European long-term ecosystem, critical zone and socio-ecological systems research infrastructure PLUS

eLTER Standard Observations – variables (eLTER SO variables)

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Editorial team:

Steffen Zacharias[1], Claudia Schütze[1], Saku Anttila[2], Nathalie Cools[4], Jaana Bäck[3], Kristin Böttcher[2], Peter Haase[5], Ingolf Kühn[1], Ulf Mallast[1], Michael Mirtl[1]

1. *Helmholtz Centre for Environmental Research – UFZ, Germany*
2. *Finnish Environment Institute, Finland*
3. *Department of Forest Sciences, University of Helsinki, Finland*
4. *Research Institute for Nature and Forest, Belgium*
5. *Senckenberg Research Institute and Natural History Museum Frankfurt, Germany*

Contributing authors:

Ilona Bärlund, Isabelle Braud, Mario Brauns, Ricardo Díaz-Delgado, Thomas Dirnböck, Martyn Futter, Veronika Gaube, Nikolaos Nikolaidis, Daniel Orenstein, Marie-Noëlle Pons, Caterina Bergami, Karsten Rinke, Christian Siebert, Ute Skiba, Harry Vereecken

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Preface

The manifold interactions of society with the environment, climate change, and changes in land use generate diverse and long-term changes in ecosystems, which result in novel global environmental risks and, consequently, new scientific challenges. For science to provide adequate answers to these key global problems, a comprehensive understanding of environmental processes and the interplay between societal drivers and environmental system responses and feedbacks is required. The current state of research is fragmented according to scientific disciplines and environmental domains. In order to understand and solve the key global problems based on ecosystem processes and biogeochemical cycles, it is necessary to adopt an inter- and transdisciplinary approach to environmental observation. This approach needs to take into account the human dimension.

The development and advancement of such integrated observation systems is a crucial prerequisite to promote holistic inter- and transdisciplinary research and is one of today's Grand Challenges of Earth system sciences for global sustainability (Reid et al., 2010). It is also defined as one of the societal challenges of the European Commission for Europe 2020 - Development of comprehensive and sustainable global environmental observation and information systems (EC, 2017).

Understanding the multiple interactions between global change and major European ecosystems, critical zone and socio-ecological systems requires an appropriately designed research infrastructure such as the eLTER RI. Through this RI, scientists and research communities can collaborate with a broad range of stakeholders including e.g., policy makers, industry, and governmental and non-governmental organizations for longer time scales than typically is possible through a project based funding. The unifying approach for the elements and construction of the eLTER RI therefore rests on four conceptual pillars:

- Long-term: eLTER RI aims to collect, record, manage, synthesize and make available information that documents the long-term development of ecosystems
- In-Situ: eLTER RI aims to collect and make available data on different spatial scales for terrestrial, freshwater and transitional water ecosystems encompassing five different ecosystem spheres (geo-, hydro-, bio-, atmo-, sociosphere) obtained from individual long-term observation in-natura sites
- Process orientation: eLTER RI aims to identify and quantify interactions, causes and effects of ecosystem processes affected by external and internal drivers
- Whole System Approach: eLTER RI aims to provide a comprehensive description of the whole ecosystem consisting of the five ecosystem spheres, its ecosystem processes, feedbacks and cycles as well as the ecosystem-human interactions.

The new challenges facing science today are accompanied by new and constantly growing demands on the design of environmental observations and environmental monitoring technologies (GCOS, 2010; Hari et al., 2016; Lawford, 2014; Mollenhauer et al., 2018; Reid et al., 2010; Shapiro et al., 2010; Zoback, 2001). The mission of eLTER is to facilitate high impact research and catalyze new insights on the compounded impacts of climate change, biodiversity loss, soil degradation, pollution, and unsustainable resource use across Europe's terrestrial, freshwater and transitional water ecosystems. The central objectives of the eLTER RI design are (i) to foster excellent science by making comprehensive environmental data available and improving its accessibility and utility and (ii) to provide the most representative coverage possible of major biogeographical and socio-ecological regions of Europe.

The entire LTER-Europe network consists of more than 600 formally accredited LTER Sites for ecosystem research (https://deims.org/). Several of these observatories are also designated as Critical Zone (CZ) sites and are partners in various CZ projects and networks.

Each of the sites and platforms represents different levels of infrastructural developments and they typically cover smaller spatial scales (single research stations, plot or field scale). Transforming these structures into a continental, harmonized, inter- and transdisciplinary research infrastructure is the central goal of the eLTER Preparatory Phase Project (eLTER PPP) and the eLTER PLUS project. Essential in this respect is a hierarchical concept of site and platform categories, consisting of a set of observatories designed for:

(i) highest operational excellence and comprehensiveness - Category 1 sites and platforms (see Chapter 2 for a description of site categories),
(ii) and a larger number of less extensively instrumented sites and platform (Category 2).

Combining intensively instrumented sites with research sites providing basic instrumentation (Category 2) will significantly increase the density of sites in the eLTER RI. This will improve spatial and temporal coverage and ensure targeted geographical representativeness.

The establishment of a standardized and harmonized design is the central prerequisite for the exchange of data between sites. This pertains to both the geographic distribution of the study sites and, most importantly, the monitoring concept. This includes the types and extent of environmental variables to be recorded, as well as the methodology to be employed. Cross-site and cross-biome compliant standardized eLTER RI observations will enable the integration of measurements from plot to continental scales as required to address the eLTER Research Challenges.

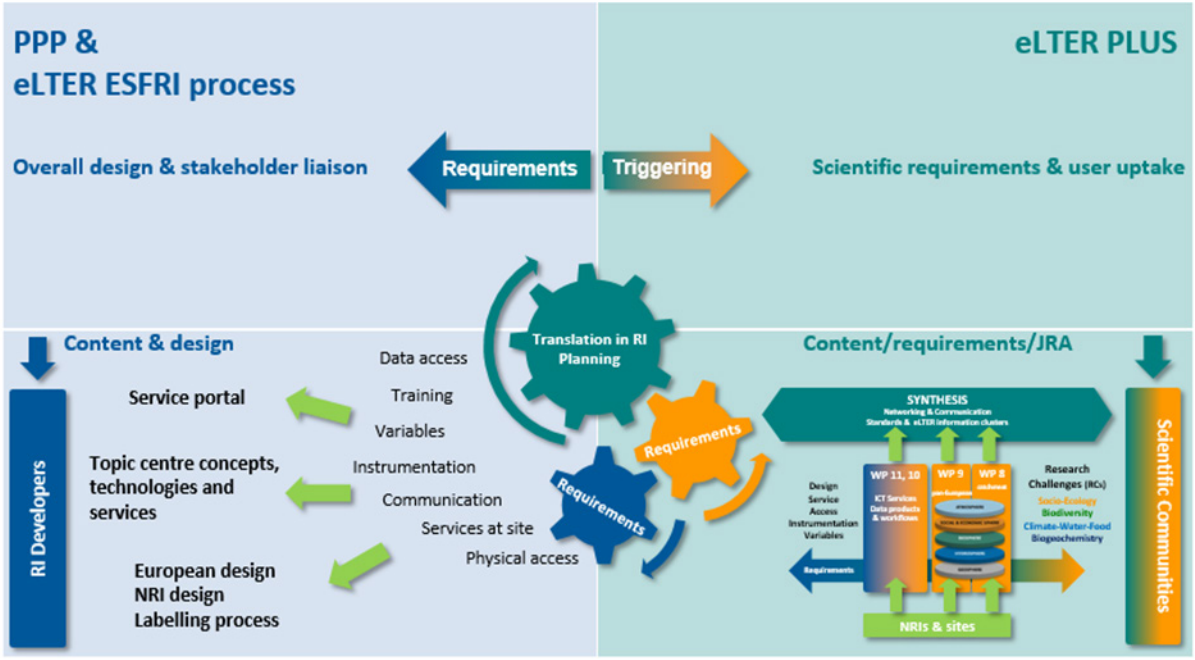

Figure 1: The links between the eLTER PPP and the eLTER PLUS project

The main objective of eLTER PPP is to prepare the emerging RI regarding implementation and operation by coordinating required planning and specifications needed for the formal ESFRI decision making. This includes the development of the operational framework and technical requirements as the cornerstones for quantifying the resources needed to construct and operate the eLTER RI. The demand for resources is greatly affected by the requirements for the mandatory monitoring program and the standards for measurement. A sustainable implementation of the network design and associated measurement protocols can only succeed if both are developed from a user's perspective. The eLTER PLUS project meets this challenge. As an Advanced Communities project, eLTER PLUS integrates the European ecosystem, critical zone and socio-ecological scientific user communities in

order to allow for joint development of capacity building at eLTER RI sites and via the innovative services they offer. Within eLTER PLUS, WP3 focuses on the 'interoperability of eLTER Standard Observation variables'. Central tasks of WP3 are the (i) development of recommendations of key variables, (ii) the identification of in-situ design needs from the perspective of remote sensing applications, and (iii) the development of a concept for the harmonization of methods and protocols, taking into account the concepts of other, already established RIs and networks. These objectives are the essential justification for the formalizing decisions to be taken in the eLTER PPP regarding network design at the European level and at the level of national research infrastructures (NRIs) (Figure 1).

This report provides a detailed overview on the "eLTER Standard Observations variables" (eLTER SO variables). The eLTER SOs are one of the essential bases for the development of an initial cost model for eLTER RI (see WP4 in eLTER PPP) and an important reference for the national eLTER ESFRI processes towards the future National Research Infrastructures (NRIs) as major building blocks of eLTER RI.

1 eLTER and the process for defining Standard Observations

1.1 Standard Observations

Based on eLTER's whole system approach, the WAILS concept (Mirtl et al. (2021), for more detailed description see chapter 1.2), the Framework of eLTER Standard Observations (eLTER SOs) defines the (i) minimum set of variables (eLTER SO variables) and (ii) the associated methods and protocols (eLTER SO protocols) to characterize adequately the state and future trends of the Earth systems, including the human dimension. SOs have to be able to determine the system's state and development and, furthermore, have a high impact, high feasibility, relatively low cost of implementation, and sufficient spatiotemporal coverage (Masó et al., 2020; Reyers et al., 2017). We are, however, mindful of the comment by Werner Heisenberg "what we observe is not nature in itself but nature exposed to our method of questioning," (Gleiser, 2018) and thus recognize the inevitable presence of trade-offs. The specific requirements for the SOs are an ability to characterize an environmental system or process that can be generated and archived in an affordable way, relying on a coordinated observation infrastructure and proven current technology (Guerra et al., 2017). SOs are a part of the harmonization process providing most critical information from the diverse primary observations in a standard format. In this sense, SOs have some commonalities with frameworks of Essential Variables as developed within various scientific communities (see further exemplary references below). On the one hand, they take into account the academic-scientific perspective on the most comprehensive description of states and fluxes possible in the environmental system under consideration and the interaction with the society, as is also reflected in concepts of Essential Variables. On the other hand, the definition of SOs aligns with the design of the eLTER RI by considering cost-effectiveness and operative feasibility as preconditions for selecting methods and protocols. In this sense, an eLTER Standard Observation is defined as a combination of three elements: (i) definition of the variable to be measured, (ii) definition of the measurement methods to be used and (iii) the protocol for measuring the variable. (Figure 2).

To make best use of the SOs, a clearly defined standardization and harmonization process was developed. One of the key roles of RIs, such as eLTER, is to ensure harmonization in data collection and provision. Standardization and harmonization are both related to assessment and monitoring programs, and aim to bring together observational data. Harmonization can be seen as a 'bottom up' methodological approach that aims to systematize the process of combining individual data that are collected in several observational networks at e.g., national level (Köhl et al., 2000). Combining data will increase sample size, but the quality of the harmonized result is only as high as the quality of the individual data sets and the comparability of the methods and protocols used. In contrast, standardization can be interpreted as a 'top-down approach', seeking to define common standards that can be later applied within different networks or RIs. Harmonization differs from standardization in that it does not impose a single methodology or norm, but rather seeks to find ways of integrating information gathered through disparate methodologies. The principal is to find pragmatic ways of making compatible and integrable datasets which have been collected for different purposes under different collection regimes, and using different standards and methodologies (GCOS, 2010). This means avoiding any conversion of the data to a single standard, but rather finding ways to make the collected data usable at some higher level of aggregation or generalization.

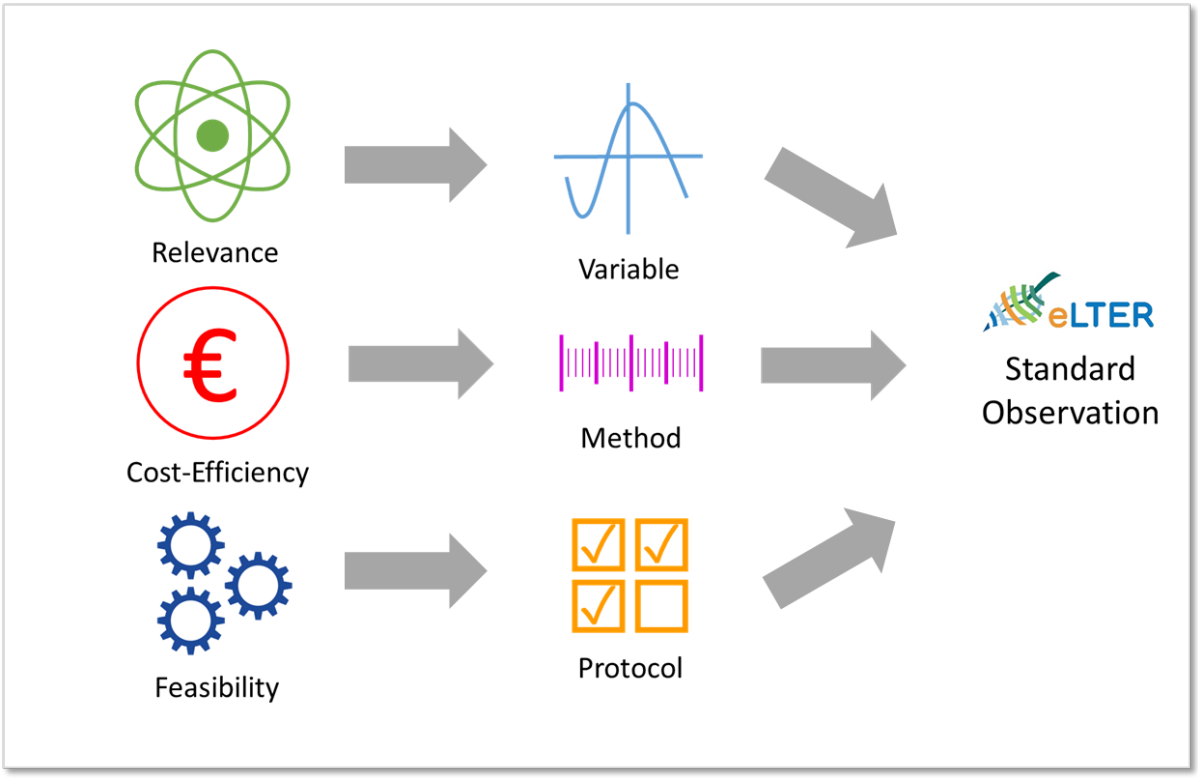

Figure 2: Definition of Standard Observations (variable/variables + method + protocol) based on consideration of scientific relevance, cost and operative feasibility.

As part of the development of the eLTER SOs, an analysis was carried out to identify and compare research platforms and associated concepts that have already been realized and which have previously initiated the development of a minimum set SOs within their research domain. This information was crucial to identify conceptual interfaces with other networks and thus potentials for international and cross-network harmonization. Pioneering work can be attributed to the development of definitions for Essential variables required for weather forecasting as early as 1850 (Masó et al., 2020). These first definitions of Essential variables were to a larger extent later incorporated into Essential Climate Variables (Bojinski et al., 2014). More recently, there was also progress in developing Essential Ocean Variables (Miloslavich et al., 2018) and Essential Biodiversity Variables (Pereira et al., 2013). These frameworks are continuously developing with the addition of new variables, domains and networks (Pacheco-Romero et al., 2020; Patias et al., 2019).

1.2 Overall concept

Biodiversity loss, eutrophication, soil degradation, climate and land use change, and the associated societal impacts are among the research challenges addressed by eLTER RI. These processes affect the Earth system in unprecedented ways, and the scientific Grand Challenge is a thorough understanding of the underlying interactions between physical, chemical and geological processes. Long-term forecasting of ecological developments is the order of the day. Understanding the multiple effects of global change on the major European ecosystems and socio-ecological systems requires an appropriately designed research infrastructure such as the eLTER RI, where scientists and research communities collaborate across domains in the long-term at whole system research sites and platforms. This requires sustained investment to improve our ability to observe the long-term evolution of European ecosystems, their coupled biotic-abiotic processes, and the coupled social-biophysical dynamics.

The design of the eLTER RI is guided by the WAILS concept - Whole-system Approach for In-situ research on Life Supporting systems - which combines two overarching scientific concepts, applicable from point to continental scales: the Press Pulse Dynamic Model (PPD) (Collins et al., 2011) as its horizontal component, and the spatially-nested hierarchical feedback paradigm of Macrosystems Ecology (MSE) (Heffernan et al., 2014) as its vertical component (Figure 3). While the PPD scheme identifies fundamental linkages between the social sphere and the geo-, hydro-, bio-, atmosphere, the MSE scheme provides a unifying framework for the holistic study of ecosystems across different spatial and temporal scales including their feedback within and across scales. This cross-scale ambition is taken into account by the fifth conceptual pillar of the eLTER RI design – Systematic and large-extent coverage of major terrestrial and aquatic environments in Europe.

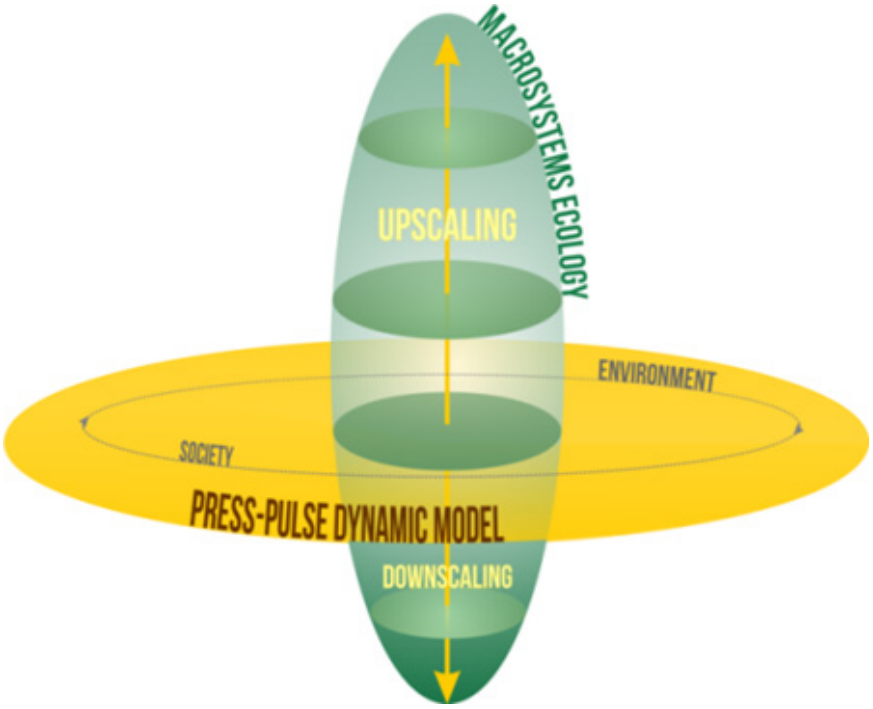

Figure 3: Schematic representation of eLTER's Whole-system Approach (WAILS, Mirtl et al., in preparation)

European LTER Sites, LTSER Platforms, critical zone observatories, and national networks are heterogeneous in terms of the investigated ecosystem type, scale of investigation, complexity, and instrumentation. Individual sites measure a wide range of biotic and abiotic variables according to site-specific requirements (the site´s "ecological profile") and often follow site-specific standards for instrumentation and protocols.

The development of the eLTER SOs demanded translation of the scientific agenda of eLTER RI into a framework of requirements for the observatories and the actual design. A conceptual approach able to help guiding this translation process is the Ecosystem Integrity (EI) Concept (Haase et al., 2018; Müller et al., 2000). The idea of EI is to assess the complexity and ability for self-organization of an ecosystem in order to safeguard sustainability in terms of functions, processes, and related ecosystem services. The EI concept provides a holistic approach to ecosystem assessment of biotic and abiotic fluxes and states. However, it falls short in capturing the human-nature interactions in detail. Nevertheless, it states that the ecosystem should be covered at the process level by describing energy, water, and matter budgets as well as the abiotic and biotic heterogeneity. With this approach, the EI concept fits very well into the WAILS scientific perspective and can be used to structure the process of selecting variables for the eLTER SOs. In detail, the eLTER SO variables should fulfil the following criteria:

- Representation of key elements of the Ecosystem Integrity concept
- Critical relevance for understanding the coupled human-nature system
- High sensitivity to environmental changes
- Critical relevance for ecosystem modeling

These four criteria determine the scope of the SOs, while the eLTER RI science case is the foundation for the selection of the variables. The four major research challenges of eLTER RI are intentionally linked with the selection of SOs in concrete, exemplary case studies in the eLTER PLUS work packages 8 and 9, which are, respectively, "eLTER WAILS Approach at site and catchment scale" and "Optimization of the eLTER Network design at the pan-European scale". The research questions formulated in both WPs formed the first basis for the selection of SOs presented in this report.

When selecting and defining the eLTER SOs, a crucial consideration for designing the eLTER RI was to strike a balance between science driven flexibility and provision of services (e.g., routine measurements, data provision). eLTER RI will generate information accessible to a wide range of stakeholders, including e.g., scientific users, governmental and non-governmental organizations, industry, and high-level decision makers. This service is challenged by the fact that the operation of the observatories is cost-wise ensured by institutional research facilities and is in parallel embedded in the respective research agendas of these institutions and their funding bodies. The more complex the design and the more comprehensive the requirements for operation, the more challenging and difficult it becomes to ensure long-term operation.

Another criterion that had to be taken into account, especially when defining methods and protocols for measuring variables, is coordination with other existing RIs and standards (e.g., ICOS, WMO, UNECE ICPs such as Forests, Waters, and Integrated Monitoring). Harmonization of methods and protocols with other networks and initiatives is another essential key for improving synergies, increasing scientific impact, and catalyzing international scientific networking.

Social-ecological SOs were developed from scratch and incorporated in the consolidation process .

1.3 Process

The selection of eLTER SO variables is a critical decision for the design of the network and the services eLTER RI will provide and the applicability of the WAILS concept in eLTER. Furthermore, the eLTER SOs drive costs in a decisive way and are therefore one of the critical key points for both the scientific decisions and the formal decision-making processes up to the Interim Council.

The process of developing the eLTER SOs has a long history. Its roots are within the eLTER H2020 and Advanced eLTER projects and a first concretization of the concept was part of the eLTER-application for the ESFRI-Roadmap. With the start of the eLTER Preparatory Phase Project (eLTER PPP) and the Advanced Community Project eLTER PLUS, we took on the task of continuing the process of harmonization and preparing the basis for formalized decisions regarding standardization.

The main objectives of the eLTER PPP in the context of the eLTER SOs are:

- To prepare for the implementation and operation of the eLTER RI by coordinating all required planning and specification (incl. standardization and harmonization) needed for the formal decision making.
- To develop the operational framework and technical requirements as the cornerstones for quantifying the resources needed to construct and operate the eLTER RI.
- To specify the resource demand, which is significantly influenced by the specifications regarding the mandatory monitoring program and the measurement standards.

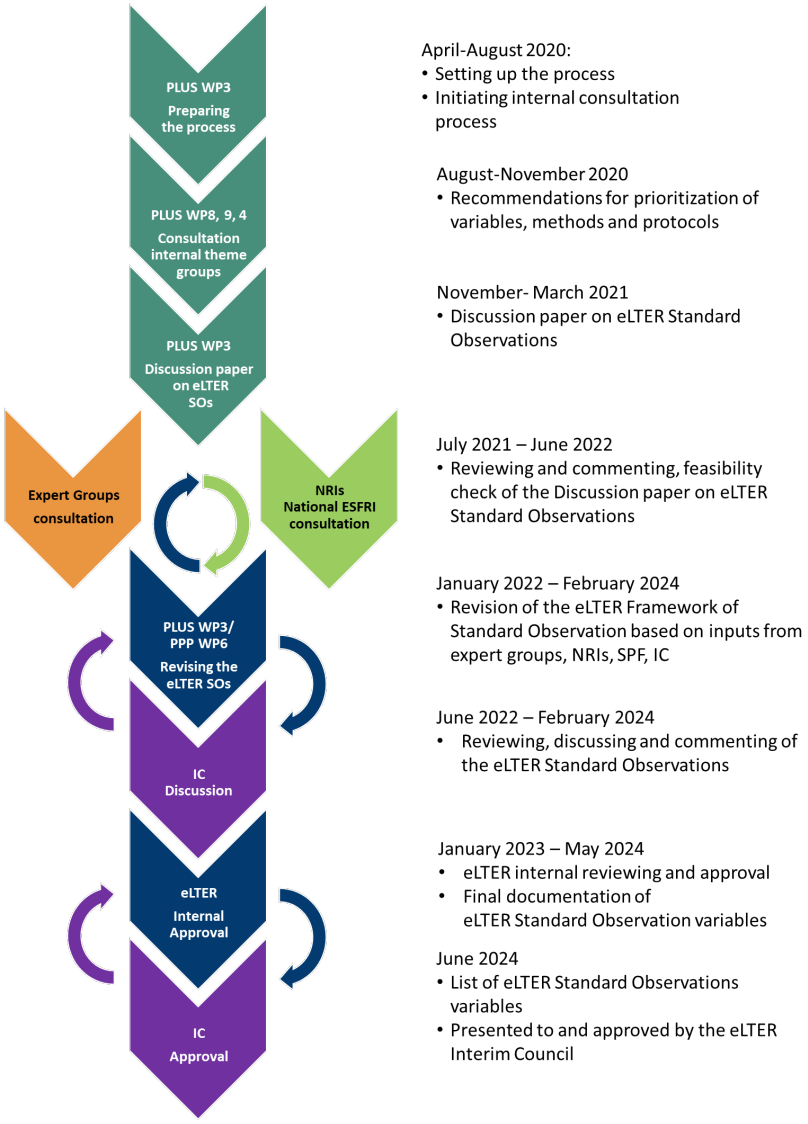

Figure 4: The process towards the eLTER Standard Observations variables

A sustainable implementation of the network design and associated measurement protocols can only succeed if both are developed with close consideration of the users' perspectives. The eLTER PLUS project meets this challenge as follows:

- It integrates the European ecosystem, critical zone, and socio-ecological scientific user communities through a joint capacity building effort at the eLTER RI sites and platforms and development and provision of innovative services.
- eLTER PLUS WP3 focuses on the 'interoperability of eLTER SO variables'.
- It develops recommendations for key variables, methods and protocols.
- It identifies in-situ design needs from the perspective of remote sensing applications.
- It develops a concept for the harmonization of methods and protocols, taking into account the concepts of other, already established RIs and networks as a precondition for sustainable scientific collaboration.

This outcome from eLTER PLUS creates the foundation for formalizing decisions to be taken in the eLTER PPP regarding network design at the European level and at the level of National Research Infrastructures (NRIs).

The **pivotal role of eLTER SOs has made it imperative that their development is carried out with the broad involvement of the eLTER community**. In the course of the conceptual development of SOs, there are various possibilities for direct participation in terms of content. Important part in the process of developing eLTER SOs were **repeated iterative consultations and dedicated workshops**. Direct participation and contribution of expertise was possible in various ways, which are briefly described below:

eLTER PLUS internal theme groups (related to the four eLTER Research Challenges)

- What: develop recommendations for prioritizing variables and measurement methods that are based on predefined criteria (see Table 1) and reflect the different scientific expertise and perspectives in eLTER
- Who: Iterative discussions within the core team of research challenge leads, WP and task leads (vetted and adapted following consultations with other internal stakeholder groups; see below)
- How: coordinated by the eLTER PLUS theme leads; theme groups on biodiversity, climate-water-food nexus, Greenhouse gas (GHG)-climate and socio-ecology,
- When: October-December 2020

Site and Platform coordinators in the national context (NRI) and eLTER Sites and Platforms forum (SPF)

- What: provision of detailed feedback on the Discussion Papers on SOs reflecting scientific expertise, national specifics, current state of national infrastructural development
- Who: open for all members of the respective NRI and the members of the SPF
- How: organized and coordinated by the NRIs and the SPF
- When: February 2021 – December 2024

External expert groups

- What: Reviewing the Discussion Papers on eLTER SOs and provide recommendations towards further development
- Who: open for larger scientific communities (external and eLTER-internal scientists) and peers in the field of environmental research
- How: Organized and coordinated by WP6 in eLTER PPP
- When: February-May 2023

eLTER expert groups

- What: Consolidation of the results of the previous consultations and development of a recommendation for the final selection of the eLTER SOs
- Who: open for expert from the eLTER community and peers in the field of environmental research
- How: Organized and coordinated by WP3 in eLTER PLUS and WP6 in eLTER PPP
- When: Jan 2023, workshop
- Result provided input for the final selection of eLTER SOs

The chronological sequence of the development of the eLTER Framework of Standard Observations is shown in Figure 4.

Table 1: Ranking principles for the criteria for the selection of variables (criteria following and adapted from Costa et al. (2016) and GEOBON (2017)

Criteria	Description	Ranking principles	Ranking
Relevance	The degree to which the variables represent key elements of the ecosystem integrity concept; Response to drivers of environmental change	Based on expert judgment from eLTER theme lead; the variable is highly relevant for many research themes/disciplines; variable responds highly sensitive for detecting/measuring current and potential future drivers of environmental change	High
		Relevant only for one or few research themes/ disciplines or not highly sensitive for detecting/measuring environmental change	Low
Cost efficiency	Describes required investment and operation costs	Measurement is already available at many locations; instrumentation can be implemented at low cost; fully automated measurements (low personnel costs) possible; low follow-up costs; high durability (withstand storms, extreme and low temperatures),	High
		Very expensive instrumentation; High follow-up costs (laboratory, cooling costs etc.); labor-intensive; low durability	Low
Operative Feasibility	Describes potential for routine measurements at a large number of sites based on standardized methods	Well established standards available, part of routine measurements in international networks; easy to apply; high probability of being harmonized	High
		Extensive expertise needed for operation; logistically difficult, e.g., complex measurement campaigns needed; lack of widely accepted/applied protocol; low probability of being harmonized	Low

2 The linkage between eLTER Standard Observations and site categories

eLTER's in-situ facilities – the eLTER Sites and eLTSER Platforms - are the fundamental building blocks of the spatially distributed eLTER RI. Each of the facilities is assigned to a defined site category.

There are several important purposes for categorizing sites:

- To describe the “quality” and focus of sites in terms of scope, involved disciplines, and instrumentation,
- To describe the relevance for specific scientific questions,
- To facilitate the networking with related monitoring networks.

The general concept of site categories was first specified in 2009 by the European LTER in order to structure the screening of "sites with high LTER potential" that started in 2005. These categories (master sites, regular sites, emerging/extensive sites) were slightly simplified to be applicable across the heterogeneous networks globally, internationally adopted in 2015 (ILTER) and thereafter mandatorily used in the basic site documentation in the DEIMS SDR (Wohner et al. (2019)), the Dynamic Ecological Information Management System - Site and dataset (Mirtl et al. 2022, eLTER Site Categories discussion paper, eLTER PPP D6.2)

To accomplish the two eLTER RI design goals – supporting excellent science by access to comprehensive environmental information and geographical coverage – the concept of a hierarchical and modular structure of site categories – was adopted and further developed by the ongoing eLTER design process. The creation and provision of data embedded in a "system context", which implies intensive integrated and long-term observation at selected sites, has to be balanced with the challenge to achieve large-scale systematic coverage of the major European terrestrial and aquatic environments taking into account also social-ecological aspects. On the one hand, this requires a set of observatories designed for highest operational excellence (“highly instrumented sites”) or novel platforms for inter- and transdisciplinary teams (“socio-ecological research”). On the other hand, these elements had to be combined with sites providing sufficient spatial coverage, linked through harmonized SOs and thereby allowing for up- and down-scaling of information.

In principle, following the globally established three-stage hierarchy, a categorization was developed (see Figure 5) by eLTER PPP WP6, which reflects the outcome of intense discussions across various bodies of the eLTER community (expert teams, National Coordinators etc.). The common denominator of all eLTER Sites is that they implement a ´Whole system approach´, which covers all spheres of the system.

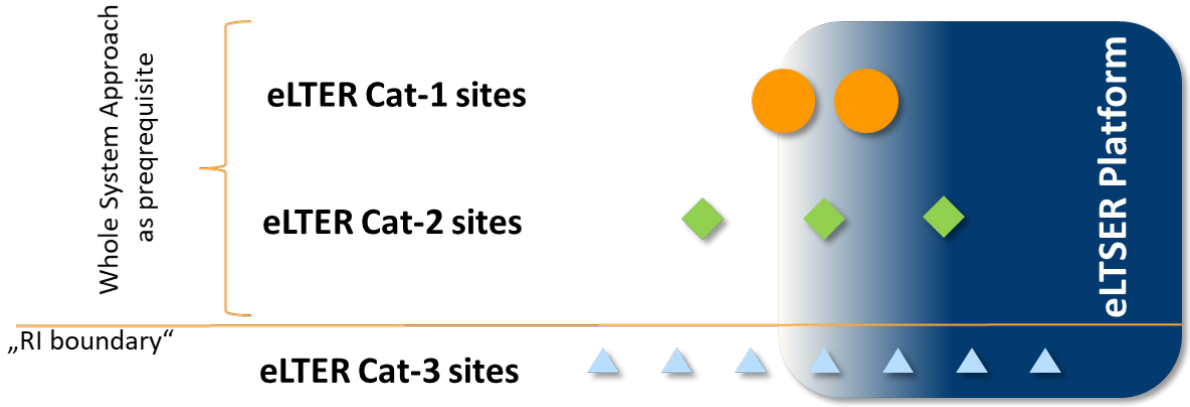

Figure 5: The hierarchical scheme of eLTER RI site classification

Table 2: Mandatory criteria for eLTER Sites Category 1 and 2

Mandatory criteria for eLTER Sites	SCat-1	SCat-2
Observational design covering the whole system (WAILS)	x	x
All system spheres covered with Standard Observations **basic method**	x	x
Specialization: for at least two spheres the Standard Observations **prime method** applied	x	
Secured capacity for Transnational (physical) Access (TA), Remote Access (RA)	x	
Guaranteeing Virtual Access (VA, i.e. open access to data)	x	x
All-year access guaranteed (road infrastructure or other infrastructure)	x	(x)
Roles populated: Site coordinator, data manager and responsible director in ROP	x	x
Full documentation in the eLTER site registry and nationally acknowledged	x	x
Long-term operation: Past operation since ≥10 yrs and future in accordance with eLTER RI planning	x	x

As described above, each eLTER SO is defined by (i) the variable and (ii) the associated method of measurement and (iii) the associated measurement protocol. For simplicity, the combination of method and protocol is described together as METHOD in the following. For the bulk of the variables, two METHODS will be defined: (a) "PRIME": this METHOD represents the highest eLTER standard (in terms of accuracy, spatial and temporal resolution) for the measurement of the respective variable, (b) "BASIC": this METHOD represents a less elaborated (and in most cases more cost-efficient) combination of measurement method and protocol.

Putting WAILS into practice, **eLTER Category-2 Sites** observe and investigate the whole ecosystem at a basic level. This is evidenced by covering all ecosystem spheres and their related core set of SOs with the basic METHOD (see Figure 6). The application of individual higher standards than defined in the basic SOs is possible, but does not influence the labeling of the site until the prime METHOD would be applied for at least two ecosystem spheres (transition point to Category 1).

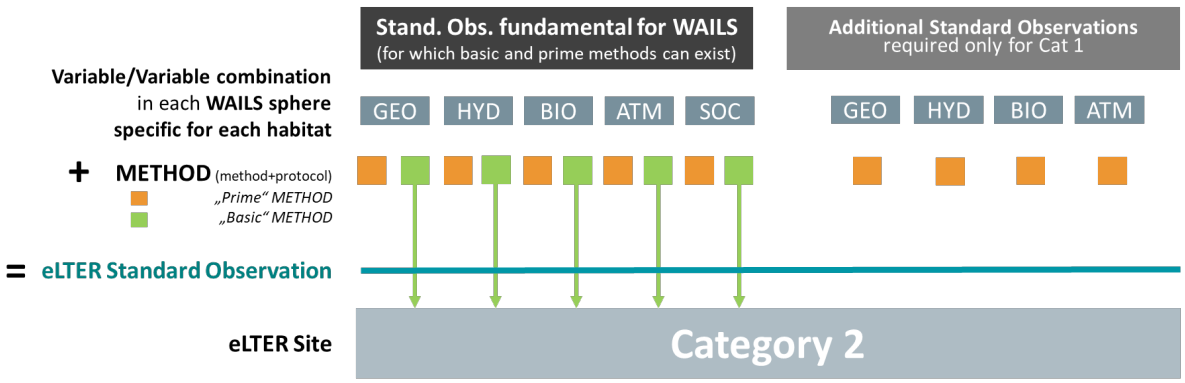

Figure 6: Schematic representation of the criteria for implementing the eLTER SOs for a Category 2 site (WAILS spheres: Geosphere – GEO, Hydrosphere – HYD, Biosphere – BIO, Atmosphere – ATM, Sociosphere – SOC))

eLTER Site Category-1 represents the highest site category. The holistic approach at Category-1 Sites covers all ecosystem spheres and the core set of all variable groups of the eLTER SOs with the basic METHOD. In addition, such sites specialize on at least 2 WAILS spheres, where the SO variables are measured with the prime METHOD (see Figure 7).

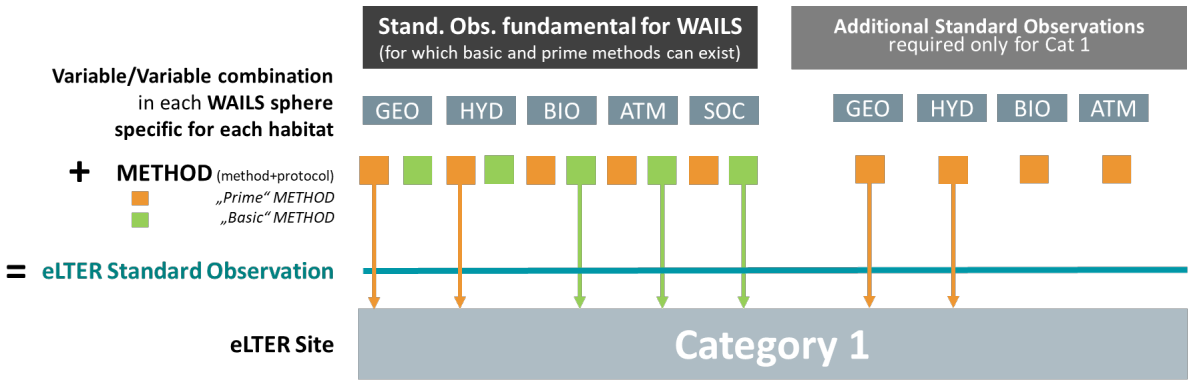

Figure 7: Schematic exemplary representation of the criteria for implementing the eLTER SOs for a Category 1 site (exemplary for a site that has a focus on geosphere and hydrosphere, WAILS spheres: Geosphere – GEO, Hydrosphere – HYD, Biosphere – BIO, Atmosphere – ATM, Sociosphere – SOC)

The last category of eLTER sites, **the eLTER Site Category 3** represent sites, which do not (yet) cover the entire ecosystem. Not all ecosystem spheres are simultaneously observed and investigated and therefore WAILS is not (yet) put into practice.

Table 2 provides an overview about the mandatory criteria for the eLTER RI sites.

eLTSER Platforms are spatially explicit living laboratories for conducting transdisciplinary, long-term, socio- ecological research and for implementing eLTER RIs WAILS research approach. They are designed and operated with the specific goal of harnessing scientific research on human-environment interactions for addressing environmental challenges and facilitating sustainability transitions. Research is conducted at the landscape scale using diverse disciplinary, interdisciplinary, and transdisciplinary approaches in tight coordination with local and regional stakeholders. Research and policy at platforms are supported by long-term environmental, social and economic data.

Like eLTER Sites, the eLTSER Platforms are defined as category 1 or category 2. The difference between both platform categories is mainly driven by the number of variables, the methods and level of detail and accuracy of eLTER Standard Observations performed in the platform. In terms of spatial design, platforms are defined by explicit geographical boundaries, with each platform required to include at least one category 2 eLTER site.

A central element of eLTER-site and platform operations is the set of eLTER SOs (see also chapter 3.1 for further description) to be measured in site and platform categories 1 and 2 (see also Figure 6 and Figure 7). This is a selection of variables that allow an integrated (as much as possible) characterization of key ecological processes in terms of water, energy and matter balances, as well as a characterization of abiotic site characteristics and selected elements of the biological diversity. Of the SOs described in the following chapters, these can cover for example:

- meteorological variables such as precipitation, temperature, air humidity, …
- parameters and variables on soils such as soil texture, soil moisture, …,
- hydrosphere variables of surface water and groundwater such as discharge data, water levels, water temperatures,
- variables on essential substance fluxes in the geosphere and hydrosphere such as dissolved organic carbon (DOC), nitrates, pH in surface water and groundwater, organic carbon in soil,
- biological variables such as plant phenology (phenocams) or soundscapes to be used for AI-based species identification (e.g., birds, bats).

A criterion for the selection of the variables was also the general feasibility for the measurement and, whenever possible, the greatest possible automation of the measurement will be aimed for.

Advancing a site from Category 2 to Category 1 requires specialization on at least two of the ecosystem spheres addressed by eLTER (compare Figure 6 and Figure 7). This comprises additional SOs on the respective environmental spheres. The operation of a Category 1 site is accordingly more demanding and involves bigger effort, since (1) the number of mandatory variables is higher and (2) in many cases a more demanding prime METHOD applies. The clear advantage of the concept consists in the possibility of transferring previously existing specializations of sites seamlessly into the eLTER RI and directly integrating already existing expertise. In many cases this will guarantee uninterrupted compliance with existing institutional obligations.

3 eLTER Standard Observations – variables

3.1 Introduction

The development of the eLTER SOs and the selection of the eLTER SO variables and the transformation of this information into criteria for the site hierarchy has been a multi-step process (see Figure 9). Given the nature of the eLTER ESFRI process towards concerted decisions across all participating countries, these activities had to be repeated iteratively.

In 2021 and 2022, two versions of the Discussion Paper on Standard Observations were published. These reports summarized the results of previous consultation rounds with WP4/8/9 in eLTER PLUS and feedback. In a first step, 173 SO variables were identified that were considered relevant from the scientific perspective of the disciplines consulted. The consultation process provided the basis for the subsequent iteration steps and further ranking with inputs from within and beyond eLTER. In parallel, the prioritization undertaken provided important input for the initial RI costs assessments, and marked the start of the discussion about conceptual considerations on the design, the site categories, and the selection of protocols and methods. Each of the suggested eLTER SO variable has been rated aiming for **(i) a broad consensus regarding the scientific relevance across several scientific disciplines, (ii) high cost efficiency and thus economic feasibility, and (iii) the existence of already established measurement methods, standards and protocols to record these variables.** The feedback and critical revision of the Discussion Paper by the National Research Infrastructures (NRIs, this mostly addresses the national LTER networks as core group) was in particular important to assess the feasibility of the SOs. In order to make the consultation process as transparent as possible, an online collaboration platform (Mattermost) was set up to ensure a traceable, transparent and consistent flow of information. As a result, a tremendous amount of important, essential and highly valuable information was provided by the participants in the consultation process considering national perspectives on the standardization process, but above all with regard to scientific relevance and feasibility. Furthermore, the feedback process was extended to the viewpoints of scientific disciplines as represented by the eLTER Expert Groups (EGs). All this aimed at finding a balance between scientific necessities and feasibility of SOs at the European level. A more detailed description of the selection process can be found in the Discussion Papers 1 and 2.

As a result of this multi-stage process, the list of identified eLTER SO variables was further consolidated and 65 SOs were selected as the basis for the eLTER Framework of Standard Observations.

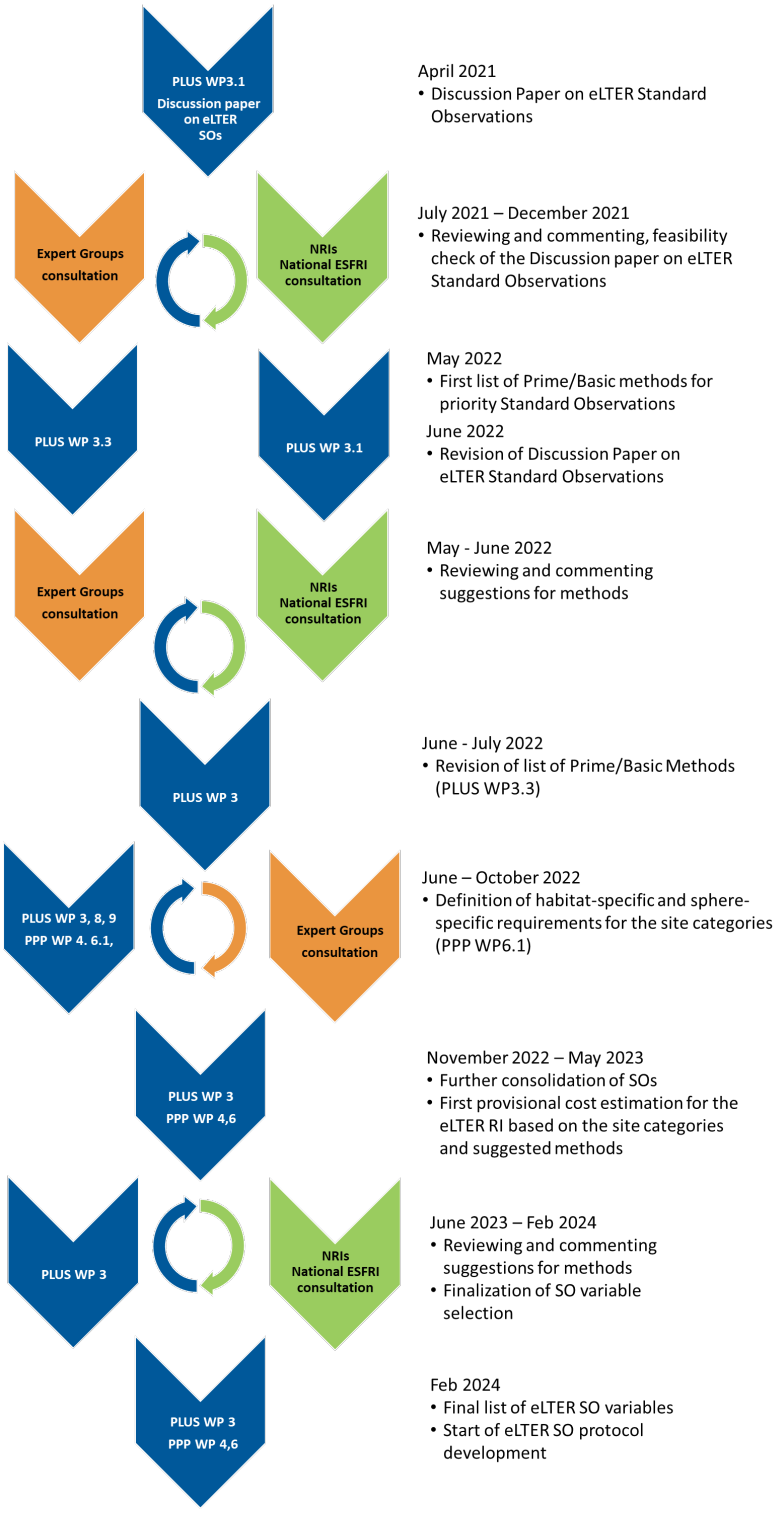

Figure 8: Detailed workflow towards the final list of eLTER SO variables

As part of the revision, certain eLTER SO variables have been grouped into an SO bundle. This has been done in cases where different variables either:

(i) can be captured by a single sensor system (e.g., multi-parameter probe for physical and chemical water variables) or analytical methods providing concentrations of several substances through a single measurement (e.g. ion chromatography),

(ii) by a "standardized" sensor combination (e.g., eLTER meteorological station), or
(iii) the required sampling (e.g., soil inventory) resp. data collection (e.g., acquisition of socio-ecological data using the same database) can be done in one step or operation.

This logic reflects more clearly the requirements of practical on-site implementation of measurement requirements. Figure 10 illustrates this concept with two examples.

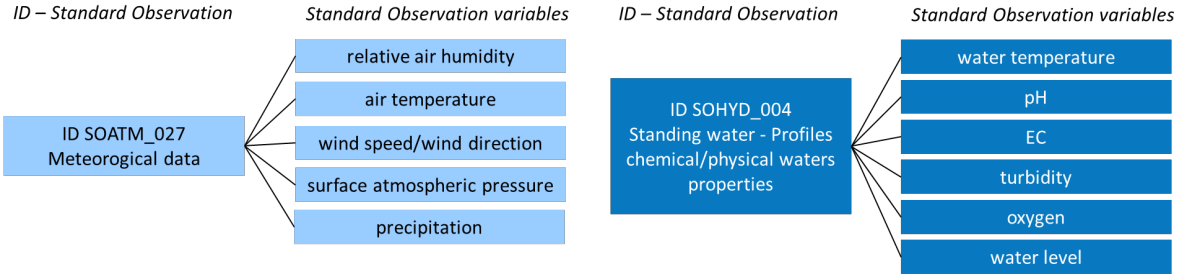

Figure 9: Exemplary representation of the combination of different SOs Variables into one SO

In order to be applicable at eLTER Sites and eLTSER Platforms across European environments and socio-ecological regions, the specification of the SO variables requires thorough consideration of habitat-specific requirements (what might be a “must” in forest, might not be feasible or reasonable for aquatic sites).

The EUNIS (European Nature Information System) Habitat Classification, developed by the European Topic Centre for Biodiversity for the European Environment Agency (EEA), was used as a basis for the classification of the habitats. This system provides a comprehensive pan-European hierarchical classification of habitats covering both the marine and terrestrial ecosystems (Chytry et al., 2020). With regard to habitat classification for eLTER, it was decided to be guided by the EUNIS classification. It should be noted that the following habitat list is by no means a complete adoption of the EUNIS nomenclature, but merely contains selected EUNIS habitat types and subtypes that, in the context of the eLTER RI design, allow a suitable framework for deriving the "WAILS core set of Standard Observations". According to this classification, the following habitat types are proposed for the classification of eLTER sites.

- Wetlands (mires, bogs, fens)
- Grasslands and lands dominated by forbs, mosses or lichens
- Heathlands, shrub and tundra
- Forests and other wooded land
- Vegetated man-made habitats (regularly or recently cultivated agricultural, horticultural and domestic habitats)
- Inland surface standing waters
- Inland surface running waters
- Coastal (transitional) waters including coastal littoral zones
- Sparsely vegetated habitats and deserts

The habitat types represent ecosystems that require specific observations in the sense of a holistic description. Not all variables can be measured meaningfully in every habitat type or are relevant for the respective one. In addition, some habitat types may require specific adaptations to the measurement procedure, which may necessitate the definition of a separate sampling occasion even if the measured variable remains the same. An example of this would be the measurement of LAI in grasslands and in forests which require to SOs (SOBIO_025 Forest LAI, SOBIO_026_Non-forest LAI) due to different methods for the LAI measurement.

Furthermore, category 1 sites require additional variables for the respective environmental spheres enhancing the core set of SOs. Also here, a habitat type-specific perspective is required taking into account the holistic WAILS perspective on the particular habitat as well as particular challenges with respect to measuring specific SOs in specific habitats.

On the one hand, many eLTER sites will be composed of more than one habitat. On the other hand, the majority of existing (and also future) RIs are focused on monitoring specific habitats, so the proposed classification can be used to determine the appropriate requirements for the composition of SOs.

In September 2022, the process of habitat-specific selection of eLTER SOs was launched as an essential basis for site categorization. In a first step, habitat experts developed a proposal for these selections, which was then consulted and commented on by the national networks in a second step. As a result, core sets of eLTER SOs were defined for each of the nine eLTER habitat groups.

It is important to stress that this document is not intended to propose or endorse any particular conceptual model of the natural environment. The WAILS sphere concept forms an essential basis for the eLTER site hierarchy, and Cat 1 sites commit to an additional focus on at least two of the four enviromental spheres (geosphere, hydrosphere, atmosphere, biosphere), reflected in the implementation of higher standards for SO measurements in these spheres. The sections that follow are structured according to the WAILS spheres, with each section containing relevant SOs for investigating that sphere. **The assignment of SOs to the WAILS spheres concerned is not always straightforward.** In the case of the precipitation, which can also be seen as a variable of the hydrosphere, it was decided to assign the corresponding measurement to the SO "Meteorological data" which is listed in the group of Atmosphere SOs. Other biotic properties are related to the assessment of carbon and energy balance, but they have little or no relevance in describing biotic diversity. Examples include measures of vegetation growth and plant transpiration. These properties are also classified as Atmosphere SOs. Some properties of water quality (hydrosphere) like the P/N ratio are crucial for assessing aquatic ecology. Accordingly, these properties are listed in the Biosphere group.

How to read the following sections?

- In the following sections, the 65 selected SOs are presented in detail.
- **The decision on the methods and the development of the SO protocols started in February 2024 and is expected to be completed end of 2024. Whenever information on specific measurement methods is given in the following descriptions, this is only to better specify the effort for the survey or the general applicability for certain habitats or eLTER site categories. The methods mentioned in these cases only reflect a preliminary state of discussion of the current ongoing process to define the SO protocols.**
- In a few cases, some SO names contain information regarding the habitats they apply. This became necessary when the particular SO required a habitat-specific method.
- In view of the future processing of SOs in database systems, uniform, persistent identifiers are defined for each SO.

3.2 Geosphere

Several of suggested variables record solid matter contents in the soil. These SOs require campaign-based soil sampling and differ in terms of methodology only in terms of subsequent laboratory analysis but not in terms of the on-site activity. The on-site measurement campaigns for these SOs can be performed for all variables together, so the SOs have now been combined into SO bundles

(SOGEO_001 – Soil inventory, SOGEO_003 – Soil chemical and physical properties, SOGEO_167 – Soil water chemistry, SOGEO_155 – Sediment (aquatic/marine)

SOGEO_001 – Soil inventory – geological characterization

- The following soil properties and variables are recorded by the soil inventory: soil texture, soil hydraulic conductivity, bulk density, soil pH, CEC, base saturation, organic matter, pedological characterization (or soil profile description), and soil type classification. Furthermore, the geological site conditions need to be characterized.
- PRIME method: expert-based on-site and profile-based soil assessment to characterize the site-specific soil properties, one-time measurement
- BASIC method: No direct measurements required. A basic method must allow European-wide standardization. Conceivable, for example, would be a method that derives data from soil maps available and harmonized throughout Europe (e.g., SoilGrid).
- The effort for a detailed soil inventory can usually only be realized for smaller areas (plot, subsites). Decisions must be made as to which areas a soil inventory can generate the greatest additional benefit. This could be for example: highly instrumented sites like areas with Eddy-Covariance stations, soil moisture monitoring sites and or sites that have an explicit focus on soil-related research.
- Pedological characterizations require trained personnel and expertise. It is currently being discussed whether the implementation of site-specific soil inventories can be provided by a centralized service. In particular, in larger areas having deep soils or are remote, soil inventories can become extremely laborious.
- The differences in the site-specific scales of the inventory and the associated implications for meaningfulness and comparability of measurement need to be critically considered.
- Measurements can be combined with installation of sensors for SOs which require in-situ soil sensors (e.g., soil moisture sensors for SOHYD_168 BASIC)

SOGEO_003 – Soil chemical and physical characteristics

- The following soil characteristics are measured by this SO: Total organic C concentration, CEC total nitrogen, total phosphorus, plant available P, pH, soil base saturation, bulk density and volume of coarse fragments (at fixed sampling depths).
- PRIME method: campaign-based horizon sampling and laboratory analysis, multi-year interval
- BASIC method: campaign-based horizon sampling and laboratory analysis, multi-year interval with lower frequency than for the PRIME method
- In case SOGEO_003 follows the PRIME method, The first sampling can be combined with the SOGEO_001 (Soil inventory) campaign.
- The effort for a spatially explicit mapping of solid soil variables can usually only be realized for smaller areas (plot, subsites). Decisions must be made as to which areas this SO can generate the greatest additional benefit. This could be for example: highly instrumented sites like areas with Eddy-Covariance stations, soil moisture monitoring sites and or course sites that have an explicit focus on soil-related research.
- Bulk density and volume of coarse fragments and soil depth need to be measured to allow matter stock calculations. Depending on the land use type bulk density (in particular for the upper soil horizon) can be much more variable than the matter concentrations
- Measurements can be combined with installation of sensors for SOs which require in-situ soil sensors (e.g., soil moisture sensors for SOHYD_168 BASIC)

SOGEO_167 – Soil water chemistry

- The following soil water characteristics are measured by this SO: soil water pH; soil water concentration per horizon: NH4-N, NO3-N, dissolved organic nitrogen (DON), dissolved organic carbon (DOC), Cation, Anion.
- Only applies to terrestrial Cat1-sites
- PRIME method: campaign-based horizon sampling of soil water and laboratory analysis, monthly intervals

SOGEO_048 – Soil infiltration

- Measurement of infiltration rates of soils
- Only applies to terrestrial habitats
- PRIME method: One-time, initial measurement using infiltrometers; for sites with expected high variability of soil hydraulic conductivity (e.g., due to agricultural soil cultivation) a higher frequency of measurements might be required
- BASIC method: can be provided by model-based estimation using information on e.g., soil texture, bulk density using pedotransfer approaches

SOGEO_155 – Sediment (aquatic/marine)

- The following characteristics of aquatic/marine sediments are measured by this SO: physical and chemical characterization (particle size distribution, pH, carbon, sulfur)
- Only applies to aquatic and transitional water habitats
- PRIME/BASIC method: One-time, initial measurement, sampling and laboratory analysis

3.3 Hydrosphere

The eLTER SO group of the Hydrosphere addresses groundwater, surface water (stagnant waters: lakes, reservoirs, transitional water and running waters: creeks, rivers, streams), soil hydrological variables and snow. All variables are explicitly quantitative and thus ideal indicators for the effect of climate and land use change on the hydrological states of sites.

This group comprises of 19 SOs. Several SO represent bundles of variables, which can either be measured by multi-parameter probes or whose measurement can be combined in one operation (e.g., water level and multi-parameter probes). This joint collection results in cost reductions compared to individual purchase of single sensors for each variable.

SOHYD_004 – Standing water - Profiles chemical/physical waters properties

- Applies to standing waters, transitional waters, wetlands only, Cat 1 and Cat 2
- Applies to sparsely vegetated habitats and deserts also, but only when a standing water is connected to the observed site, Cat 1 and Ca 2
- The water quality properties measured by this SO are: water temperature, pH, EC, turbidity, oxygen concentration, water depth
- Use of multi-parameter probe including a wiper to prevent from biofouling, for lakes mounted on buoys, 1 h measurement frequency, proposed RI protocol: WFD, ICP Waters, NEON; costs: 5.000 – 10,000 €.
- PRIME and BASIC method differ with regard to the measuring frequency
- For oxygen also high-quality optodes are available.
- Shallow lakes need horizontal profiles.

- During winter and ice cover, feasibility limitations and data gaps may occur.

SOHYD_005 – Running water - chemical/physical properties

- Applies to running waters and standing waters (inflow/outflow), Cat 1 and Cat 2
- Applies also to vegetated man-made habitats and sparsely vegetated habitats and deserts, but only if a running water system is connected to the observed site
- The water quality properties measured by this SO are water temperature, pH, EC, turbidity, oxygen, NO3, SAC 254, water level.
- PRIME method: automatic on-site multiparameter probe
- BASIC method: manual sampling and laboratory analysis
- Can be combined with SOHYD_010 – Running water level
- In mountainous areas, maintaining stream/river weir measurements over long periods can be challenging due to high flow events that can destroy equipment. This may require site specific adaptations.
- In particular for the basic method sampling should be done at gauging stations (if available) to have access to additional hydrological data.
- For running waters with high bedloads in certain regions it is impossible to observe it over a long time.

SOHYD_006 – Groundwater - chemical/physical properties

- Applies to Cat 1 and Cat 2
- Applies not to transitional waters
- Applies to running waters only if Cat 1 with a focus on hydrosphere
- The groundwater quality properties measured by this SO are: water temperature, water level and electrical conductivity.
- PRIME: multiparameter probe (water level, temperature, EC).
- BASIC: e.g., low-cost barologger (water level, temperature, no EC), lower measurement frequency
- Groundwater water temperature in sites with several groundwater bodies, this measurement can become very expensive and feasibility very low. This must be taken into account in the actual design on site.

SOHYD_010 – Running water level

- Applies to Cat 1 and Cat 2
- PRIME: direct measurement.
- BASIC method: No direct measurement required; Application of hydrological model resp. provision of data from national monitoring programs.
- Can be combined with water quality measurements e.g., SOHYD_005.

SOHYD_011 – Standing water – Ice cover/thickness

- Applies to standing waters/transitional waters only, Cat 1 and Cat 2
- Methods of measurement currently under discussion
- For the method it must be decided whether ice thickness and density or only the areal extent is to be recorded.
- Copernicus Lake Ice Extent product (https://land.copernicus.eu/global/products/lie) should be considered. Data for the sites can provided as central service
- Daily measurements are unnecessary, but it is important to derive dates with and without ice. Tool-wise a time-lapse camera is appropriate for remote areas.
- For lakes with restricted access during winter (avalanches) very difficult conduct or even impossible.

- SO applies to freezing environments only.

SOHYD_012 – Snow

- Applies to all habitats except transitional waters, Cat 1 and Cat 2
- Snow cover and snow structure are essential variables shaping much of the terrestrial ecosystems of northern Europe. They are also variables that are changing currently with repercussions for the entire system. Development of snow data layers (spatially explicit models of snow presence, depth and structure) for the areas where changes of snow matter to the system dynamics should be a priority.
- PRIME method: direct measurement using snow cams + automated snow sonic devices
- BASIC method: Sentinel-2 snow cover product,
- Cams are cheaper but need more maintenance.
- To estimate snow water equivalent, measurements of snow density
- SO applies to freezing environments only

SOHYD_168 – Soil water content/temperature

- Applies to all habitats except transitional waters, Cat 1 and Cat 2
- PRIME: Cosmic-ray neutron sensing (CRNS) probes + addition of 4 soil moisture profiles (dielectric sensors) within the CRNS footprint (up to 5 depths), continuous operation (15 mins resolution)
- BASIC: few soil moisture sensors (e.g., dielectric sensors) should be operated (e.g., parallel to the meteorological station) providing indication about range and dynamics of soil moisture sensors should be designed for long-term burial.
- eLTER observation data (especially CRNS data which are able to cover several ha) are of highest relevance for calibration and validation of remotely sensed soil moisture products.
- Installation of sensors for BASIC can be combined with measurements for SOGEO_001, SOGEO_003

SOHYD_169 – Running water - carbon

- Applies to running waters only, Cat 1 and Cat 2
- The water quality properties measured by this SO are: concentration of DOC, DIC
- PRIME/BASIC method: Sampling and lab analysis, higher frequency of sampling for PRIME method
- Sampling of all surface water sample-based SOs can be combined

SOHYD_170 – Standing water – Profile carbon

- Applies to standing waters, transitional waters only, Cat 1 and Cat 2
- The water quality properties measured by this SO are: profiles of concentration of DOC, DIC
- PRIME/BASIC method: Sampling and lab analysis, higher frequency of sampling for PRIME method
- Sampling of all surface water sample-based SOs can be combined

SOHYD_064 – Groundwater - nutrients

- For terrestrial sites only mandatory (as PRIME) for Cat 1 sites with a focus on hydrosphere
- Applies as Cat 2 for standing waters/transitional waters only
- The water quality properties measured by this SO are: concentration of TP, SRP, TDN, NO_3, NO_2, NH_4, DOC, DIC
- PRIME/BASIC method: Sampling and lab analysis, higher frequency of sampling for PRIME method

SOHYD_171 – Surface water – Major ion concentrations

- Applies to aquatic habitats and transitional water habitats only, Cat 1 and Cat 2
- The water quality properties measured by this SO are: concentration of major ions Cl, SO_4, Br, Na, K, Mg, Ca, and Silica
- PRIME/BASIC method: Sampling and lab analysis, higher frequency of sampling for PRIME method
- Sampling of all surface water sample-based SOs can be combined

SOHYD_062 – Groundwater – Major ion concentrations

- For terrestrial sites only mandatory (as PRIME) for Cat 1 sites with a focus on hydrosphere
- Cat 2 only mandatory for standing waters/transitional waters
- The water quality properties measured by this SO are: concentration of major ions Cl, SO_4, Br, Na, K, Mg, Ca
- PRIME/BASIC method: Sampling and lab analysis, higher frequency of sampling for PRIME method
- Sampling of all groundwater sample-based SOs can be combined

SOHYD_058 – Surface water – Stable isotopes

- Applies to Cat 1 sites with focus on hydrosphere only
- For terrestrial habitats only mandatory if a water body is connected to the observed site
- The measured stable isotopes ^{18}O and ^{2}H are used to evaluate age and origin of water and processes in the hydrological cycle
- PRIME method: Sampling and central lab analysis (central service)
- Sampling of all groundwater sample-based SOs can be combined

SOHYD_059 – Groundwater – Stable isotopes

- Applies to all Cat 1 sites (except of transitional waters) with focus on hydrosphere
- The measured stable isotopes ^{18}O and ^{2}H are used to evaluate age and origin of water and processes in the hydrological cycle
- PRIME method: Sampling and central lab analysis (central service)
- Sampling of all surface water sample-based SOs can be combined

SOHYD_067 – Running water – Micropollutants

- Applies to aquatic Cat 1 sites (including wetlands) with focus on hydrosphere only
- This SOs measures the concentration of micropollutants in running waters using not-target screening methods
- PRIME method: Sampling and central lab analysis (central service)
- Sampling of all surface water sample-based SOs can be combined

SOHYD_174 – Secchi-depth

- Applies to standing water habitats and transitional waters only, Cat 1 and Cat 2
- This SOs measures the Secchi-depth
- PRIME/BASIC method: same method with higher frequency of sampling for PRIME method

SOHYD_164 – Glacier front variation

- This SO is only relevant for sites with a glacier in the study area.
- This SOs measures the dynamics of the glacier front
- The decision on the method and protocol is not yet finalized.
- However there are several standard methods in glacier research including remote sensing approaches established. E.g., WMO recommendations:

https://library.wmo.int/records/item/68660-guide-to-instruments-and-methods-of-observation?offset=2

SOHYD_165 – Glacier mass balance

- This SO is only relevant for sites with a glacier in the study area.
- This SOs measures the mass balance of the glacier
- The decision on the method and protocol is not yet finalized.
- However there are several standard methods in glacier research including remote sensing approaches established. E.g., WMO recommendations: https://library.wmo.int/records/item/68660-guide-to-instruments-and-methods-of-observation?offset=2

SOHYD_166 – Glacier area

- This SO is only relevant for sites with a glacier in the study area.
- This SOs measures the dynamics of the glacier area extent
- The decision on the method and protocol is not yet finalized.
- However there are several standard methods in glacier research including remote sensing approaches established. E.g., WMO recommendations: https://library.wmo.int/records/item/68660-guide-to-instruments-and-methods-of-observation?offset=2

3.4 Biosphere

The eLTER SO group of the Biosphere addresses the biotic diversity of eLTER sites. This group comprises of nine SOs. At present, the collection of biological data, in particular, often requires a very detailed expertise on the part of the researchers and is often difficult or impossible to automate. Furthermore, for many biological variables there are hardly any or only very few generally accepted standards for the recording so far and the recording in the field is often based on (partly long-established) local protocols. Especially with regard to securing the legacy data, the harmonization of these measurement methods poses a particular challenge and is often hardly or not possible. Nevertheless, in many cases, it is possible to map existing data to each other so that biological data measurements with different standards can still be made interoperable and hence analyzed jointly and a posteriori can be related to more automated sensor measurements. Against this background and in particular concerning the best possible feasibility, the selection of the proposed variables focused on suggesting variables for which automated and harmonized collection and observation seems possible (e.g., sound recorders, camera traps, malaise traps, bulk samplers for eDNA analysis) and thus a good basis for standardization is given. However, these proposed SOs are not intended to replace existing in-situ non-automated measurements or established on-site protocols but need to be calibrated against them.

The current list of SOs for the biosphere has still a strong focus on terrestrial ecosystems. Three SOs with focus on freshwater and transitional water habitat types have been originally defined in the context of the hydrosphere group but are only required for describe the eutrophication status (biosphere-related aspect) and are now listed here (SOHYD_172 and 173).

SOs currently still under discussion include e.g..: acquisition of algae, fish, zooplankton, macrophytes, benthic invertebrates, seabirds. However, the discussion process in eLTER also highlighted the greater difficulty in finding shared and widely accepted protocols for a number of aquatic biological targets. Therefore, it was decided to postpone these SOs and to put them back into expert consultation. In line with the workpackage goal "Methodological innovation", WP1 of the PLUS project will organize a process to which all interested experts of the eLTER consortium are invited. The aim should be to

jointly develop an agreed concept and protocol for the measurement of these variables that will subsequently be piloted in suitable sites. After successful piloting of the methods and protocols (feasibility and cost-efficiency), the corresponding SOs can be resubmitted at a later stage.

SOBIO_014 – Flying insects

- Applies to all habitats, Cat 1 and Cat 2
- Malaise trap sampling (biomass and DNA metabarcoding for species level identification)
- DNA metabarcoding will be centralized (central service)
- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere
- Many eLTER sites are in protected areas so that destructive methods may require separate permitting procedures

SOBIO_017 - Vegetation composition – plot scale

- Applies to all terrestrial habitats, Cat 1 and Cat 2
- Species level identification based on plot-based vegetation surveys
- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere
- Applies to terrestrial habitats only

SOBIO_018 – Acoustic recording

- Applies to all terrestrial habitats, Cat 1 and Cat 2
- Species level identification using acoustic recordings and machine-learning (ML)-based species identification algorithms, annual operation
- This SO can be supported by a central service which operates the ML-based species identification.
- In recent years, there has been considerable progress in ML-based methods for species identification (e.g., BirdNet) and the method is already being used successfully in some eLTER sites. It is expected that further advances will be made in the coming years.
- The method has already been successfully tested (mainly for birds) in various eLTER sites.
- For some species groups for which there is still too little data to train ML approaches (e.g., alpine amphibians) the method still has weaknesses. But, eLTER can play a pioneering role in this area and contribute to overcome these data gaps.
- In particular data on birds are collected in many regions also by highly skilled birders. Consideration should be given to the added value that can be unlocked by incorporating such data to complement bioacoustic data collection.

SOBIO_019 – Pollen and spores

- Applies to terrestrial habitats Cat1 with a focus on biosphere only (except sparsely vegetated habitats and deserts)
- Species level identification using Cyclone samplers, multispectral imaging and ML-based approaches for species identification, temporal resolution: daily (if weekly sampling of the trap is possible), proposed RI protocol: Lifeplan, costs: 6,000 € for the sampler, 2,000 € for analysis
- Regarding the species identification also DNA barcoding could be applied.

SOBIO_021 – eDNA Water

- Applies to all habitats (except sparsely vegetated habitats and deserts)Cat 1 and Cat 2
- Applies to terrestrial habitats only if flowing or standing waters are in direct spatial connection to the site (not applicable on sites without surface water bodies)
- Sampling of surface water and centralized DNA metabarcoding (central service)

- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere
- With eDNA it is not possible to get quantitative (abundance) data. However, there are already some semi-quantitative approaches available. In the near future, it can be expected that some progress in overcoming this issue can be made by applying metagenomics instead of metabarcoding.
- While DNA metabarcoding is already successfully used for the detection of certain taxonomic groups (e.g., fish, invertebrates), it currently still has weaknesses with respect to the detection of certain other taxonomic groups. eLTER can play a pioneering role in the further development of the method in this respect.
- eDNA is also of great relevance to other RIs (e.g., EMBRC, Elixir, ...) with regard to the description of biomolecular aspects, and consideration should be given to the extent to which collaboration on content can be established here. Furthermore, eDNA may also be used to assess essential variables discussed by the GEO-BON initiatives.

SOBIO_022 – eDNA soil

- Applies to all habitats (except transitional waters) Cat 1 and Cat 2
- Sampling and centralized DNA metabarcoding (central service)
- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere
- Collaboration with SOILBON

SOBIO_096 – Surface water - Chlorophyll

- Applies to aquatic habitats and transitional waters only, Cat 1 and Cat 2
- This SO measures the chlorophyll *A* concentration which is a measure of the amount of algae growing in a waterbody. It can be used to classify the trophic condition of a waterbody
- PRIME: Automated measurement using optical sensor
- BASIC: Sampling and lab analysis
- Applies to aquatic habitats only

SOHYD_172 – Running water – P/N

- Applies to running waters only, Cat 1 and Cat 2
- This SO measures the P/N ratio (total phosphorus (TP), soluable reactive phosphorus (SRP), total dissolved nitrogen (TDN), NO_3, NO_2, NH_4) of water as a measure for eutrophication
- Sampling and lab analysis
- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere, for BASIC only mandatory during the vegetation period

SOHYD_173 – Standing water – P/N

- Applies to standing waters only, Cat 1 and Cat 2
- This SO measures the P/N ratio (total phosphorus (TP), soluable reactive phosphorus (SRP), total dissolved nitrogen (TDN), NO_3, NO_2, NH_4) of water as a measure for eutrophication
- Sampling and lab analysis
- Higher frequency of sampling (PRIME) for Cat 1 sites with a focus on biosphere, for BASIC only mandatory during the vegetation period

3.5 Atmosphere

The eLTER SO group of the Atmosphere group comprises 19 SOs and addresses (i) the atmospheric conditions of eLTER sites and measures (ii) variables and properties to quantify energy, water and

matter balances. As a result of the latter, a number of the following SOs capture biotic variables and traits associated with plant growth and ecosystem productivity.

SOATM_027 –Meteorological data

- Applies to all habitats, Cat 1 and Cat 2
- The following meteorological variables are measured by this SO: relative air humidity, precipitation, air temperature, wind speed/wind direction, surface atmospheric pressure
- Multi-parameter weather station in accordance with WMO standards
- PRIME/BASIC method: same method with higher sampling frequency for Cat 1 sites with a focus on atmosphere
- Forest sites: relative air humidity (as air temperature and wind speed) can differ significantly below and above forest canopy. For forest sites it is recommended to measure simultaneously below and above forest canopy and make a reference measurement outside of the forest stand
- The recording of wind gusts needs to be considered. This is particularly relevant with regard to the recording of extreme events.
- Relevance of measuring surface atmospheric pressure regarding ecological research questions was discussed critically. On the other hand, it is a basic meteorological variable, which is routinely part of the standard measurement of other research infrastructures in environmental research and is used by different environmental models and calibration purposes of other sensors. This is of relevance in particular with respect to anticipated co-location. As the variable is already recorded in many multi-parameter weather stations, there is a strong argument for keeping the variable as part of this SO.
- Applies to all habitats

SOATM_028 – Radiation

- Applies to all habitats, Cat 1 and Cat 2
- The following radiation components are recorded in this SO: Photosynthetically active radiation (PAR), Global and solar radiation (diffuse and direct shortwave incoming radiation)
- Continuous measurement of radiation components using pyranometer (short-wave radiation); upward-looking radiometer (pyranometer or quantum sensor) with shading device (diffuse radiation), quantum sensor (PAR)
- Sensors can be operated as part of a standard meteorological station and be combined with the SO “Meteorological data”
- PRIME/BASIC method: same method with higher sampling frequency for Ca1 sites with a focus on atmosphere

SOATM_098 – Soil heat flux

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- Soil-ground heat flux is a key parameter in the analysis of soil-atmosphere interactions. It is an indispensable component of the surface energy balance.
- PRIME method: Soil heat flux plates

SOATM_103 – Atmospheric deposition in precipitation

- Applies to all habitats, Cat 1 and Cat 2
- This SO measure physical properties and chemical composition of precipitation water: bulk NH4-N, NO3-N, NO2-N, total nitrogen (Ntot), SO4, PO4-P, K, pH, anion, cation, DOC, alkalinity, electrical conductivity
- PRIME/BASIC method: same method, bulk sampler and lab analysis

SOATM_108 – Dry deposition of N-components

- Applies to all habitats, Cat 1 and Cat 2
- This SO measures the dry N-deposition (gaseous compounds and particulates)
- PRIME method: Passive and string sampler and lab analysis
- BASIC method: retrieval based, no direct measurement
- Applies to all habitats

SOATM_176 – Eddy covariance

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- This SO measures the CO_2-flux and concentration, latent heat flux, sensible heat flux
- PRIME method: Eddy covariance (3D sonic anemometer and Gas analyzer, data acquisition, etc.)
- In forests, the method requires the erection of cost-intensive measuring towers

SOBIO_023 – Forest – Aboveground biomass

- Applies to forest habitats only, Cat 1 and Cat 2
- This SO quantifies the annual aboveground vegetation biomass at the site-scale
- Forest inventory (3-year interval), continuous measurement of tree growth using automated dendrometers, annual quantification of ground vegetation using clipping etc. and weighing fresh mass as well as dry mass, proposed RI protocol: ICOS, costs: 750 – 1,000 € for automated dendrometers, work hours
- Aboveground biomass may be accessed in the near future through satellite data. (https://sentinels.copernicus.eu/web/success-stories/-/copernicus-sentinel-1-essential-for-monitoring-forest-biomass/2.5). A new dedicated satellite instrument planned from 2023 (https://www.esa.int/Applications/Observing_the_Earth/FutureEO/Biomass
- PRIME/BASIC method: same method

SOBIO_024 – Non-forest – Aboveground biomass

- Applies to terrestrial non-forest habitats only, Cat 1 and Cat 2
- This SO quantifies the annual aboveground vegetation biomass at the site-scale
- Methods for non-forested sites (grassland, cropland) still under discussion; ICOS protocols could be applied here for the prime method, i.e., clipping and weighing

SOBIO_177 – Tree growth

- Applies to forest habitats Cat 1 sites with a focus on atmosphere only
- This SO quantifies the annual aboveground vegetation biomass at the site-scale
- PRIME method: Automated point dendrometers or band dendrometers

SOBIO_090 – Gross primary productivity

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- This SO quantifies gross primary productivity (GPP) calculated from Eddy-Covariance measurement
- PRIME method: Retrieval based SOs, GPP will be derived from net ecosystem exchange measured by SOATM_176 – Eddy covariance

SOBIO_091 – Transpiration

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- This SO quantifies the transpiration rate calculated from Sap flow.
- PRIME method: Sap flow measurements

SOBIO_092 – Forests - Litterfall

- Applies to forest habitats only, Cat 1 and Cat 2
- This SO measures the litterfall in forests
- PRIME/BASIC method: same method, Sampling nets

SOBIO_093 – Belowground biomass

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- Annual measurement of belowground biomass
- Method still under discussion

SOBIO_015 – Phenological traits (Remote Sensing)

- Applies to all habitats, Cat 1 and Cat 2
- This SO describes the vegetation phenology (phenological parameters including start, maximum, end of season) at the European scale based on satellite-based remote sensing
- Acquisition of data products on phenological information (including start, maximum, end of season) based on optical remote sensing derived indexes (e.g., NDVI, Plant Phenology Index etc.) whereby Sentinel2/MSI (Copernicus) is currently the most promising one, + in-situ validation with phenocams, temporal resolution: depending on the data source used can range from 5-15 days, proposed RI protocol: Copernicus, costs: work hours for data acquisition
- Provision via a central service currently under discussion. Several high-resolution vegetation phenology and productivity data is provided by Copernicus and could be harvested centrally.

SOBIO_016 – Phenological traits (on-site)

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- Acquisition of phenological traits (including start, maximum, end of season)
- Phenocams are suggested as obligatory on-site measurement to validate the Prime SO on remotely sensed plant phenology based on satellite remote sensing (see above).
- Automated Phenocams are under development and may be available soon.

SOBIO_025 – Forest – LAI

- Applies to forest habitats Cat 1 sites with a focus on atmosphere only
- Annual measurement of LAI
- PRIME method: Digital hemispherical photography, linear ceptometry

SOBIO_026 – Non-forest – LAI

- Applies to non-forest terrestrial Cat 1 sites with a focus on atmosphere only
- Annual measurement of LAI
- PRIME method: Linear ceptometry

SOBIO_095 – Leaf – Elements

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- Biennial measurement of leaf C, N, K, P, Ca, Mg, Mn content
- PRIME method: Sampling and lab analysis

SOBIO_140 – Vegetation - LiDAR

- Applies to terrestrial Cat 1 sites with a focus on atmosphere only
- Measurement of vegetation structure using LiDAR measurements
- PRIME method: Terrestrial LiDAR

- The possibility of running the measurement as a centralized service is currently under discussion.

3.6 Sociosphere

The eLTER SO group for the Sociosphere includes qualitative and quantitative descriptions of characteristics that describe the socio-ecological domain of the ecosystem. In general, it includes observations describing the demographic profile of the [human] population, land use, resource use, and economic and governance structures. A total of 13 SOs are assigned to this variable group.

The Sociosphere SOs play a decisive role in defining the criteria for the establishment of eLTER platforms (eLTER platform category 1 and 2). Prime methods apply to eLTER platforms only and will produce more accurate and precise data (e.g., national statistics) and site-specific surveys, but they are more time- and resource-intensive to collect. Data is provided in either quantitative or qualitative formats, depending on the SO (for instance, demographic or land cover data is quantitative, while governance and stakeholder variables are largely qualitative and require textual explanations.

Basic methods for Socio-economic SOs can differ with regard to the requirements for sites and platforms. Socio-economic data for sites (Cat 1 and Cat 2) is generally provided via a centralized service. For platforms, for some sociosphere SOs special requirements apply for the Basic method. The details are described below.

SOSOC_031 – Yield

- This SOs quantifies agricultural production from cropland, grasslands, forests, and fishery
- PRIME method: site-based survey
- BASIC method: retrieval based (central service) for sites and platforms
- SO should cover income from all agricultural production (cropland, grassland, agroforestry, forestry, livestock)
- Crop production is insignificant in arctic regions.

SOSOC_030 – Land-based income

- This SOs quantifies the average regional income (Farm net value (FNVA), FNVA/AWU (agricultural factor income per annual work unit), family farm income (FFI), FFI/FWU (family work unit), Farm worker wages)
- PRIME method: annual analysis of national statistics
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

SOSOC_114 – Livestock

- This SOs quantifies livestock numbers, breeds, and feed and grazing management
- PRIME method: annual analysis of national statistics and (every 6 years) site-specific surveys
- BASIC method for sites: retrieval based (central service)
- BASIC method for platforms: retrieval based (central service) and (every 3 years) expert judgement based on expert-knowledge

SOSOC_032 – Governance structure and character

- This SO applies to platforms only (not for sites)
- This SOs describes governance structure
- PRIME method: annual analysis of national statistics and site-specific surveys (6-year interval)

- BASIC method: expert judgement based on primary and secondary documents, articles, legislation and expert knowledge (3-year interval)
- Measuring governance structure and character across all sites in Europe is challenging. Various detailed questions have not yet been conclusively clarified: E.g., is this national level indicators, is it how well the site is governed or local governance structures including partnerships among public, private and civil society?

SOSOC_036 – Land cover and use (CORINE)

- PRIME/BASIC method: same method, evaluation (6-year interval) on the basis of existing national or European (e.g., CORINE) land cover/use maps
- SO is already monitored at and is available for many of the European LTER sites and platforms
- The spatial resolution of the CORINE data is limited (1:25,000). This limits the applicability for the detection of small-scale changes (diachronic analysis). Alternatively, Copernicus provides annual land cover maps in 100 m resolution

SOSOC_037 – Land cover and use (Statistics)

- This SO assesses land cover, land use and land use actors, farm structure / land management/area statistics (incl. conv./organic; conv./cons./no tillage)
- PRIME method: annual analysis of national statistics and site-specific surveys (6-year interval)
- BASIC method for sites: retrieval based (central service)
- BASIC method for platforms: retrieval based (central service) and expert judgement based on primary and secondary documents, articles, legislation and expert knowledge (3-year interval)

SOSOC_040 – Ecosystem services profile

- This SO applies to platforms only (not for sites)
- This SO comprises a bundle of variables describing the ecosystem service profile
- PRIME method: expert judgement and site-specific surveys (every 6 years)
- BASIC method: analysis of statistics and expert judgement (3-year interval)
- quantification of ecosystem services and basic as presence and absence of service

SOSOC_042 – Economics – GDP

- This SO quantifies the per-capita income, Gross domestic product (GDP)
- PRIME method: Annual acquisition using official national statistics
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

SOSOC_043 – Demography

- This SO describes the regional demography (total population size and density; population age profile; educational attainment; residential density)
- PRIME method: annual acquisition using official national statistics (national census bureau)
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

SOSOC_044 – Employment

- This SO assesses the status of employment.
- PRIME method: annual acquisition using official national statistics (national census bureau)
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

SOSOC_045 –Consumption statistics

- The SO describes the regional consumption statistics
- PRIME method: annual analysis of national statistics and (every 6 years) site-specific surveys
- BASIC method for sites: retrieval based (central service) analysis of European statistics
- BASIC method for platforms: retrieval based (central service) analysis of European statistics and (every 3 years) expert judgement based on expert-knowledge

SOSOC_183 – Resource use

- The SO quantifies the regional resource use (extraction or movement on purpose by human activity (DE), imports (IMP), exports (EXP), domestic processed outputs (DPO), biomass (BI), domestic material consumption (DMC), direct material input (DMI), physical trade balance (PTB), NAS: biomass, metal ores, non-metallic minerals, fossil energy carriers (other products, waste, emissions)
- PRIME method: annual analysis of national statistics
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

SOSOC_184 – Subsidies

- The SO monitors the CAP (common agricultural policy) payments for direct support, rural development, market measures
- PRIME method: annual analysis of national statistics
- BASIC method: retrieval based (central service) annual analysis of European statistics for sites and platforms

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