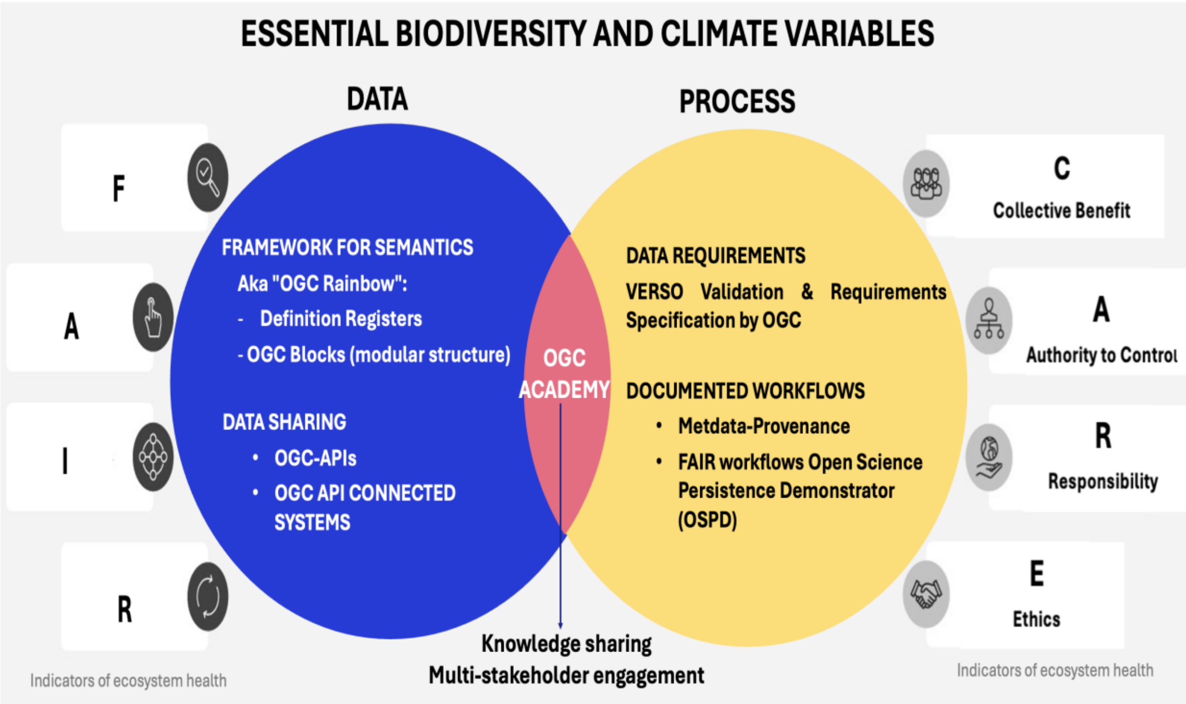

Figure 6.- Standardised ecosystem for observational systems of biodiversity and climate change

This ecosystem connects **multi-source observations**—field measurements, Earth observation products, predictive models, and participatory data—within a **coherent framework of open and interoperable standards** such as **OGC**, **ISO/TC 211**, **TDWG**, and **W3C**. Together, these organisations define the **syntactic, structural, and semantic layers** that allow heterogeneous data to be integrated into shared knowledge graphs, web APIs, and analysis pipelines.

From a governance perspective, the creation of a standardised observation ecosystem represents a shift from isolated data infrastructures toward a **federated, modular, and community-driven architecture**, where interoperability is treated as an evolving capability rather than a fixed endpoint

(OGC Europe, 2023). It also facilitates the transition from project-based data management to **long-term, sustainable infrastructures**, ensuring that information produced through public investment remains accessible and reusable over time (European Commission, 2020).

In the context of **FAIR, CARE** principles, this ecosystem guarantees that environmental information is not only **findable, accessible, interoperable, and reusable**, but also **ethically governed and AI-ready**. FAIR ensures technical openness; CARE ensures equity and respect for data ownership; and FAIR-R extends these principles to prepare data for responsible use in artificial intelligence workflows (Verhulst, 2024; Wilkinson et al., 2016).

Ultimately, a standardised ecosystem of biodiversity and climate observation underpins the **credibility, comparability, and scalability** of environmental evidence. It allows governments, researchers, and private actors to collaborate on a **shared knowledge base** for sustainability, bridging the gap between **scientific observation, policy frameworks, and financial accountability mechanisms** such as TNFD and ESG disclosures.

10.1 Data Harmonisation

Data harmonisation lies at the core of a standardised ecosystem for biodiversity and climate observation. It involves **reconciling and making compatible heterogeneous data** —originating from multiple sources, scales, domains, or observation methodologies— so that they can be integrated, compared, and reused consistently. The ultimate goal is to ensure that environmental data form a **reliable and verifiable foundation** for analysis, modelling, and evidence-based decision-making.

In practice, data harmonisation follows a progressive and iterative process structured across three complementary dimensions —syntactic, structural, and semantic— representing the incremental optimisation of interoperability across datasets, systems, and domains.

10.1.1 Syntactic Harmonisation

Syntactic harmonisation focuses on the **uniformity of data formats and encodings** used for information exchange, ensuring that data can be correctly interpreted by different systems. Typical approaches include adopting open and standardised formats such as **JSON**, **GeoJSON**, **CSV**, **RDF**, or **XML/GML**, enabling the combination of *in situ* observations, satellite products, and model outputs within interoperable workflows.

10.1.2 Structural Harmonisation

Structural harmonisation concerns the **coherent definition of data schemas** and conceptual models that organise entities, attributes, and relationships. The aim is to ensure that diverse datasets follow **compatible structures** that facilitate automated integration.

Key reference models include **Darwin Core (DwC)** and its monitoring extensions (e.g., the *Humboldt Extension*), **ISO 19115** for metadata, **GeoDCAT-AP** for geospatial catalogues, and **CityJSON** or **SensorML** for domain-specific contexts. These models provide a consistent framework for documenting data provenance, quality, and purpose, thereby improving traceability and long-term reusability.

10.1.3 Semantic Harmonisation

Semantic harmonisation ensures that data not only share formats and structures but also **carry the same meaning**. It requires a shared understanding of concepts, variables, and relationships, formalised through controlled vocabularies and interoperable ontologies. Examples include **TDWG RDF** and **OBO Foundry** ontologies, the **OGC GeoSPARQL** model for expressing spatial relationships, and **QUDT** (*Quantities, Units, Dimensions and Data Types*) for ensuring consistent representation of measurement units.

This dimension also involves **semantic mapping and local profiling**, enabling regional or national classifications (such as *Natura 2000* habitat types versus regional designations) to be aligned with common conceptual models. Such mappings ensure that data remain interoperable across geographies and institutional contexts without loss of meaning.

10.1.4 Supporting Tools and Components

To operationalise these three dimensions of harmonisation, **BioClima** relies on an integrated set of **interoperability tools, registries, and modular components** that together constitute the foundation of the OGC interoperability ecosystem:

- **OGC RAINBOW** – A registry and validation environment for standards, vocabularies, profiles, and conceptual models. It serves as the semantic backbone of the ecosystem, enabling profile registration, versioning, and automated data validation against published specifications. Rambow allow us to have multilingual form the concept models.

- **GBIF Integrated Publishing Toolkit (IPT)** – An open-source platform for publishing biodiversity datasets compliant with **Darwin Core** and **Ecological Metadata Language (EML)** standards, ensuring interoperability and global visibility.

- **TDWG RDF Models** – Semantic web representations of biodiversity standards that enable linked-data publication and integration of biodiversity and spatial data within FAIR and AI-ready frameworks.

- **OGC Building Blocks (BBs)** – Modular units of interoperability that encapsulate best practices, architectural patterns, and reusable technical components. Building Blocks enable the **composition of interoperable ecosystems** from standardised elements (e.g., APIs, validation schemas, or shared vocabularies). The focus of the OGC BuildingBlocks is simplification and coherence through modular testing with examples and test cases combined with scalable capabilities to integrate many such modules into comprehensive standards covering many aspects. Standardised, well tested, inherently FAIR components that can be evaluated and adopted individually with reusable implementations. In **BioClima**, BBs provide the structure to **align data harmonisation with process and workflow harmonisation**, ensuring coherence across syntactic, structural, and semantic levels and facilitating integration into national and European infrastructures.

Together, these three layers of harmonisation —supported by **OGC RAINBOW**, **GBIF IPT**, **TDWG RDF**, and the **OGC Building Blocks**— form the technical foundation for a **truly interoperable data ecosystem**.
This approach ensures that biodiversity and climate observations are **comparable, traceable, and reusable** across scientific, institutional, and policy domains, laying the groundwork for **harmonised and standardised geospatial indicators** developed under the BioClima project.

10.2 Process harmonisation

While data harmonisation focuses on the technical alignment of formats, schemas, and semantics, **process harmonisation** ensures that the **workflows and operational procedures** behind data production, transformation, and publication are equally consistent and interoperable. In the context of **BioClima**, process harmonisation guarantees that all components of the observation ecosystem—ranging from data collection to policy reporting—can interact seamlessly through documented, reusable, and verifiable workflows.

10.2.1 Documented Workflows

The documentation of workflows represents a fundamental step in achieving process interoperability. Workflows describe how data are **collected, transformed, validated, and published**, capturing the dependencies between steps, actors, and tools involved in each process. When described using formal and machine-readable approaches, workflows become **reproducible and transparent**, allowing others to validate or replicate the same process in different contexts.

In BioClima, workflows are documented and shared through the **Open Science Persistence Demonstrator (OSPD)**[5], a reusable framework developed under the **Open Science Building Blocks** initiative.
The OSPD enables the description of workflows using **FAIR metadata profiles**, integrating elements such as:

- **Data provenance**, following **W3C PROV-O** and **ISO 19115 Lineage** for tracking data origins and transformations.
- **Quality assurance procedures**, based on **ISO 19157** and **QUDT** models for documenting uncertainty, completeness, and measurement accuracy.
- **Licensing and data usage policies**, referencing **ODRL** and **Creative Commons** to ensure clarity and legal compliance.
- **Execution context**, including tools, APIs, and computing environments (Docker, Jupyter, or cloud pipelines), captured using reproducible configuration files.
- **Multilingual support:** Access to data information in different languages can be supported.

By documenting these processes through the OSPD, BioClima enables **transparent, traceable, and persistent workflow publication**, supporting the broader goals of open and reproducible environmental science.

[5] **Open Science Persistence Demonstrator (OSPD):** The **OSPD** is a component of the **Open Science Building Blocks (OS-BB)** framework developed by **OGC Europe** to demonstrate how **scientific workflows can be persistently documented, validated, and shared** according to the **FAIR principles**.
It provides a reusable and modular architecture to record the provenance, quality, licensing, and execution context of processes in a machine-readable format, ensuring that workflows remain **traceable, reproducible, and verifiable** over time.
In practical terms, the OSPD serves as a **bridge between data and process harmonisation**, enabling workflows to be validated through profiles, linked to standardised APIs, and maintained within open registries (e.g., RAINBOW).

10.2.1.1 Data Harmonisation Requirements

Data harmonisation within processes ensures that **transformations, validations, and exchanges** follow consistent standards and semantic definitions across the entire workflow lifecycle.
It not only concerns the structure of the data but also the way **inputs, intermediate results, and outputs** are validated and aligned with reference profiles. This guarantees that each process component —from data acquisition to policy reporting— produces outputs that are interoperable and semantically coherent.

In **BioClima**, this process-level harmonisation is operationalised through the integration of the **OGC Data Exchange Tool**. The tool enables **profile-based interoperability**, supporting the registration, validation, and transformation of datasets according to standardised profiles defined in **OGC RAINBOW**.

By leveraging these profiles, the Data Exchange Tool acts as a **bridge between data models, APIs, and workflows**, ensuring that information flows are both technically and semantically consistent.

The **OGC Data Exchange Tool** facilitates this harmonisation through three core functions:

- **Profile Management:** Each dataset or API can be validated against a specific application profile defined in RAINBOW, ensuring that all exchanged data comply with common specifications (e.g., GeoSPARQL, SHACL, or Darwin Core RDF).

- **Data Transformation Pipelines:** The tool allows the execution of automated transformations between formats or schemas (e.g., JSON → RDF, CSV → GeoJSON), guided by the metadata and semantic constraints of each profile.

- **Integration with Workflows:** Through its modular architecture, the Data Exchange Tool can be embedded within **OGC API Connected Systems** and **Open Science Persistence Demonstrator (OSPD)** workflows, enabling reproducible, standards-based data exchange.

In combination with the **OGC Building Blocks**, the **Data Exchange Tool** provides a **reference implementation** for how harmonisation requirements can be operationalised across data and process layers.
It ensures that all data transformations are **validated, traceable, and semantically transparent**, while maintaining full alignment with FAIR, CARE, and FAIR-R principles.

Through this integrated approach, BioClima establishes a **harmonised process architecture** that unifies scientific workflows, technical components, and policy-driven reporting mechanisms.
By combining **documented workflows**, **standardised data transformation pipelines**, and **semantic validation**, the project ensures that its observation processes are not only technically interoperable but also **transparent, auditable, and aligned with the principles of Open Science**.

10.3 Data Sharing

Data sharing represents the operational dimension of interoperability — it defines the **channels, protocols, and services** through which environmental data can be accessed, distributed, and reused in an open, traceable, and secure way. Within **BioClima**, data sharing relies on the **OGC API** family of standards and the **OGC API Connected Systems** pattern, which enable the federation of heterogeneous sources and the orchestration of data flows across platforms.

10.3.1 OGC API (Family of Standards)

The **OGC API** family provides **modular and RESTful interfaces** for accessing and interacting with geospatial resources, ensuring lightweight and interoperable integration across systems. It includes standards such as:

- **OGC API – Features, Records, Coverages, Tiles, Styles, Processes**, and **Environmental Data Retrieval (EDR)**, which support spatio-temporal queries and data extraction on demand.
- These APIs allow for **consistent, well-documented, and FAIR-aligned** access to *in situ* observations, remote sensing products, and model outputs, while incorporating ethical and responsible principles from **CARE** and **FAIR-R**.

10.3.2 OGC API Connected Systems

OGC API Connected Systems provides a framework to **link and federate multiple OGC API services** with other components — such as catalogues, validation services, event queues, and quality pipelines — in order to create integrated and automated ecosystems. This approach ensures that:

- Systems can **discover, chain, and communicate** through standardised links and self-descriptions.
- **Composite workflows** can be established (e.g., discovery → filtering → extraction via **EDR** → publication), supporting both **synchronous** and **asynchronous** communication patterns (including *publish/subscribe* where applicable).
- **Traceability and consistency** are maintained through shared metadata profiles (e.g., **ISO 19115**, **GeoDCAT-AP**, **PROV-O**) and semantic validation mechanisms.

10.3.3 Implementation in BioClima

- **Publishing and access:** Datasets are exposed through **OGC API** services (Features, EDR, Records) and, where appropriate, via the **GBIF Integrated Publishing Toolkit (IPT)** using **Darwin Core** and **EML** standards.

- **Federation and orchestration:** The **OGC API Connected Systems** pattern links catalogues, validators, and transformers into reproducible workflows — for example, validation → enrichment → publication.

- **Semantics and validation:** The **RAINBOW** environment and **OGC Building Blocks** provide registries, profiles, and validation templates (RDF, SHACL, GeoSPARQL) to ensure **syntactic, structural, and semantic coherence**.

- **Governance and reuse:** Persistent identifiers, standardised metadata, and open licences (e.g., **Creative Commons**, **Open Data Commons**) guarantee **traceability, citability, and responsible reuse**.

By combining **OGC API** and **OGC API Connected Systems**, BioClima goes beyond traditional data publication to establish a **federated ecosystem of interoperable services** that interconnect observation networks, institutional infrastructures, and policy reporting frameworks. This approach ensures that BioClima's data are not only technically accessible, but also **ethically governed, transparent, and AI-ready**, supporting the long-term sustainability and credibility of environmental information.

11 Work Plan

The activities developed under WP1 have shown that building a standardised and interoperable ecosystem for biodiversity and climate observation requires a coordinated approach that spans the data, process, and semantic layers. Based on these initial results, the preliminary BioClima framework provides the conceptual foundation upon which the work plan for the subsequent phases of the project will be structured.

This framework highlights the need for a **progressive and multidimensional harmonisation process**, addressing syntactic, structural, and semantic interoperability in a coherent and incremental manner. To this end, the project will promote the systematic use of **open standards** (OGC, ISO, TDWG, W3C) as the common reference axis across all technical activities.

In parallel, **continuous coordination mechanisms with relevant OGC Working Groups** will be established. This interaction will ensure full alignment between BioClima's methodologies and the broader international efforts towards environmental and climate interoperability, avoiding duplication and maximising the reuse and impact of project outcomes.

Building on this shared framework, the following work plan defines the specific tasks that will guide BioClima's implementation, detailing activities, expected results, and monitoring mechanisms designed to achieve the project's objectives.

Recommendations for Standards Development (WP1)

The activities under WP1 have established a strong foundation for the development of a harmonised and interoperable framework supporting biodiversity and climate observation. Building on these results, BioClima will focus on strengthening its contribution to international standardisation efforts, ensuring that its technical developments are consistent with global practices and reusable across multiple policy and regional contexts. The following actions outline the main priorities for advancing standardisation and interoperability within the BioClima ecosystem.

1. **Strengthen collaboration with OGC Working Groups**: BioClima will actively contribute to the *Climate Resilience DWG*, *Data Quality DWG*, and *Geospatial Reporting Indicators SWG*, which already address key technical, policy, and interoperability challenges related to biodiversity and climate monitoring. This engagement will ensure that BioClima outcomes remain technically aligned with ongoing OGC standards development, while also supporting the broader harmonisation of climate and biodiversity reporting practices.

2. **Develop localised reporting profiles through OGC RAINBOW**: Leveraging the OGC RAINBOW registry, BioClima will define semantic resources — including ontologies, multilingual support, indicator parameters, and cross-jurisdiction mappings (e.g., *Natura 2000* vs. national protected-area designations). These regionalised RAINBOW profiles will facilitate semantic interoperability, enabling adaptation to local policy frameworks while ensuring that indicators remain comparable and reusable across contexts.

3. **Apply the OGC Data Exchange Tool for profile-based validation**: The *OGC Data Exchange Tool* will operationalise harmonisation and interoperability testing by validating datasets, APIs, and services against the defined RAINBOW profiles. This validation process will promote standard-based data exchange, guarantee provenance traceability, and support reproducible data transformations in alignment with FAIR and FAIR-R principles.

4. **Document and publish workflows through the Open Science Persistence Demonstrator (OSPD)**: BioClima will describe, validate, and disseminate its data workflows via the *Open Science Persistence Demonstrator (OSPD)* — a reusable framework developed under the *Open Science Building Blocks* initiative. Each workflow will be accompanied by FAIR-compliant metadata, including provenance (W3C PROV-O, ISO 19115 Lineage), data quality (ISO 19157, QUDT), and licensing (ODRL, Creative Commons), ensuring transparency, reproducibility, and long-term persistence of results.

Integration with AI (WP3) and Dissemination (WP5)

WP1 outputs not only serve as the foundation for standardisation but also enable downstream integration with Artificial Intelligence workflows and dissemination activities. The harmonised datasets, FAIR-R principles, and open validation mechanisms developed under WP1 provide the structural and semantic backbone required for data-driven modelling, stakeholder engagement, and knowledge transfer across BioClima's ecosystem. The following paragraphs summarise how WP3 and WP5 will build upon these results.

1. **Artificial Intelligence (WP3):** The harmonised datasets and FAIR workflows developed under WP1 will provide a robust foundation for the integration of Artificial Intelligence methods within the project. Through the **FAIR-R extension**, datasets will become *AI-ready*, enabling WP3 to train models for biodiversity monitoring, predictive climate indicators, and automated data quality assessment. The outputs from WP1 will therefore serve as the semantic and structural backbone for WP3's analytical and predictive components.

2. **Dissemination and Stakeholder Engagement (WP5):** WP5 will ensure that BioClima's results are effectively communicated, reused, and scaled through multiple dissemination and training channels, including the **BioClima Academy**, **OGC Europe's communication platforms**, and **GEO/GEOSS networks**. Dissemination activities will prioritise capacity building, standardisation training, and the promotion of interoperability best practices to foster wide adoption of BioClima's methodologies and tools across the global environmental data community.

9.1 Planned Tasks

The work plan for the next phase of standards activities for BioClima focuses on consolidating the results achieved under WP1 and ensuring their practical application across the other work packages. The planned tasks are structured around four main pillars: coordination with standardisation bodies, technical development of profiles and validation mechanisms, a pilot demonstration, and dissemination of best practices.

T1. Coordination with Working Groups and Standardisation Bodies

- Maintain active participation in the most relevant OGC Working Groups, including the *Climate Resilience DWG*, *Data Quality DWG*, and *Geospatial Reporting Indicators SWG*.
- Establish or strengthen connections with complementary organisations and initiatives such as TDWG (Biodiversity Information Standards), ISO/TC 211, and the forthcoming *ESG DWG*.
- Produce quarterly alignment reports summarising progress and synergies, ensuring technical consistency between BioClima and international interoperability initiatives.

T2. Development of the Technical Interoperability Ecosystem

- Define and register semantic profiles within **OGC RAINBOW**, including indicator parameters, ontologies, multilingual support, and mappings between jurisdictional designations (e.g. Natura 2000 and national frameworks).
- Implement automated validation pipelines using the **OGC Data Exchange Tool**, testing the interoperability of datasets and APIs against the defined profiles.
- Document standardised workflows through the **Open Science Persistence Demonstrator (OSPD)** to guarantee transparency, traceability, and reproducibility across all processes.

T3. Mini-Pilot for Integration and Validation

- Develop a demonstrative mini-pilot focused on the integration of biodiversity and climate data, applying the profiles and tools defined under WP1.
- Assess data interoperability, traceability, and quality using the Data Exchange Tool and RAINBOW infrastructure.
- Identify technical or semantic gaps requiring new or extended standards and report them to the relevant OGC Working Groups for further development.

T4. Dissemination, Training, and Best Practices

- Prepare a set of **best practice guidelines** and methodological recommendations on FAIR–CARE–FAIR-R interoperability for biodiversity and climate observation.
- Organise a **technical workshop** for the standards community and environmental data users, promoting the replicability of BioClima's results.
- Integrate the resulting content into the **BioClima Academy** and OGC Europe's training and dissemination platforms.

T5. Monitoring and Evaluation

- Establish key performance indicators (KPIs) to track participation in working groups, the number of validated profiles, harmonised datasets, and dissemination activities carried out.
- Produce an interim evaluation report serving as input for subsequent deliverables (D1.3 and D2.1).

The following table summarises the planned tasks under WP1 for the upcoming implementation period. Each task is aligned with the overarching objective of establishing a harmonised and standardised ecosystem for biodiversity and climate observation, ensuring interoperability across data, processes, and semantics.

The table indicates the responsible partners, start month, expected duration, and main outputs or deliverables associated with each activity. This planning framework provides a structured roadmap to monitor progress, facilitate coordination with other work packages, and ensure the timely delivery of BioClima outcomes.

Table 3.- Standardisation and Interoperability Work Plan

Task ID	Task Title	Responsible Partner(s)	Start Month	Duration (months)	Main Outputs / Deliverables
T1	**Coordination with Working Groups and Standardisation Bodies**	OGC (lead), WP1 Consortium, with contributions from TDWG, ISO/TC211,	M12	12	Quarterly alignment reports; documented participation in OGC Climate Resilience DWG, Data Quality DWG,

		ESG DWG liaison partners			and Geospatial Reporting Indicators SWG
T2	**Development of the Technical Interoperability Ecosystem**	OGC (lead), with technical input from WP3 partners	M12	12	RAINBOW semantic profiles; validation pipelines implemented via OGC Data Exchange Tool; documented workflows in OSPD
T3	**Mini-Pilot for Integration and Validation**	OGC (lead), coordinated with WP2 and WP3	M14	6	Demonstration report on data integration and validation; identified gaps and recommendations for new standards
T4	**Dissemination, Training, and Best Practices**	OGC Europe (lead), supported by WP5 partners	M15	8	BioClima Best Practices Guide; Technical Workshop; Training materials integrated into BioClima Academy
T5	**Monitoring and Evaluation**	OGC (lead)	M12	12	KPI dashboard; Interim Evaluation Report feeding into D1.3 and D2.1

Together, these planned tasks will ensure that BioClima moves from conceptual design to practical implementation, establishing the technical and organisational conditions for interoperable biodiversity and climate data. The outcomes of these activities will directly support the definition of geospatial indicators in WP2, the integration of AI-driven workflows in WP3, and the dissemination and capacity-building actions in WP5.

12 Conclusions

The development of this preliminary framework for biodiversity-specific geospatial reporting indicators marks a significant step toward establishing the technical and conceptual foundations of BioClima. It provides a coherent vision for how open standards, FAIR–CARE–FAIR-R principles, and interoperable data ecosystems can support transparent, ethical, and reproducible observation and reporting on biodiversity and climate change.

WP1 has demonstrated that achieving interoperability requires a multi-layered approach —addressing syntactic, structural, and semantic dimensions— complemented by robust governance and validation mechanisms. The integration of OGC, TDWG, ISO, and W3C frameworks provides a solid foundation for cross-domain interoperability and supports alignment between scientific observation, public policy, and sustainability reporting mechanisms such as the TNFD and ESG frameworks.

A core outcome of this deliverable is the identification of the technical and organisational components needed to operationalise interoperability within BioClima: the **OGC RAINBOW** registry for semantic profiles and validation, the **OGC Data Exchange Tool** for quality assurance and data transformation, and the **Open Science Persistence Demonstrator (OSPD)** for documenting reproducible workflows. Through engagement with OGC Working Groups —including the Climate Resilience DWG, Data Quality DWG, and Geospatial Reporting Indicators SWG— BioClima strengthens Europe's leadership in sustainable and interoperable environmental data management.

From a sustainability perspective, this framework contributes to:

- **Environmental sustainability**, by promoting open and standardised data that improve evidence-based decision-making and reduce duplication of observation efforts;
- **Technical sustainability**, through modular, reusable, and standards-based tools that ensure long-term usability and alignment with future European Data Spaces; and
- **Institutional sustainability**, by embedding BioClima outcomes into ongoing OGC, TDWG, and ISO standardisation activities, ensuring continuity beyond the project's lifetime.

The planned tasks for the upcoming period will further consolidate these foundations through continued standardisation efforts, pilot validation, and dissemination of best practices via the BioClima Academy. Together, these activities ensure that BioClima evolves from a conceptual framework into a fully operational, sustainable ecosystem for biodiversity and climate observation.

The outcomes of D1.2 will directly feed into:

- **WP2**, providing the foundation for indicator development and harmonisation;
- **WP3**, enabling AI-ready, FAIR-R datasets and automated workflows;
- **WP4**, applying these methods in real-world case studies, where WP1 outputs will directly support data integration, validation, and the operational use of indicators**,** and
- **WP5**, guiding training and outreach activities to promote sustainable adoption of interoperability practices.

By connecting scientific observation, technical standardisation, and sustainability governance, BioClima contributes to a long-term, trusted, and ethically governed European ecosystem for biodiversity and climate data — one that supports global environmental goals while ensuring the responsible and sustainable use of shared digital resources.

It is important to emphasise that this deliverable does not aim to present a closed and definitive set of geospatial biodiversity indicators. At this stage of the project, the emphasis has deliberately been placed on defining the methodological framework and the process for standardising the indicators, including the principles, interoperability requirements and validation mechanisms necessary for their consistent development in line with international standards.

The identification, consolidation, and standardisation of specific indicators requires a greater degree of maturity in the technical results and consensus among the various stakeholders involved. For this reason, the explicit and detailed definition of the **set of standardised indicators will be addressed in Deliverable D1.3 (M24)**, once the process described in this document has been applied and validated within the framework of the project.

This progressive approach ensures the methodological soundness of the indicators, their alignment with international reporting frameworks (such as TNFD, SDGs and ESG) and their full integration into an interoperable ecosystem based on open standards and FAIR–CARE–FAIR-R principles.