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Long-term environmental monitoring infrastructures in Europe: observations, measurements, scales, and socio-ecological representativeness

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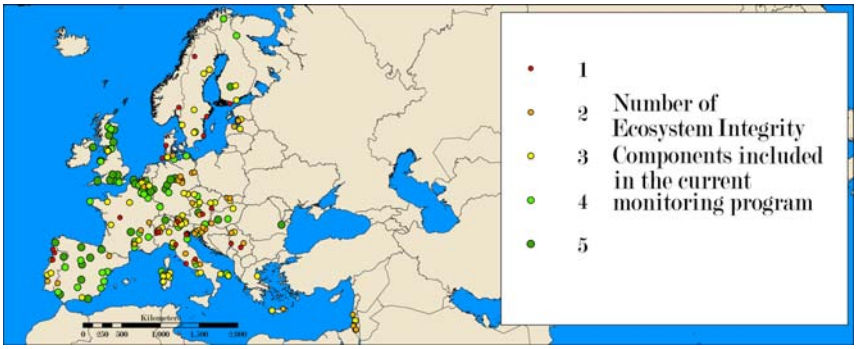
HIGHLIGHTS

- First study on conceptual and infrastructural comparability of LTER-Europe
- Analysis of biogeographical and socio-ecological representativeness of LTER-Europe
- Classification of LTER Europe sites based on the LTER framework of standard observations

GRAPHICAL ABSTRACT



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ABSTRACT

The challenges posed by climate and land use change are increasingly complex, with ever-increasing and accelerating impacts on the global environmental system. The establishment of an internationally harmonized, integrated, and long-term operated environmental monitoring infrastructure is one of the major challenges of modern environmental research. Increased efforts are currently being made in Europe to establish such a harmonized pan-European observation infrastructure, and the European network of Long-Term Ecological Research sites – LTER-Europe – is of particular importance. By evaluating 477 formally accredited LTER-Europe sites, this study gives an overview of the current distribution of these infrastructures and the present condition of long-term environmental research in Europe. We compiled information on long-term biotic and abiotic observations and measurements and examined the representativeness in terms of continental biogeographical and socio-ecological gradients. The results were used to identify gaps in both measurements and coverage of the aforementioned gradients. Furthermore, an overview of the current state of the LTER-Europe observation strategies is given. The latter forms the basis for investigating the comparability of existing LTER-Europe monitoring concepts both in terms of observational design as well as in terms of the scope of the environmental compartments, variables and properties covered.

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Nomenclature

DEIMS-SDR	Dynamic Ecological Information Management System – Site and Dataset Registry
EI	Ecosystem integrity
eLTER	European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure
ESFRI	Policy European Strategy Forum on Research Infrastructures
EBV	Essential biodiversity variables
GEO	Group on Earth Observations
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
ILTER	International Long-Term Ecological Research
LTER	Long-Term Ecosystem Research
RI	Formalized Research Infrastructure in the context of the European Strategy Forum on Research Infrastructures

1. Introduction

Human interactions with the environment, changes in climate and land use and their long-term impacts on ecosystems generate major global environmental risks and new scientific challenges of highest complexity. In order to provide answers to the great challenges facing humanity like changes in temperature and precipitation regimes, land use change and loss of biodiversity, eutrophication, or pollution, today's environmental science must gain comprehensive understanding about processes and cross-compartment feedbacks and their drivers across the appropriate temporal and spatial scales. The UN 2030 Agenda for Sustainable Development encompasses 17 sustainable development goals (SDGs) which are broken down in 169 associated targets (UNGA, 2015). As a prerequisite for achieving these goals, European policy must take into account the socio-economic significance of an array of well-functioning ecosystem services. Several of the 169 targets explicitly mention the sensible utilization of ecosystems, and a considerable number of them are directly related to ecosystem services, including genetic diversity, water quality, sustainable tourism, the use of natural resources, and environmentally related health issues and risks. Against this backdrop, the development and enhancement of integrated observation systems fostering inter- and transdisciplinary research is one of the Grand Challenges of Earth System Science for global sustainability (Reid et al., 2010) and also defined as one of the European Commission's Societal Challenges for Europe 2020 - Developing comprehensive and sustained global environmental observation and information systems (EC, 2017a).

The new challenges for Earth System Science are placing a number of new demands on observation designs and capabilities of monitoring technologies (Reid et al., 2010; Vihervaara et al., 2010, 2013; Zoback, 2001). There are the needs to describe and predict mass fluxes and energy balances at the systems level, to identify and describe the complex feedbacks between the different environmental compartments, to detect and evaluate signals of natural variability at a wide range of spatial and temporal scales, and finally to predict the consequences of human interaction at the scale of the natural system. In order to meet these needs, integrated multi-scale monitoring and modeling approaches are required (Ali et al., 2013; Banwart et al., 2013; Blöschl and Sivapalan, 1995; Haberl et al., 2006; Kirchner, 2006; Levin, 1992; Lin, 2003; Montgomery et al., 2007; Parr et al., 2002) and call for the "next generation of ecosystem research in Europe" (Mirtl, 2010). This situation is compounded by the fact that biodiversity monitoring schemes are mostly separated from abiotic monitoring and consistent strategies for greater integration between both sides are needed (Haase et al., 2018; Vihervaara et al., 2013). Furthermore, many environmental systems react with considerable delay to changes in the environmental conditions requiring long-term monitoring efforts to identify the major drivers like climate change (Dalton, 2000; Nisbet, 2007; Vihervaara et al., 2013; Zacharias et al., 2011).

These issues are tackled by Long-Term Ecosystem Research (LTER), an essential component of worldwide efforts to better understand ecosystems. Through long-term research and monitoring, LTER seeks to improve our knowledge of the structure and functions of ecosystems and their response to environmental, societal and economic drivers.

The International Long-Term Ecological Research (ILTER; Vanderbilt and Gaiser, 2017) network currently covers approximately 900 LTER sites globally. Within ILTER, LTER-Europe is a regional (continental) network representing the European LTER sites and 24 countries with well-established national and European governance structures.

Since its launch in 2003, LTER-Europe has sought to better integrate traditional natural, more disciplinary sciences and more holistic ecosystem research approaches including the impact of humans on environmental systems. LTER-Europe was heavily involved in developing the concept of Long-Term Socio-Ecological Research (LTSER). As a result, LTER Europe now comprises not only LTER sites but also larger LTSER platforms, where long-term interdisciplinary research is encouraged.

LTER-Europe builds on an in-situ infrastructure of 477 formally accredited ecosystem research sites (65% terrestrial, 26% aquatic and 9% transitional waters) and 35 LTSER Platforms for socio ecological research. The infrastructures are operated by around 100 institutions. LTER-Europe brings together research sites originally set up in varying contexts (projects and networks driven by national/institutional strategies and domain specific requirements) and provides an excellent setup to establish Pan-European research focusing on entire ecosystems.

One of the key requirements towards continental-scale environmental in-situ research infrastructures is a representative coverage of the socio-environmental gradients addressing environmental and geographical characteristics (e.g. altitude, climate, landforms, geology, land cover, biogeography), as well as social and economic gradients (e.g. demography, economic density). The majority of the existing ecological research activities is still performed on smaller spatial scales (e.g. plot scale, field scale, research stations), representing a large variety of funding schemes. However, an overarching concept to integrate such activities is still missing. In Europe, the development and provision of such a concept to transform the existing in-situ research sites into a continental-scale, harmonized, integrated, inter and cross-disciplinary research infrastructure is one of the key objectives of two EC-funded projects: "eLTER H2020" (Integrated European Long-Term Ecosystem & Socio-Ecological Research Infrastructure; duration 2015–2019) and "Advance_eLTER" (Advancing the European Long-Term Ecosystem, Critical Zone and socio-Ecological Research Infrastructure towards ESFRI; 2017).

Within the aforementioned EU projects a comprehensive survey was conducted to investigate the status of the monitoring programs of European LTER sites. Based on this survey the objectives of this study are to evaluate the current status of the observation strategies of LTER sites in Europe by: (i) providing an overview on biotic and abiotic observations across LTER-Europe sites, (ii) identification of gaps in the observation concepts, (iii) identification of gaps in the socio-ecological coverage, and (iv) provision of recommendations on how to overcome existing deficits and option towards future joint developments of infrastructural components for integrated long-term environmental research in Europe.

2. Methods

2.1. LTER framework of standard observations

LTER sites and national networks have mainly been developed in a bottom up manner (Haase et al., 2016). As a consequence, sites were established for different research and monitoring reasons and their research and design is largely driven by institutional and program-related