

White paper on Terrestrial Ecological and Environmental Research Infrastructures in Finland

Analysis of the current landscape and proposal for future steps

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ABSTRACT

White paper on Terrestrial Ecological and Environmental Research Infrastructures in Finland - Analysis of the current landscape and proposal for future steps

This White Paper presents a vision of globally leading, scientifically important and socially relevant environmental research infrastructures (RIs) in Finland, and identifies what we consider as the key issues to be developed to improve the impact and to support the Finnish national infrastructures in their international visibility. The focus is on: 1. The scientific questions driving the terrestrial ecosystem and environmental research globally and in Finland; 2. Specific requirements by different user groups in Finland for ecological and environmental RIs; and 3. Roadmap for the sustainable ecological and environmental RI in Finland. We also present the strategies of organizations regarding their RI development, and the existing infrastructures and networks which form the basis for future development. The final goal of this document is to encourage the development of a coherent vision at national level, and to increase the scientific significance, national synergies and benefits towards a stronger research community.

The need for developing a national RI strategy for environmental field arises from the global challenges, which threaten the ecosystems' functioning. Human activities are imposing many identified, but also previously unknown pressures to ecosystem properties and functions, which are also feeding back to the societies via the quality and quantity of ecosystem services. However, the ecosystem responses to changes in environment are in many cases poorly quantified and the studies only cover short time scales. In order to succeed in providing answers to the grand challenges (ICSU 2010), integrated research infrastructures and efficient analysis tools are crucially needed. The request to improve our knowledge of the state of the environment and the complex biosphere-hydrosphere-atmosphere interactions, and to detect and analyze the impact of global change on these systems has been recognized as a general priority in developing environmental research infrastructures in EU and globally.

Currently, Finland is one of the world leaders in atmospheric and environmental sciences, both in terms of research and in coordinating the European and global observation station networks and infrastructures. With this existing experience from close-by research fields and the high research outputs from ecology and ecophysiology in our research organizations, Finland has also the potential to actively promote the ecosystem RI concept, and to act as an example of integrated RIs for other countries. The vision is to develop the capacity of the Finnish ecosystem research community to integrate, upscale and synthesize the observations with relevant holistic process understanding as well as open and reliable data management practices. This can be implemented by creating functional and cost-efficient in-situ platforms and by providing quality-checked data in findable, accessible, interoperable and reusable (FAIR) manner for high-level environmental research.

This White paper was made in connection with the INAR Ecosystems initiative funded by Academy of Finland and updated with proceeding of European processes, and it provides a starting point for national cooperation in environmental research infrastructures.

Keywords: Terrestrial ecosystems, research infrastructures, ESFRI

TIIVISTELMÄ

Työpaperi Suomen ekosysteemi- ja ympäristötutkimuksen infrastruktuureista – Analyysi nykytilanteesta ja ehdotus seuraaviin vaiheisiin

Tässä työpaperissa esitellään näkemys kansainvälisesti huipputasoisen, tieteellisesti tärkeän ja yhteiskunnallisesti merkittävän suomalaisen ympäristötutkimuksen infrastruktuurin nykytilasta ja tulevaisuuden kehityksestä. Työpaperi listaa tärkeimmät kehityskohteet suomalaisten infrastruktuurien vaikutuksen ja kansainvälinen näkyvyyden parantamiseksi. Se käsittelee erityisesti: 1. Tieteellisiä kysymyksiä, jotka ohjaavat ekosysteemi- ja ympäristötutkimusta maailmanlaajuisesti ja Suomessa; 2. Erilaisten käyttäjäryhmien erityistarpeita Suomessa, liittyen ekosysteemi- ja ympäristötutkimuksen infrastruktuureihin; ja 3. Suomalaista tiekarttaa, joka mahdollistaa ekosysteemi- ja ympäristötutkimuksen infrastruktuurien kestävyuden. Työpaperi esittelee myös suomalaisten yliopistojen ja tutkimuslaitosten tutkimusinfrastruktuuristrategiota, sekä olemassa olevia infrastruktuureja, jotka muodostavat perustan tulevalle kehitykselle. Tavoitteena on ennen kaikkea tukea kansallisen yhtenäisen vision rakentamista ja vahvistaa tieteellisen merkittävyyden, kansallisten synergioiden ja hyötyjen kautta tutkimusyhteisöä.

Ekosysteemi- ja ympäristötutkimuksen infrastruktuureille on tärkeää kehittää kansallinen strategia, sillä globaalit haasteet uhkaavat ekosysteemien toimintaa. Ihmistoiminta vaikuttaa monin tavoin mutta myös vielä tuntemattomin tavoin ekosysteemien rakenteeseen ja toimintaan, ja näiden muutosten vaikutukset heijastuvat takaisin yhteiskuntaan ekosysteemien tarjoamien palveluiden laadun ja määrän kautta. Ekosysteemien vaste ympäristön muutoksiin tunnetaan usein vain vajanaisesti, tai tutkimukset kattavat vain lyhyitä ajanjaksoja. Yhtenäiset tutkimusinfrastruktuurit ja tehokkaat analyysimenetelmät ovat keskeisiä, jotta globaaleihin haasteisiin onnistutaan löytämään vastauksia. Ympäristötutkimuksen infrastukturin kehittämistä tärkeimmäksi kohteeksi on niin Euroopassa kuin maailmanlaajuisesti tunnistettu tarve ymmärtää paremmin ympäristön tilaa ja monimutkaisia biosfääri-hydrosfääri-ilmakehä – yhteyksiä sekä havaita ja analysoida globaalin muutoksen vaikutuksia näihin systeemeihin.

Suomi kuuluu tällä hetkellä ilmakehä- ja ympäristötieteiden alalla maailman johtaviin maihin sekä tutkimuksen että eurooppalaisten ja maailmanlaajuisen havaintoasemaverkoston ja infrastruktuurien (ICOS, ACTRIS) koordinoimisen osalta. Perustuen tähän lähitieteiden olemassa olevaan kokemukseen ja monien suomalaisten yliopistojen ja tutkimuslaitosten merkittäviin ekologian ja ekofysiologian tutkimustuloksiin, Suomella on mahdollisuus aktiivisesti edistää ekosysteemitutkimusinfrastruktuurin käsitettä ja toimia muille maille esimerkkinä infrastruktuurien menestyksekkäästä kansallisesta integraatiosta. Tämän raportin tarkoituksena on pohtia, miten voidaan yhtenäistää, laajentaa ja yhdistää havainnot toimivan ja kustannustehokkaan asemaverkoston avulla ja avoimen ja luotettavan datanhallinnan järjestelmän kehittämiseksi.

Työpaperi on kirjoitettu osana Suomen Akatemian rahoittamaa INAR Ecosystems –aloitetta ja päivitetty eurooppalaisten projektien edetessä. Se muotoilee vision ja lähtökohdat kansalliselle yhteistyölle ympäristötutkimusinfrastruktuurin kehittämiseksi.

Asiasanat: Terrestriset ekosysteemit, tutkimusinfrastruktuurit, ESFRI

SAMMANDRAG

Infrastrukturer för ekosystem- och miljöforskning i Finland – en analys av nuläget och förslag till nästa steg

Detta arbetsdokument är en presentation av den internationellt högtstående, vetenskapligt viktiga och för samhället betydelsefulla finländska infrastrukturen för miljöforskning, dess nuläge och framtida utveckling. Dokumentet presenterar de viktigaste utvecklingsmålen för främjandet av de finländska infrastrukturernas synlighet och verkan. Särskilt behandlas: 1. De vetenskapliga frågor som styr utvecklingen inom ekosystem- och miljöforskningen globalt och i Finland; 2. Olika nationella användargrupperns behov som tangerar infrastrukturer inom ekosystem- och miljöforskning; och 3. Den finländska vägkarta som möjliggör dessa infrastrukturers beständighet. Arbetsdokumentet presenterar också de finländska universitetens och forskningsinstitutens strategier för forskningsinfrastruktur, samt de existerande infrastrukturerna, som utgör basen för den framtida utvecklingen. Målsättningen är framför allt att stöda en enhetlig nationell vision och stärka forskningssamfundet genom att främja vetenskaplig relevans, samt nationella synergier och intressen.

Det är viktigt att utveckla en nationell strategi för ekosystem- och miljöforskningens infrastrukturer, eftersom ekosystemens funktion är hotad av globala utmaningar. Mänsklig aktivitet påverkar ekosystem på många, delvis ännu okända sätt, och trycket reflekteras tillbaka på samhället genom mängden av och kvaliteten i de tjänster ekosystemen erbjuder. Emellertid känner man ofta endast delvis till hur ekosystemen reagerar på miljöförändringar eller också täcker undersökningarna bara korta tidsperioder. Enhetliga forskningsinfrastrukturer och effektiva analysmetoder är centrala för att hitta lösningar på de globala utmaningarna. Både globalt och i Europa har man identifierat de primära behoven att förstå miljöns tillstånd och de komplicerade relationerna mellan biosfären, hydrosfären och atmosfären, vid sidan av observationer och analys av hur de globala förändringarna påverkar dessa system. Detta styr utvecklingen av miljöforskningens infrastrukturer.

Finland är för närvarande ett av de ledande länderna inom atmosfär- och miljövetenskaper både vad gäller forskning och koordination av europeiska och globala nätverk och infrastrukturer för observation (ICOS, ACTRIS). På grund av denna erfarenhet inom närstående forskningsområden och betydande forskningsresultat inom ekologi och ekofysiologi vid våra forskningsinstitutioner, har Finland också potential att aktivt främja ett koncept för ekosystemforskningsinfrastruktur och fungera som en föregångare inom nationella integrerade forskningsinfrastrukturer.

Avsikten med denna rapport är stärka förmågan att integrera, skala upp och sammanföra observationer i en öppen och pålitlig datahanteringsprocess. Detta kan ske genom att implementera FAIR-principerna, för att göra data sökbara (Findable), tillgängliga (Accessible), interoperabla (Interoperable) and återanvändningsbara (Reusable).

Arbetsdokumentet är producerat inom INAR Ecosystems-initiativet som finansierats av Finlands Akademi och har uppdaterats då europeiska projekt framskridit. Det beskriver en vision och erbjuder en utgångspunkt för en gemensam nationell infrastruktur för miljöforskning.

Nyckelord: Terrestriska ekosystem, miljöforskning, forskningsinfrastrukturer, ESFRI (European Strategy Forum on Research Infrastructures)

PREFACE

Research infrastructures (RIs) are equipment, facilities, information systems, data storages and data, as well as services enabling research to happen in different parts of a RI. They can be centered, distributed or virtual and form together networks and assemblies completing each other. There are many large multinational RIs in Europe and their number is increasing following the aims of European Strategy Forum on Research Infrastructures (ESFRI). The most important object of RIs is to support the top-level science and to produce high-level services for researchers.

Since a long time, there is a shared understanding among the Finnish universities and research institutes of the necessity of a common vision and strategy for organising the functions of ecological and environmental RIs. This includes a wish for more efficient collaboration, shared usage and integration of RIs. The aim is to support the synergy benefits for example in using the long-term data, and to promote the participation to international infrastructure processes and the visibility of Finland at European RI field.

The Academy of Finland has provided FIRI-project funding (INAR Ecosystems) for a broad-based consortium for 2017-2021 in order to advance the integration. All the main actors from Finnish Universities and research institutes are part of the consortium and thus it covers the different views of ecological environmental research quite well. INAR Ecosystems is part of Institute for Atmospheric and Earth System Research (INAR) RI, which is on the Finnish RI roadmap 2014-2020.

The integration work has started by establishing a working group of the representatives of different parts, led by prof. Jaana Bäck from University of Helsinki. She leads also the INAR Ecosystems –project. The working group has produced this White paper, which collects the strategic outlines of participant institutes on developing ecosystems and environmental infrastructures and lists the international infrastructure projects and networks they are involved in. The White paper aims to construct a new vision on Finnish ecosystems and environmental RI and to bring up new functional solutions, advance the collaboration between institutes and disciplines and to create preconditions for national and international funding. The White paper was originally written in 2018 and the information related to the state of eLTER, AnaEE and ACTRIS was updated in August 2019.

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1 The scientific questions driving the terrestrial ecosystem and environmental research globally and in Finland

Many of the most dramatic effects of global change on environment will occur across a range of temporal scales and large spatial extents, encompassing the national and even continental boundaries. The challenges are therefore considerable. Climate change, insecurity (from water to terrorism), population growth and urbanisation, resource scarcity, decrease in biodiversity and productivity of ecosystems, and an increasing pace of technological change are some examples. Properly informed, the societies can adapt to and mitigate the harmful effects. Thus, it is widely accepted that multidisciplinary, integrated approaches to environmental observation and experimentation at the continental and global level are necessary to provide a more holistic understanding on the current state and future evolution of our environment. Such knowledge is indispensable for projections of future changes and for informing decision making targeted at achieving UN Sustainable Development Goals.

The global initiatives such as GEO-GEOSS (Group on Earth Observations - Global Earth Observation System of Systems), AMAP (Arctic Monitoring and Assessment Programme) and IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) are examples of the wide scale projects for observing, reviewing and monitoring the changes in the environment. These global organizations depend on local data providers who are able to contribute with *in situ* observations to the global data archives and their analyses. Be it disaster response, climate change or sustainable development, it is evident that national research organizations and data providers and the Earth observation community achieve most by working hand in hand.

Ecosystems are responsive to changes in environment, but can also significantly contribute to mitigating harmful changes, such as climate change. For example, terrestrial ecosystems are currently accumulating a large part of anthropogenic carbon emissions in vegetation and soils (Le Quere et al. 2018), but changes in this sink in the future may be nonlinear and will crucially influence the climate change manifestation globally (Bellassen & Luyssaert 2014). The ability of scientists to understand and predict these dynamics depends currently, in large part, on existing site-based RIs developed in response to historic events (Peters et al. 2014) or according to national priorities. However, analysis of the functional and structural relationships between ecosystem components and the surrounding abiotic environment and society requires a long-term perspective and broad, interdisciplinary and comprehensive approach through an integrated set of RIs and well-developed data and analysis tools.

1.1 Regional aspects

Arctic and subarctic

In the high-latitude regions of Earth, temperatures have risen about 0.6 °C per decade over the last 30 years, twice as fast as the global average (Pachauri et al, 2014). Exploitation of natural resources in the region is also rapidly increasing. This is causing profound impacts on the sensitive Arctic ecosystems, as well as on its approximately four million inhabitants. There is thus a need to continue studying the extent and magnitude of the occurring rapid changes, as well as exploring and implementing cost-effective adaptation and mitigation actions.

Research on regional-scale phenomena requires, in addition to high-frequency and -quality data from highly instrumented research stations, also spatial data on for example land-use and its changes,

other socio-economic drivers, and data on anticipated changes from large-scale modelling. Data from regional monitoring programmes and inventories is also valuable in this context. New techniques such as mobile measurement platforms, unmanned aircraft systems (UAS), and information from new satellites with high spatial resolution (COPERNICUS/Sentinel) can also complement site-based approaches. Such techniques are particularly useful in the vast and inaccessible Arctic regions.

The information from Arctic research infrastructures is needed also to support environmental policy. Formal monitoring and assessment programmes operating under the Arctic Council, such as AMAP and CAFF (Conservation of Arctic Flora and Fauna) are main users of research information. These programmes report synthesized information to high-level decision-makers and operate different monitoring structures, databases and assessment structures (e.g. expert groups).

Boreal terrestrial

More than 70% of the land area in Finland is covered by forests, while agriculture covers 9%. Boreal forests are typically dominated by evergreen coniferous trees (Norway spruce and Scots pine), which are also the main sources for timber and other raw materials from production forests in Finland. Most of the southern forests are managed according to specific recommendations, whereas in Northern Finland a large part of the forests belongs to nature conservation areas with several national parks where management is limited. Forests provide significant ecosystem services to society, and the maintenance and viability of these services will be crucial for the society in general, and for Finland in particular. Generally, three categories of ecosystem services are distinguished: (1) provisioning services which provide food, fuel, genetic resources, water and energy; (2) regulating and maintenance services which secure the climate regulation, protect against natural hazards such as floods and erosion, and pollinate, etc.; and (3) cultural services which maintain recreation activities and provide aesthetic, religious and spiritual experiences (Haines-Young and Potschin, 2013).

Maintaining these services in adequate level requires that we understand how the ecosystems are functioning, observe the current and predict the future changes in the state of ecosystems, and design tools for mitigating the harmful changes threatening the ecosystems and the services they provide. Among the crucial factors affecting these services are climate change, pollution, land use changes and unsustainable management (EASAC 2017). The need for a strong *in situ* research infrastructure component has been recognized by the Finnish organizations already in early 1900's, when e.g. some experimental field stations were built and forest research measurements were established.

Baltic sea coastal and inland aquatic ecosystems, catchments

Lakes and their catchments have a special place in the landscape, as they represent the largest store of accessible freshwater on the planet, and provide irreplaceable ecosystem services. In addition to their role as carbon sources or sinks, eutrophication, habitat destruction in lakes and in their catchment together with global changes in precipitation and thermal conditions (Trenberth et al. 2007) are listed to be the main threats to lake ecosystems today. In many cases, the effects of disturbances accelerate in time, and the recovery of a lake ecosystems may have long delays after the conservation decisions have been made and acts for the lakes carried out (Jeppesen et al. 2005). Lakes are also situated in the landscape downstream from terrestrial ecosystems which can be heavily managed for their exportable goods and services. In a socio-economic context, lakes are therefore ideally suited for studying how the demands of economic networks from local to global scale interact with the integrated social-natural water system embodied in lake catchments. One widely observed recent phenomenon is the increasing water color ("brownification") associated with an increase in dissolved organic carbon (DOC) in lakes and running waters of the Northern hemisphere (Monteith et al. 2007). The brownification has far-reaching consequences as it affects the structure and function of the aquatic ecosystems; and thereby provision of ecosystem services for the human society.

In Finland, limnological and hydrological data from lakes are internationally extraordinary with a great number of datasets spanning over 50 years. However, the potential of these valuable data sets has yet not been fully utilized, especially when considering a multi-lake comparative approach over large environmental gradients. Therefore, an efficient, integrated research infrastructure would be crucial in allowing research spanning over relevant time and spatial scales.

1.2 Strategies of Research Performing Organizations in environmental research

As indicated above, Finland is positioned in the zone where large changes in ecosystems are forecast, encompassing the northern boreal and subarctic ecosystems with wide geographical extent and variability in historical land use and eco-climatic conditions. In this perspective, Finland has potentially a big contribution to the European Research Area. However, the realization of the potential requires clear planning and jointly agreed working modes and responsibilities, and also calls upon defining the strategic priorities in relation to the international RIs.

The strategically important ecological research questions of national, environmentally focused Research Performing Organizations (RPOs) are dealing with the current state of both natural and managed ecosystems and landscapes, and their trajectories in the future. The main organizations working in the field are Universities of Eastern Finland, Helsinki, Jyväskylä, Oulu, and Turku, and three research institutes (Natural Resources Institute Finland (Luke), Finnish Environment Institute (SYKE) and Finnish Meteorological institute (FMI)). Here we summarize the strategic statements these organizations have made concerning their research in the field:

- One of the key research areas of University of Helsinki (UH) is ‘Climate, environment and natural resources’. UH aims at promoting top-level research in the field of environmental and atmospheric sciences and has established the Integrated Atmospheric and Earth system Research (INAR) Unit from the beginning of 2018. INAR mission includes participation in international and multidisciplinary collaboration, taking a responsible role in several ESFRI projects and promotion of shared use of research infrastructures nationally and internationally.
- Ecosystem research in Finnish Meteorological Institute (FMI) is mainly concentrated in the northern research facilities. In addition to the wide scale of atmospheric and surface measurements and remote sensing programs run in the Arctic Research Center of Sodankylä and the global greenhouse gas (GHG) monitoring program and air quality activities run at the Pallas supersite (together Pal-Sod GAW), both sites have been equipped to monitor the ecosystem-atmosphere interactions and the impacts of climate change and land use on northern ecosystems. FMI’s strategy is to reinforce the profile of Pal-Sod GAW station as a globally leading subarctic research site of carbon cycle, soil, snow and cryosphere processes and ecosystems dynamics.
- Environmental change and sufficiency of natural resources is one of the four global challenges which University of Eastern Finland (UEF) seeks to find solutions. The strategic top-level international research areas “Forests, Global Change and Bioeconomy” and “Aerosols, Climate Change and Human Health” that address this challenge facilitates the collaboration between several research groups working at the Department of Environmental and Biological Sciences, School of Forest Sciences and the Department of Applied Physics at UEF. Both of the strategic research areas benefit from the INAR RI and other RIs on ESFRI.
- “Boreal Green Bioeconomy” is one of the four main research areas in Natural Resources Institute Finland (Luke). Use of forests simultaneously as efficient carbon sinks and feedstock sources requires research and innovation actions and development of forest management, land use and risk control practices in changing environment.

Infrastructures are used for studying the effects of forest and cultivation operations and varying environmental conditions, including changing climate on tree and agricultural plant growth and above- and below-ground processes as well as on leaching of nutrients and hazardous substances. These results are used for developing methods for sustainable use of forest and water resources (research area “Blue bioeconomy”) and food production (“Innovative Food System”). Luke has several large experimental field trials, and the ICP-Forests and National Forest Inventory provide invaluable data sources for analysis of the past development of forests and for process-based models that contribute on future predictions of ecosystem responses to changes in the climate, deposition and management practices. Luke applies open access data policy and further develops interface for open data.

- The Finnish Environment Institute (SYKE) aims at developing the ecosystem observatories and related data systems in cooperation with other main institutes and universities in the field. The development of infrastructures for open data access and enhancement of integrative environmental science are also priorities in SYKE. The institute serves as the national centre for environmental data in Finland, and maintains many national monitoring programmes in this field.
- In the policy programme of the latest strategy of University of Turku (UTu) the infrastructures are a special emphasis, and UTu participates in the planning and use of international infrastructures, on regional collaboration and shared use. The university’s two research stations run by Kevo Subarctic Research Institute and Archipelago Research Institute are important centers for studies on ecology, environment and natural resources, and are in shared international use for research and teaching. The UTu strategy also emphasizes open science and open data.
- The University of Oulu (UO) strategy 2016-2020 has a research focus area ‘Earth and near-space system and environmental change’. This research includes studies at Oulu campus, Sodankylä campus and the Oulanka Research station in Kuusamo. Multidisciplinary research activities are conducted mainly in the Faculties of Science and Technology. Oulanka Research Station is part of the Infrastructure-unit of UO. “Changing environment of the North” is one of the four research themes of the focus area. Research includes studies on aquatic and terrestrial ecosystems and communities. The research links geosciences, ecology and hydrology to understand biodiversity and global change and is based on time series analysis and novel bioinformatic and modelling methods. UO emphasizes open access research, cooperation and alliances including joint research infrastructures.”
- The wide-ranging research area of natural resources and environment in University of Jyväskylä (JyU) studies the effect of human impact on the environment and the sustainable use of natural resources, and aims to provide tools for reducing harmful impacts of human activities on nature. This area integrates terrestrial and aquatic ecosystem research as well as conservation and management of natural resources in inland lakes and their catchment areas.
- CSC – IT Center for Science Ltd. (CSC) as a national IT centre for science promotes the use of state-of-the-art e-infrastructure for research communities. Besides national services, CSC is actively participating in European e-infrastructure developments, as coordinator of the EUDAT Data infrastructure, active participant to EGI and PRACE e-infrastructures as well as one of the key partners in European Open Science Cloud (EOSC) projects. This network and expertise in European infrastructures aims to bring benefits to the Finnish research communities. CSC is actively supporting environmental science community in Finland and on European level.

2 Specific requirements by different user groups in Finland for ecological and environmental RIs

The challenges of global change, including changing climate, decreasing water resources, deterioration of biodiversity and habitat loss, increasing frequency of extreme events and changes in land use and societal developments, require new research strategies and well-functioning infrastructures for environmental research. In order to understand, assess and predict natural and anthropogenic fluctuations in ecosystems, qualitative and quantitative changes must be recorded and evaluated over long periods, and attempts must be made to identify the causes of change. These research questions require well-managed RIs, interoperable both cross the domains and internationally, whose data is easily accessible for multiple users and that clearly contribute to the common understanding of our living planet (Figure 1).

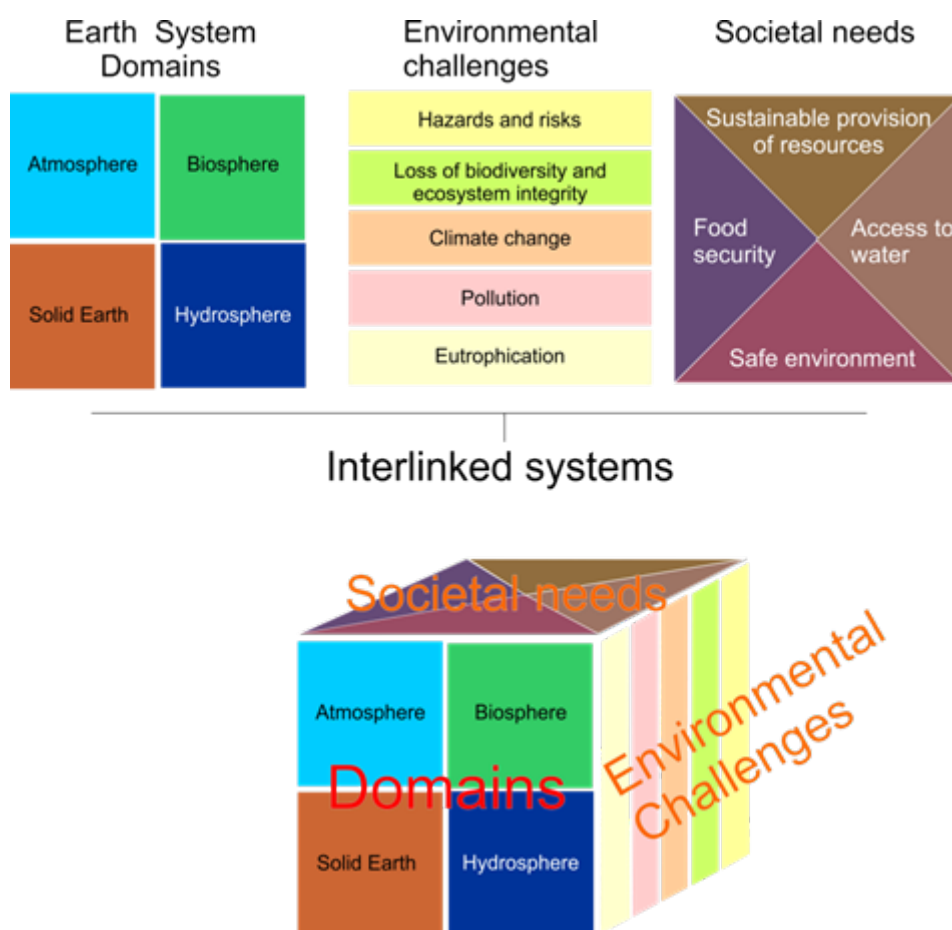


Figure 1. The environmental RIs cover all four Earth System domains and provide solutions to different environmental challenges and societal needs. An integrated system will be able to overcome the boundaries and address the challenges in a coherent manner. Figure from ENVRI/A.Asmi.

Research infrastructures are platforms providing services for a variety of user groups and communities, either nationally or internationally. They differ from projects by having long-term perspective with sustainable commitments from research organizations, strategic objectives of which they fulfil. The RI users range from research communities, students, authorities and policy makers, educators and teachers, media, industry and SMEs, to NGOs and citizens. The services RIs provide may be new tools, methods,

data products and knowledge, in addition to the access to historical or currently produced samples and data, and physical or virtual access to the platforms, i.e. research sites. In many cases, environmental and ecosystem RIs also provide fundamental long-term monitoring information, e.g. on the effects of air pollutants, water quality and productivity of agricultural and forest ecosystems. Furthermore, their data may also contribute to the surveillance of international agreements (e.g. UNFCCC Kyoto and Paris agreements, CLRTAP protocols, Convention on Biological Diversity (CBD)) and assessing their implementation. The usefulness of an RI to other users than researchers depends on how well their higher-level products and services are planned and communicated.

Here we define two main user groups of site-based ecological-environmental RIs, with commonalities warranting joint implementation and strategy. The first one is public agencies which monitor and thus serve the authorities in their tasks for reporting and implementing national and international regulations, and the second one is the international and national research-oriented users who have scientifically justified targets and requests.

2.1 Public agencies

Luke and SYKE are doing as statutory service several monitoring programmes having also a long history and long-time series. Luke and its predecessor the Finnish Forest Research Institute (Metla) has conducted National Forest Inventory (NFI) since 1920's as a continuous monitoring and inventory system for the state of forests and forest resources. NFI has been the backbone of the Finnish forest policy and industrial investments since its emergence and a leading NFI worldwide. Systematic monitoring of the stock of game and fish, effects of forestry on watersheds, invasive species, seed crops of forest trees, and forest damages are examples of public monitoring Luke is conducting as a governmental research and development organization. The results of the public monitoring system are used in different policies of the state and at the same time they serve also as long-term datasets for high-level research (detailed in the following section). For the forest research, Luke has also developed a network of research forests throughout the whole country, including provenance trials ongoing since over 80 years. In addition, Luke is a strong partner in the Pan-European International Co-operative Programme (ICP) on Assessment and Monitoring of Air Pollution Effects on Forests, which provides open data for forest ecosystem studies.

SYKE serves as the national centre for environmental data in Finland, and its information systems are widely used for environmental monitoring, environmental modelling, forecasting and impact analysis. SYKE and Centres for Economic Development, Transport and the Environment (national environmental administration) are responsible for surveying and monitoring of surface water quality in Finland. SYKE is coordinating the national monitoring of surface waters, mainly under the WFD (Water Framework Directive), and has also main tasks regarding national biodiversity monitoring. In addition, SYKE is responsible for monitoring and assessment and modelling of the effects of air pollution on ecosystems under UNECE CLRTAP ICP Waters (the International Cooperative Programme for assessment and monitoring of the effects of air pollution on rivers and lakes), ICP IM (the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems) and ICP M&M (the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends).

2.2 International and national researcher communities

Scientific users need open data and access to high quality in situ research sites. Although research topics are often funded with fixed-term projects, it is important that a sustainable base funding exists for the research platforms and sites, guaranteeing their longevity and full-scale services. Increasingly, integration and multi-disciplinarity are emphasized also in funding agencies' decisions of research funding, and

the infrastructures capable of adhering in interoperability, *i.e.* complying with commonly agreed formats standards and policies (*e.g.* for data and metadata) are the ones valued most.

European scale RIs emphasize scientific impact and excellence, offering cutting-edge, essential services for research, on a non-economic basis, with an outlook to the European Research Area (ERA) and global challenges. No single country can respond to these questions alone, and therefore joint efforts and strategies are crucially needed. In pursuing a common overall approach, the countries can reach a much better use of scarce resources and develop a stronger integration and competitiveness. The advantages of opening national infrastructures to international use have become clearer only in the last 10-15 years, thanks to specific initiatives started in the EU Research Programs, and there is now an established method to improve the national investments and both the national and European quality of research, while increasing the capability of the EU. The pan-European character of RIs requires considerable efforts in harmonizing and managing the often very diverse existing national RI components, and therefore integrating and opening national RIs for external users is a long-lasting process. Therefore, EU Council has created a specific tool for Research Infrastructure initiatives, the ESFRI (European Strategic Forum on Research Infrastructures).

In many cases, being part of the international RI makes it possible to do science that aims to solve grand challenges. These challenges are not confined in single country or region but require that methods, instruments and data are comparable, interoperable and harmonized across whole Europe and larger areas. In European context nine interrelated pre-conditions are identified that underpin the long-term sustainability of RIs: scientific excellence, training and access, innovation potential, interaction with industry, socio-economic impact, data management, upgrading and decommissioning, governance and funding models, as well as international cooperation. These need to be addressed in a successful RI. In a distributed environmental RI (operated by several countries and institutes), a challenge is to obtain common agreement on all of these aspects to be a mature RI.

Clearly not all existing RIs will be or need to be fulfilling such pan-European standards. Some of the existing national RI will naturally remain in purely national use for specific user groups. They are used in regional services such as specific focused research topics, education and training, but they can - and should - also be used when assessing and developing national as well as international measuring networks and monitoring programmes. However, their data may still be highly relevant, and should be archived in national databases for wider uses and long-term storage. In Finland, we aim through integration to find a balance between local and regional needs and international requirements.

3 Roadmap for the sustainable, integrated environmental RI in Finland

The infrastructures are capable of providing cost-efficient services to all users when designed in a careful manner. In the Annex 1, we have listed both the national and international Biosphere domain, site-specific RIs, and with this information we are suggesting the following vision and a roadmap to achieve the vision.

A vision of the future, integrated Biosphere-domain RI in Finland is based on the need for high level and efficient infrastructure, which supports top-level science in research and fulfils the current and future societal needs (See Figure 1). Such an RI provides platform for *in situ* ground and remote observing systems for scientists from different scientific disciplines, as well as systematic and harmonized data for developing, improving and validating large-scale model systems for forecasting future changes in the different terrestrial and aquatic ecosystems, and in different ecoregions of Finland. It allows integration of ecosystem datasets with biophysical sensor systems and satellite remote sensing methods. Such an RI will also serve as a platform for experimental ecosystem research where the functional relationships between organisms and their environment can be tested. Importantly, it is also integrated to the European and Global research infrastructure landscape, complementing the pan-European RIs with professionally managed research platforms, situated in regionally important locations in Finland.

The integrated and efficient Biosphere domain infrastructure will compose of strong (mostly already existing) components, which are upgraded as necessary, to fulfil the requirements from international (ESFRI) RIs. The crucial steps needed are:

- identifying the units that are capable of adhering the requirements and assessing their strengths and development needs;
- ensuring the sustainable basis for operations within organizations and along their core strategies, aiming at collaboration and joint use of resources;
- enhancing the scientific excellence by upgrading instrumentation, developing data management practices, opening and harmonizing data flows and training new generations of researchers;
- integrating the operations with a joint national node, capable for achieving scientific and operational maturity enabling Finnish partnership in the European RI initiatives in the field of environmental and ecological sciences.

The steps described above allow a fundamental transformation from sporadic, project based and organization-centred research infrastructures towards a large-scale, integrated Biosphere domain infrastructure, capable of generating useful services more efficiently and sustainably. This will require a paradigm shift for the ecosystem science community in providing and using coordinated RI service structures, as well as integration and sharing of data. The aim is to develop a coordinated and collaborative structure where researchers and public agencies work together to address environmental issues at a range of scales useful for both research and policy tools. By working towards implementing the commonly agreed FAIR data principles (Findable, Accessible, Interoperable and Reusable, www.go-fair.org/fair-principles/) and using common parameters the data will be more interoperable. This calls for extended use of persistent identifiers and offering sustainable models for data citation.

Co-location is one central tool in RI integration. It can greatly improve resource efficiency, reduce redundancy, and help finding operative and managerial synergies to reduce costs. Co-location maximizes also the societal and scientific impact. Co-location means sharing and joint use of basic infrastructure, such as power lines, roads, local servers and other support structures. Co-location includes integra-

tion in technical and operative activities but also in scientific aspects. Sharing skills and knowledge of operative staff at the sites over the organizational boundaries to enhance synergies is one of the main impacts in national scale. In its simplest form of co-location, few RIs operate on the same premises or site. From there the integration can proceed towards true scientific collaboration, scientific breakthroughs and innovations.

In connection to European RIs, there are usually national mirror organizations or national nodes of distributed RI in each member country that contribute to the European scale infrastructures. The task of these nodes is to combine the national interests and excellence and to direct the national efforts so that both the European and national targets for RI are sufficiently met. In Europe, the large environmental RIs remain currently thematically and organizationally separate (although efforts are being done for interoperability and co-location, see ENVRI section in ANNEX 1 and Figure 1). However, on national level, finding synergies to save resources and foster integration at many levels (managerial, operational, scientific) is relatively straightforward under a domain-based umbrella (Figure 2).

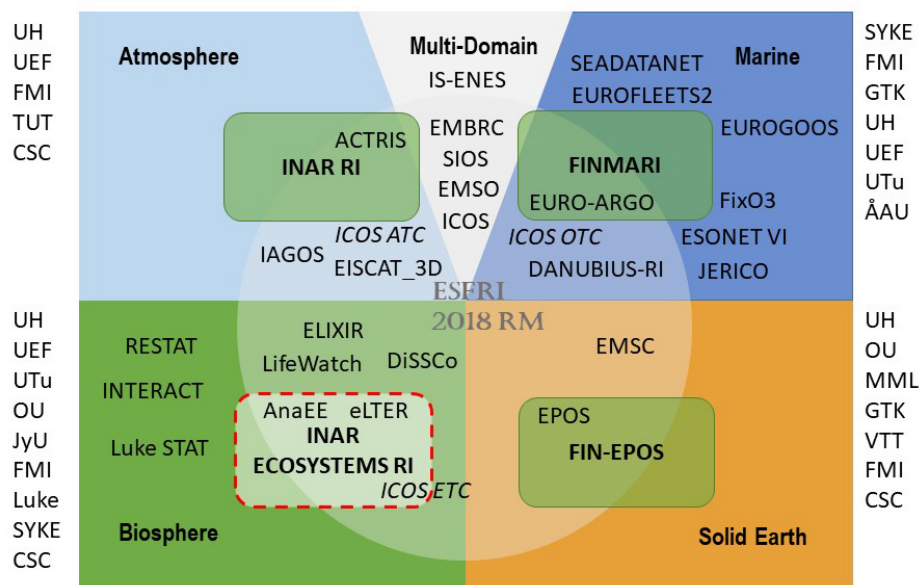


Figure 2. The European RIs in environmental sciences, divided into four domains: Marine, Atmosphere, Solid Earth and Biosphere. Inside the lighter circle are the RIs belonging to ESFRI Roadmap 2018. The rounded squares show the national consortia corresponding the ESFRI roadmap. ICOS is a multi-domain RI having components in Atmosphere (ICOS ATC), Biosphere (ICOS ETC) and Marine (ICOS OTC) domains. ICOS ETC is closely linked to national activities in INAR Ecosystems and similarly the ICOS ATC to INAR RI. Outside the figure: lists of research organizations, which participate in RI operations and development. Figure modified from ENVRI. UH=University of Helsinki, UEF=University of Eastern Finland, FMI= Finnish Meteorological Institute, TUT=Tampere University of Technology, CSC=CSC - IT Center for Science Ltd., UTu= University of Turku, OU=University of Oulu, JyU= University of Jyväskylä, Luke= Natural Resources Institute Finland, SYKE= Finnish Environment Institute, GTK=Geological Survey of Finland, ÅAU=Åbo Akademi University, MML=National Land Survey of Finland, VTT=Technical Research Centre of Finland

The national integration of the umbrella ‘Biosphere RI’ has started with the founding of the **INAR Ecosystems RI** as part of the FIRI 2016 funding call, where it was awarded 1.7 M€ for five years. In INAR Ecosystems, the Finnish organizations performing ecological and environmental research initiated the true development of an integrated ecological and environmental RI in Finland to strengthen the Finnish ecosystem research and its linkages to related disciplines, especially to atmospheric sciences.

3.1 Benefits from integration to Biosphere RI

Synergies are available through integration in management, curation and availability of research data. A requirement of funding agencies is that RI should produce data correspond FAIR principles (see above). Opening and harmonizing data flows create more opportunities for researchers within the same science domain, as well as across domains. Making national ecosystem science data accessible is also a step towards joining European RIs. Through this, the community gets access to European-wide data collections, and optimally these are usable through the services or are described by same metadata vocabulary than the national resources. Additional benefit is the increased publicity of national data products and the recognition and international collaboration possibilities brought by interesting data resources.

The work towards data and metadata integration should benefit from the existing data-oriented European e-infrastructures and national services. This allows taking benefit of investments already made for e-infrastructures. It is also useful to align with selections and policies adopted at the European level. For example, the European LTER infrastructure is a partner of the EUDAT data infrastructure and utilizing especially its services for searching (B2FIND) and storing (B2SHARE) of data, for which integration to LTER's international DEIMS database has started. On national level, it is useful to follow this approach to utilize EUDAT services for data that is to be published internationally. Recently, the European Open Science Cloud (EOSC) initiative has been launched, aiming to act as a common access point for key e-infrastructure services in Europe. The European LTER infrastructure follows developments in EOSC, and it is reasonable to do so also on the national level.

One option to conceptualize the above vision is a **hierarchical site network** (as suggested by Hari et al. 2015 and similar to the one in the accepted eLTER roadmap proposal in 2018, see Figure 3). Such an approach provides efficient tools for questions related to large spatial scales, heterogeneity of ecosystems and their complexity in landscape, and allows application and upscaling of the results to the global level. The hierarchical network also allows organizations to utilize and develop their existing monitoring sites in a more efficient and optimal way, and opens new possibilities for collaboration in research and education, sustaining partnerships between organizations and scientists using the RI. Below, we characterize the hierarchical site network (number in parenthesis is approximate number of sites in Finland we anticipate currently belonging to each category):

1. Flagship (Master) sites (ca 2-5)

- comprehensive measurement strategy covering several environmental domains
- integrated process studies, experimentation, long-term, continuous observations
- located in the main ecosystems and climatic zones
- well-instrumented, extensive services, testbeds for new technologies and methods, platforms for multidisciplinary science initiatives
- fundamental building blocks and co-location of ESFRIs (e.g., ICOS, ACTRIS, eLTER, AnaEE) providing data to international RIs
- both national and international user groups

2. Advanced (Regular) sites (ca 10-15)

- well-equipped and comprehensive in some measurement type or services
- measurement frequency or precision lower than in the Flagship sites
- located in the main ecosystems and climatic zones
e.g. Fluxnet, GAW stations
- possibility to upgrade to Flagship site if so decided (strategic decision by owner organization)
- data usually provided also for international use and databases

- both national and international user groups

3. Basic (Satellite) sites (ca 100)

- location based on practical issues or coverage rather than specific scientific uses
e.g. regional weather stations, forest inventory sites
- low cost for instrumentation and operations, providing ‘background’, basic data
- used for scaling the more detailed measurements to wider areas
- data used and published mainly nationally, or for specific purposes in international networks and databases
- mainly national users

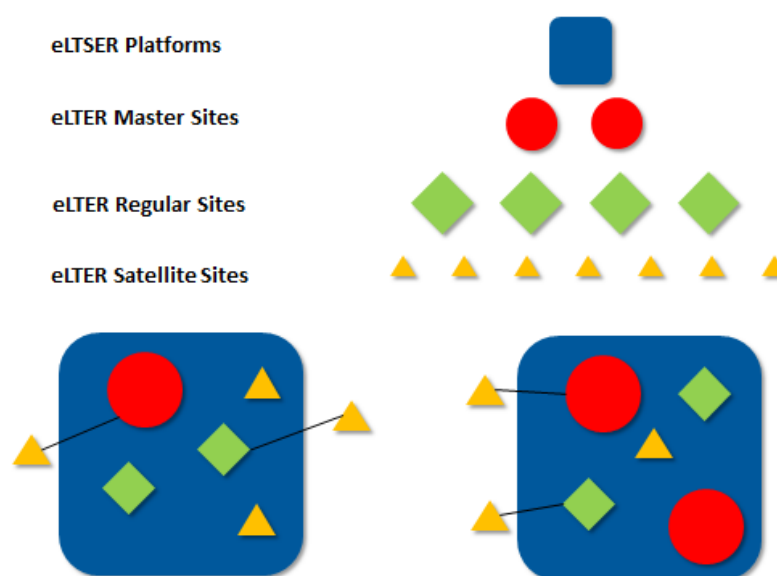


Figure 3. Schematic illustration of the hierarchical site network, with four different categories of sites. Lowest are the satellite sites, in the middle the regular sites and on the top the Master sites. Platforms are larger areas, which can host several different sites. Figure from eLTER.

Examples of similar, large-scale national environmental observatories are e.g. the ‘Terrestrial Environmental Observatories’ (TERENO in Germany and the ‘Terrestrial Ecosystem Research Network’ (TERN in Australia (see ANNEX 2). The TERENO and TERN approach could provide a good model for developing regional-scale ecological and environmental RIs also in Finland.

4 Strategy for integrative approach in Biosphere ESFRI partnering: ICOS-Finland, FinLTSER and AnaEE Finland

The ESFRI Landscape Analysis (ESFRI 2016) has identified the main RIs operating in Europe, including national, regional and international facilities as well as consortia that offer integrated services and transnational access to state-of-the-art resources for research. Of the ESFRI research infrastructures ICOS, AnaEE and eLTER are the most relevant to site-based biosphere domain research. ICOS is the *Integrated Carbon Observing System*, concentrating on greenhouse gas measurements, AnaEE is the *ANALysis and Experimentation of Ecosystems*, and eLTER is the Integrated European Long-Term Ecosystem, critical zone & socio-ecological Research Infrastructure. These RIs are highly complementary in answering the global questions about the state of our environment, sustainability of natural resources, conservation of biodiversity and provision of other important ecosystem services. In addition to these, several support, collaboration and networking activities exist, mostly for predetermined duration and with a project-like operational structure. However, at European scale, a true synergy between different *in situ* RI components is still missing, and additional efforts are needed to bring the communities together.

In a pan-European context, the driving force in environmental RI development is the unifying, global scientific questions, and the aim is to provide scientific excellence in answering them. Finland has become one of the world leaders in atmospheric and environmental sciences, both in terms of science and in coordinating European and global observation station networks. Finland has already taken a leading role in ICOS ERIC (Head Office in Helsinki since 2016) and has identified 13 top level sites which each have their unique features and complement the ICOS site selection (ANNEX 4). In the two other *in situ* RIs, eLTER and AnaEE, Finland also has a great possibility and excellent research units (see ANNEX 5 and 6), capable of contributing to the European landscape via the INAR Ecosystems RI. Our vision will allow active participation in both, with sharing responsibilities among the national organizations according to their specializations and strategies. Participation can include hosting suitable eLTER or AnaEE wide services in Finland. However, this requires long-term, sustainable commitments and therefore careful planning has started under INAR Ecosystems.

The strengths of the Finnish ecological-environmental research community, facilitating the integration are:

- long traditions in collaboration with co-located strong sites in several places (e.g., Hyytiälä, Pallas-Sodankylä);
- large long-term monitoring systems and experiments especially in forests;
- a country-wide research station network placed in strategically important ecoclimatological locations (see ANNEX 3);
- cutting-edge multi-disciplinary science and education;
- prioritisations and commitments of organizations in developing the infrastructures;
- good understanding of RI operations and management;
- strong synergies and joint interests between the universities and research institutes, already manifested in many joint projects;
- expertise on managing environmental research data combined with national data services and close connections to European e-infrastructure.

The timelines of the *in situ* ESFRIs eLTER and AnaEE and the combined timeline for all environmental RIs are illustrated below (Figure 4). The strategy of the INAR Ecosystems RI is to be a central

partner in European eLTER ESFRI process with participation in the Preparatory Phase Project (PPP, 2020-20224), and to construct the national component for eLTER RI (ANNEX 5). Simultaneously, the process of upgrading experimental sites for AnaEE will take place with already existing preliminary site selection (ANNEX 6). The integration allows us to make a balanced proposal of sites for these European RIs, with a clearly defined responsible leading organization in Finland and co-location whenever that is feasible.

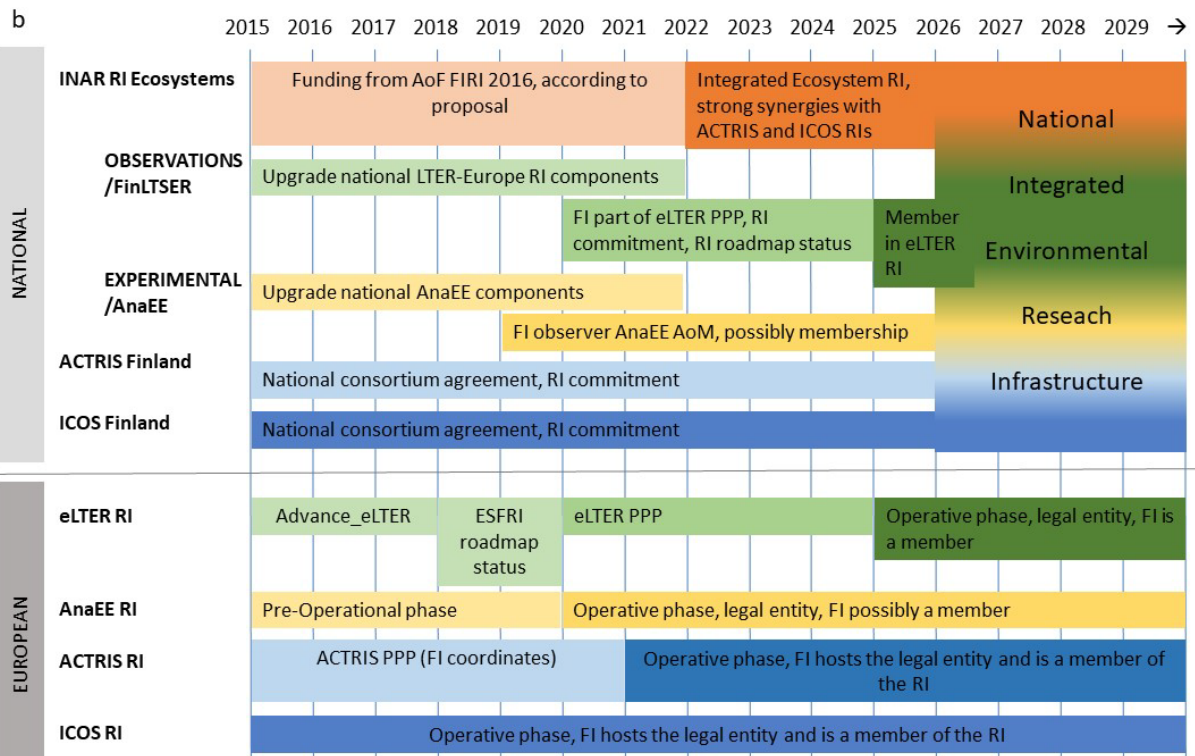
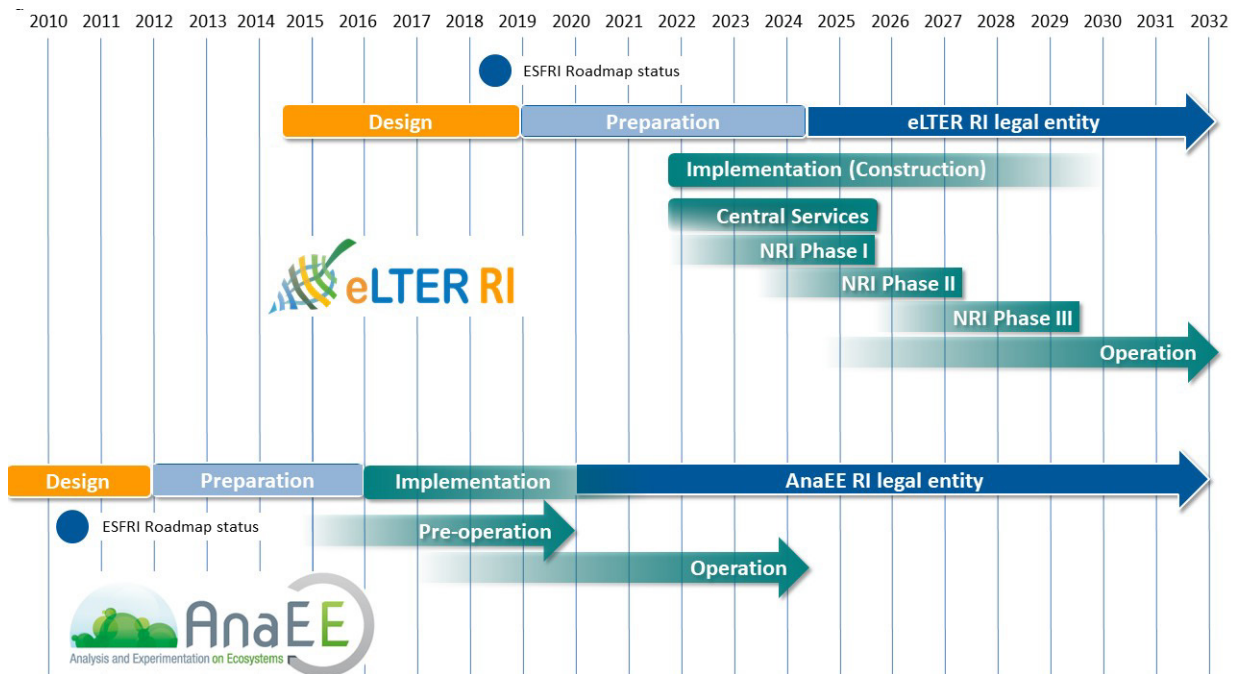


Figure 4. Timelines are planned according the ESFRI processes, and include the integration and coordination of the RI roadmap processes on European and national levels. eLTER (a) and AnaEE (b) and the combined timeline for all environmental RIs (c). Figure a modified from eLTER.

The final target is to find a common ground for integrating all environmental infrastructures nationally and to facilitate such integration in European scale by giving an example and proof of its operations (National Integrated Environmental RI).

The eLTER and AnEE RIs have also complementarities with the existing and planned data and collection ESFRI infrastructures LifeWatch (e-infrastructure for Biodiversity and Ecosystem Research) and DiSSCo (Distributed System of Scientific Collections), as well as Danubius (International Centre for Advances Studies on River-Sea Systems), which is focusing on large river systems. The integration with these is planned within ENVRIplus and its continuation ENVRI-FAIR, where the common landscape is screened and a fruitful dialogue is ongoing within the Biosphere domain.

4.1 Cooperation agreements between the Research Performing Organizations

Formal consortium agreements between organizations have been made in the INAR Ecosystems consortia for dividing the funding awarded for upgrades and construction in the FIRI. During the ESFRI process, national organisations need to define the roles and responsibilities as counterparts of the European RIs with formal MoUs. This is already done for FinLTSER in 2018. We foresee several organizations actively contributing to both national and international process of constructing the AnaEE and eLTER.

5 Summary

This White paper was made in connection with the INAR Ecosystems initiative and updated with proceeding of European processes, and it provides a starting point for national cooperation in environmental research infrastructures.

This document presents a vision of globally leading, scientifically important and socially relevant environmental research infrastructures (RIs) in Finland, and identifies what we consider as the key issues to be developed to improve the impact and to support the Finnish national infrastructures in their international visibility. The focus is on: 1. The scientific questions driving the terrestrial ecosystem and environmental research globally and in Finland; 2. Specific requirements by different user groups in Finland for ecological and environmental RIs; and 3. Roadmap for the sustainable ecological and environmental RI in Finland. We also present the strategies of organizations regarding their RI development, and the existing infrastructures and networks which form the basis for future development.

The final goal is to encourage the development of a coherent vision at national level, and to increase the scientific significance, national synergies and benefits towards a stronger research community.

The need for developing a national RI strategy for environmental field arises from the global challenges, which threaten the ecosystems' functioning. Human activities are imposing many identified, but also previously unknown pressures to ecosystem properties and functions, which are also feeding back to the societies via the quality and quantity of ecosystem services. However, the ecosystem responses to changes in environment are in many cases poorly quantified and the studies only cover short time scales. Pressures such as biodiversity loss, climate change, sustainable use of natural resources and land use demand a holistic research strategy, and therefore the terrestrial ecosystem research is closely linked with the surrounding environment. In order to succeed in providing answers to the grand challenges (ICSU 2010), integrated research infrastructures and efficient analysis tools are crucially needed. The request to improve our knowledge of the state of the environment and the complex biosphere-hydrosphere-atmosphere interactions, and to detect and analyze the impact of global change on these systems has been recognized as a general priority in developing environmental research infrastructures in EU and globally.

Currently, Finland is one of the world leaders in atmospheric and environmental sciences, both in terms of research and in coordinating the European and global observation station networks and infrastructures such as Integrated Carbon Observation System (ICOS) and European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases (ACTRIS). With this existing experience from close-by research fields and the high research outputs from ecology and ecophysiology in our research organizations, Finland has also the potential to actively promote the ecosystem RI concept, and to act as an example and model of integrated RIs for other countries. The vision is to develop the capacity of the Finnish ecosystem research community to integrate, upscale and synthesize the observations with relevant holistic process understanding as well as open and reliable data management practices. This can be implemented by creating functional and cost-efficient in-situ platforms and by providing quality-checked data in findable, accessible, interoperable and reusable (FAIR) manner for high-level environmental research.

This development brings the scientific value of the national in-situ ecological infrastructures into a level where they are both promoting their own organization's scientific and strategic goals, and also capable to actively participate in the European scale site-based Biosphere domain RI projects and legal entities. Examples of such European level projects and RIs are Integrated European Long-Term Ecosystem, critical zone & socio-ecological Research Infrastructure (eLTER), Analysis and Experimentation

on Ecosystems (AnaEE) and ICOS. The development of the capacity of the Finnish ecosystem research community will simultaneously complement the environmental, atmospheric and Earth system RIs, and ensure the forefront position of the Finnish RIs in European and global contexts. It will enable to build up large-scale ecosystem research and monitoring programs to ensure that the importance and condition of natural ecosystems are adequately recognised and managed.

Such integration has been initiated in INAR RI, which aims to integrate the environmental infrastructures particularly ACTRIS, ICOS, and ECOSYSTEM component (eLTER and AnaEE). INAR RI acts as an umbrella RI, taking care of the implementation and national coordination (national focal point) of the ESFRI roadmap infrastructures in the environmental domain in Finland, namely ICOS, ACTRIS, AnaEE and eLTER. INAR RI components form the National Research Infrastructures (NRIs) studying the atmosphere, biosphere and their interactions. The activities in these NRIs are aligned by INAR RI towards common targets in European RI landscape.

All the relevant national research organizations are participating in INAR Ecosystems RI, a project funded by the Academy of Finland FIRI-program (<https://www.aka.fi/en/research-and-science-policy/research-infrastructures/>). It provides a framework for multidisciplinary research and utilizes both experimental (AnaEE) and observational (eLTER) approach. INAR Ecosystems RI is promoting the integration of the Finnish Biosphere domain infrastructures by maintaining and developing highly instrumented research sites, and developing metadata and data interoperability and common services for both internal partners and all stakeholders nationally and internationally. In particular, it focuses on the RIs listed on the roadmap of European Strategy Forum on Research Infrastructures (ESFRI) in the environmental and biological area. INAR Ecosystems has close interaction with key national and European e-infrastructures and aims to utilise their services for data management and analysis. INAR Ecosystems also provides tools for combining the public agency monitoring programmes with data collected for research purposes. It forms a link between the national and international level RIs in Finland and develops a hierarchical RI structure where stations, methods and resources complement each other in a cost-efficient way, supporting also organizations' strategies.

ACRONYMES

- ACTRIS** European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases, www.actris.eu
- AMAP** Arctic Monitoring and Assessment Programme, www.amap.no
- AnaEE** ANALysis and Experimentation of Ecosystems, www.anaee.com
- CAFF** Conservation of Arctic Flora and Fauna, www.caff.is
- CBD** Convention on Biological Diversity, www.cbd.int
- CLRTAP** Convention on Long-Range Transboundary Air Pollution, www.unece.org/fileadmin/DAM/env/lrtap/welcome.html
- CSC** CSC – IT Center for Science Ltd., www.csc.fi
- Danubius** International Centre for Advances Studies on River-Sea Systems, www.danubius-ri.eu
- DiSSCo** Distributed System of Scientific Collections, www.dissco.eu
- DOC** dissolved organic carbon
- EGI and PRACE e-infrastructures as well as one of the key partners in
- eLTER** Integrated European Long-Term Ecosystem, critical zone & socio-ecological Research Infrastructure, www.lter-europe.net/elter-esfri
- ENVRI** the community of the Environmental research infrastructures, projects and networks, envri.eu/home/
- ENVRI-FAIR** ENVironmental Research Infrastructures building Fair services Accessible for society, Innovation and Research, envri.eu/envri-fair/
- EOSC** European Open Science Cloud, www.eosc-portal.eu
- ESFRI** European Strategic Forum on Research Infrastructures, www.esfri.eu
- EUDAT** Collaborating data infrastructure, eudat.eu
- FAIR** Findable, Accessible, Interoperable and Reusable, www.go-fair.org/fair-principles/
- FinBIF** The Finnish Biodiversity Information Facility; a national data center for biodiversity information, laji.fi/en
- FIRI** Finnish Research Infrastructure, <https://www.aka.fi/en/research-and-science-policy/research-infrastructures/>
- FMI** Finnish Meteorological institute, en.ilmatieteenlaitos.fi/
- GAW** Global Atmosphere Watch, www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html
- GBIF** The Global Biodiversity Information Facility, www.gbif.org/en
- GEO-GEOSS** Group on Earth Observations - Global Earth Observation System of Systems, www.earthobservations.org/geoss.php
- GHG** greenhouse gas
- ICOS** Integrated Carbon Observing System, www.icos-ri.eu
- ICP Forest** Pan-European International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forest, www.unece.org/fileadmin/DAM/env/lrtap/WorkingGroups/wge/forests.htm

- ICP IM** the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems, www.unece.org/fileadmin/DAM/env/lrtap/WorkingGroups/wge/im.htm, www.syke.fi/nature/icpim
- ICP M&M** the International Cooperative Programme on Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends, www.unece.org/fileadmin/DAM/env/lrtap/WorkingGroups/wge/mapping.htm
- ICP Waters** the International Cooperative Programme for assessment and monitoring of the effects of air pollution on rivers and lakes, www.unece.org/fileadmin/DAM/env/lrtap/WorkingGroups/wge/waters.htm
- INAR Ecosystems** Institute for Atmospheric and Earth System Research – Ecosystems, www.helsinki.fi/en/inar-institute-for-atmospheric-and-earth-system-research/inar-ri-ecosystems-0
- INAR** Institute for Atmospheric and Earth System Research, www.helsinki.fi/en/inar-institute-for-atmospheric-and-earth-system-research
- IPBES** Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, www.ipbes.net/
- JyU** University of Jyväskylä, www.jyu.fi/en
- LifeWatch** e-infrastructure for Biodiversity and Ecosystem Research, www.lifewatch.eu
- Luke** Natural Resources Institute Finland, www.luke.fi/en
- LUOMUS** Finnish Museum of Natural History, www.luomus.fi/en
- Metla** Finnish Forest Research Institute, www.luke.fi
- NECD** National Emission Ceilings Directive, www.eea.europa.eu/themes/air/national-emission-ceilings/national-emission-ceilings-directive
- NFI** National Forest Inventory, www.luke.fi/en/natural-resources/forest/forest-resources-and-forest-planning
- NRIs** National Research Infrastructures
- RESTAT** The Finnish network of university research stations, www.researchstations.fi/indexeng.html
- RI** Research infrastructure
- RPOs** Research Performing Organizations
- SITES** Swedish Infrastructure for Ecosystem Science, www.fieldsites.se/en-GB
- SLCPs** short-lived climate-forcing pollutants
- SMEAR** Station for Measuring Earth Surface - Atmosphere Relations, www.atm.helsinki.fi/SMEAR
- SYKE** Finnish Environment Institute, www.syke.fi/en-US
- TERENO** Terrestrial Environmental Observatories (in Germany), http://www.tereno.net/overview-en?set_language=en
- TERN** Terrestrial Ecosystem Research Network (in Australia), tern.org.au
- UAS** unmanned aircraft systems
- UEF** University of Eastern Finland, www.uef.fi/en/etusivu

UH University of Helsinki, www.helsinki.fi/en
UO University of Oulu, www.oulu.fi/university
UTu University of Turku, www.utu.fi/en

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ANNEX 1. Characteristics of the current ecological and environmental research infrastructure landscape in Finland; history, specialization, users, funding structure, services

INAR RI (Integrated Atmospheric and Earth System Science Research Infrastructure)

INAR RI aims to integrate environmental infrastructures particularly ACTRIS, ICOS, and ECOSYSTEM component (eLTER and AnaEE). INAR RI acts as an umbrella research infrastructure, taking care of the implementation and national coordination (national focal point) of the ESFRI roadmap infrastructures in the environmental domain in Finland, namely ICOS, ACTRIS, AnaEE and eLTER. INAR RI components form the National Research Infrastructures (NRIs) studying the atmosphere, biosphere and their interactions. The activities in these NRIs are aligned by INAR RI towards common targets in European RI landscape. INAR RI is in the Finnish national RI roadmap 2014-2020.

It functions as a distributed infrastructure that includes components from the University of Helsinki (lead), the Finnish Meteorological Institute, the University of Eastern Finland, Tampere University of Technology, CSC – IT Center for Science, and Luke (Natural Resources Institute Finland). The main goal of INAR RI is to guarantee the world-class research facilities in order to enable the internationally state-of-the-art science in the field of atmospheric and Earth system research and to ensure the forefront position of the Finnish INAR research infrastructure in Europe and in global context. INAR Ecosystems forms an integral part of the INAR RI with the in situ ecosystem observations and experimentation.

INAR RI belongs to the University of Helsinki strategic core areas, and it has been included in the recently founded unit INAR Institute (active from the beginning of 2018). INAR RI has been funded by the Academy of Finland FIRI-funding instrument in three separate calls: in 2013, 2014 and also recently in 2017 (INAR Ecosystems). The INAR Ecosystems sits in the core of the above suggested integration, as it covers all organizations currently active in Biosphere domain research in Finland (UH, FMI, UEF, JyU, UO, UTu, Luke and SYKE).

INAR research strategy is based on combining process-level understanding with comprehensive, long-term field measurements in investigating the couplings between the biosphere and atmosphere on one hand, and on the need for complementary approaches relying on the combination of field data, laboratory and field experiments, satellite observations and model simulations on the other hand.

Key INAR RI components are the four SMEAR (Station for Measuring Earth Surface - Atmosphere Relations) stations in Värriö, Hyytiälä, Helsinki and Kuopio, and the Pallas-Sodankylä Global Atmospheric Watch station. These stations are continuously operational (SMEAR I in Värriö since 1991) and can be used by INAR partners and other members of the scientific community based on joint agreements. The data produced in these stations are openly available and feed in European and global databases. The SMEAR II in Hyytiälä Forest Field Station is a versatile and sustained flagship station operating 24/7 since 1996. SMEAR stations, due to their comprehensive instrumentation, are contributing to several, co-located RI networks, as well as European and Global RIs, by providing access to research data, access to site, and education. The INAR RI services are being systematically developed, to fulfil the requirements of the research community and society in general.

University field station network (RESTAT)

The Finnish network of university research stations (RESTAT Finland) is unique and acknowledged in several international evaluations (www.researchstations.fi). The network includes 10 field stations of various sizes; larger ones can host more than 100 students/researchers (Lammi and Hyytiälä) while smaller ones the capacity is some tens of users. These stations belong to the universities of Helsinki (6

stations), Turku (2), Oulu (2), Jyväskylä (1) and Åbo Academy (1). The oldest of the stations are Tvärminne Zoological Station (founded 1902) and Hyytiälä (1910) while the youngest is Konnevesi Research Station (1983). Stations are originally founded to fulfil the needs of individual universities. During the recent decades the stations have created their own research profiles which are largely determined by their discipline and biogeographical locations. These research stations have only few or no researchers of their own. Therefore, the stations mainly provide just facilities and services to the visiting scientists that are coming from their own university but also from other universities all over the world as well as governmental institutes.

Typically all the stations collect environmental data for background information to the various research projects. The stations are equipped with various research devices, which are nowadays often sophisticated automatic measurement devices. The larger stations have also well-equipped laboratories and facilities for experimental research.

List of Research stations is in ANNEX 3.

Other University-owned facilities (laboratories, test fields, greenhouses, etc.)

Most universities possess ecosystem research infrastructure components in their main campuses, including field and greenhouse trials, laboratory-scale experimental facilities and similar. Some of these are technologically well advanced and can, with some upgrading, fulfil the criteria of AnaEE RI (e.g. the Viikki Agricultural Production Laboratory VAPL and Algalab [UH], Kuopio Ecotrons and Joensuu UV-B/warming field [UEF], and Oulu Physiological Laboratory [UO]). However, most of them have been built by departments and research groups for specific purposes, and are not designed to modify their operations to opening for wider user communities. This needs therefore careful planning and strategic decisions from the owner organizations.

For example, Turku University hosts the National pollen monitoring and information by Aerobiology Unit. The unit has conducted continuous monitoring of airborne biological particles in Turku with Burkard pollen and spore traps since 1974. At present air particle samples are continuously collected at nine Finnish locations.

Infrastructures for the environmental and ecological research in Ylistö campus of JyU offer modern instrumental and analytical facilities expected of an active research in ecological and environmental science. Specialist facilities include DNA laboratory with automated DNA sequencing as well as DNA fragment analysis and a quantitative PCR instruments, a stable isotope analytical laboratory for ecosystem research, experimental animal unit, extensive experimental aquarium facilities and greenhouses. The Natural History Museum serves as an archive for natural scientific research, and displays environmental subjects and research material. Infrastructures for the environmental and ecological research in JyU employs 13 technical staff, including specialist research technicians, general laboratory technicians, and workshop and data management staff. Ylistö campus connects researchers in natural resources and environmental science from Luke, SYKE and JyU since the Luke and SYKE regional offices located in the campus. Versatile field equipment such as all-terrain vehicles, boats, samplers, traps, meteorological stations, portable field measuring systems as well as data management systems for aquatic and terrestrial research are in joint use.

Luke station & site network: history, specialization, users, services

Luke is present throughout the whole country from southern Finland up to northernmost point of Finland. Network of field research station and sites, experimental research forest sites and monitoring sites covers the whole country. The total number of sites will be in future 25. These sites have a long history; oldest experiments are over 100 years old. These sites with long history are concentrated mainly in for-

est and agricultural research. Game and fish research sites with monitoring networks have been operational since 1970's. Main laboratory facilities of Luke with high quality infrastructure are located in five sites, namely in Viikki (Helsinki), Joensuu, Oulu, Rovaniemi and Jokioinen, some of them in collaboration with local university. In the field research stations there are mainly facilities to conduct different kind of field measurement and to do some minor laboratory work. In addition, there are also office premises. The technical staff assisting in operational fieldwork is available at the stations.

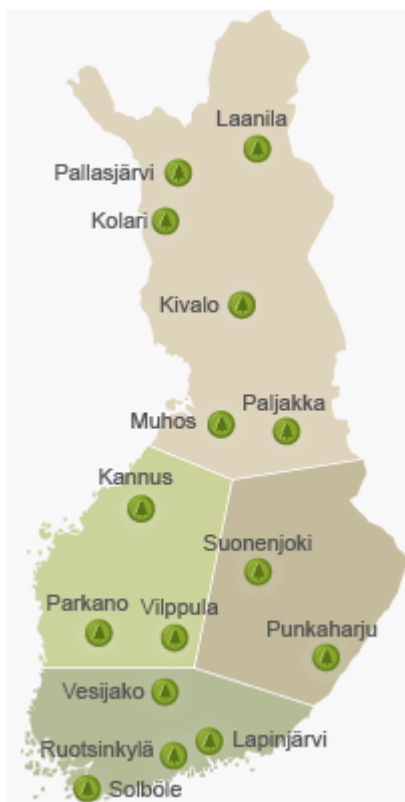


Fig. A1. Experimental research forest sites of Luke cover the whole Finland. Figure from Luke.

Environmental data management infrastructures

Environmental data management infrastructure on national level is being developed to complement the data management at the institutions and research stations. Central role for national research data management is with CSC - the national IT infrastructure for research. CSC provides a variety of data management and analysis services which are interoperable with international data services. For example, real-time data from SMEAR measurement stations in Finland have been transferred to CSC's data platform already for several years. This data is now available through a data portal, Smart SMEAR, offered by CSC with support from the national Open Science and Research programme. The portal allows users to visualize and download data over selected time period and set of variables, thus making the data discovery for research more efficient.

CSC also coordinates the European Collaborative Data Infrastructure EUDAT, which is offering data management services for the full research data lifecycle - including storage, sharing, identifying, and analysing of data. The eLTER research infrastructure has collaboration with the EUDAT aiming to take up some of their services for data search and storage, supporting the infrastructure's own DEIMS data service. In addition, European Commission is investing heavily on data infrastructures through European Open Science Cloud (EOSC) programme. Several Finnish institutes are participating in EOSC

related projects, for example EOSC Hub, ENVRI-FAIR, EOSC secretariat and EOSC-Nordic. These build the services and capacities for environmental science to make their data FAIR (Findable, accessible, interoperable and reusable) on European level.

Utilising these services have great potential to improve the visibility and availability of Finnish research data on environment for the national and international research communities, thus increasing the impact of data generated in Finland. On the other hand, the services also facilitate the usage of international data in research performed at Finnish institutes, thus enabling more and better research.

International RIs (ESFRIs and international networks)

ICOS ERIC and ICOS Finland

ICOS RI (www.icos-ri.eu) provides the long-term observations required to understand the present state and to predict future behavior of the global carbon cycle and greenhouse gas emissions. The objectives of ICOS RI are to provide effective access to a single and coherent data set to facilitate research into multi-scale analysis of greenhouse gas emissions, sinks and the processes that determine them, and to provide information, which is profound for research and understanding of regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. ICOS RI tracks carbon fluxes in Europe and adjacent regions by observing the ecosystems, the atmosphere and the oceans through integrated national station networks. Currently (by end of 2018) ICOS RI consists of more than 130 measurement stations, of which over 80 ecosystem, 30 atmosphere and 20 ocean stations.

ICOS Central Facilities provide support and services to the ICOS station networks and takes care of the data processing. ICOS data is distributed to the users via ICOS Carbon Portal.

ICOS ERIC has currently 11 Member countries and one Observer country. The Joint Research Centre contribute to the ICOS station network with one ecosystem and one atmosphere station. The legal entity ICOS ERIC has its statutory seat in Finland, where the Head Office is located. Finland has committed to ICOS RI on governmental level for decades.

ICOS Finland is part of ICOS RI. It has three partners, UH (coordinator), FMI and UEF. ICOS Finland has altogether 13 stations, the 9 ecosystem stations are listed in ANNEX 4. The special mission for the ICOS Finland is to study the sinks and sources of greenhouse gases for typical boreal ecosystems. The focus is on coniferous forests, wetlands and the Baltic Sea.

The Finnish partnership brings several advantages and added-value for ICOS in expertise and areal coverage. The Finnish sites represent the boreal and sub-arctic Eurasian environments with both east-west and south-north transitions in eco-climatic features. Atmospheric research is national priority research area in Finland. Large infrastructures in Finland for atmospheric research are in the forefront of research and technical development. The ICOS RI studies are also closely linked with other trace gases and atmospheric aerosols. FMI hosts the Mobile Laboratory, part of the Atmosphere Thematic Center of ICOS RI.

LTSER and FinLTSER

The key feature of LTSER is its long-term approach to determine the impacts of drivers and pressures of environmental change and to investigate ecosystem processes and their response to environmental pressures. Many of the central ecological processes and problems, such as biodiversity changes and effects of climate change on biogeochemical cycles, take place over the long time scales and gradually. Short-term projects are not enough to elucidate trends in global change and the effects of policies on environ-

ment. A permanent infrastructure is therefore required for monitoring these changes. European LTER infrastructure network (LTER-Europe, www.lter-europe.net) was established in 2003 to cover this need.

The eLTER H2020 (2016-2019) and Advance-eLTER (2018) projects provided a solid design study and clear vision on implementation of the eLTER RI towards a legal entity under the leadership of Germany. In 2018, eLTER was accepted in the ESFRI Roadmap as ESFRI project. The Preparation Phase Project (eLTER PPP) funded by European Commission will start in February 2020. eLTER PPP aims at developing for example the governance and financial structures of the infrastructure. In the same time, a second project, eLTER PLUS, also funded by European Commission, will start. eLTER PLUS would be a research project continuing the work of eLTER H2020 and focusing on network activities as well as scientific questions that eLTER RI could answer. The Finnish national node, FinLTSER (www.helsinki.fi/en/inar-institute-for-atmospheric-and-earth-system-research/finltser-finnish-long-term-socio-ecological-research-network), aims to be an integrated, multi-functional, well-instrumented network of infrastructures for ecological and socio-ecological research and monitoring. FinLTSER is also a research network of scientists, collectively engaged in and dedicated to multi- and interdisciplinary long-term and large spatial scale research and monitoring in ecological entities including the human dimension. These long-term ecosystem research platforms support, enhance and promote the interdisciplinary investigation of long-term biodiversity and eco-system processes at varying spatial and temporal scales. FinLTSER is based on the field stations of the universities as well as other research and monitoring infrastructures of the participating governmental research institutes (SYKE, Luke, FMI). The need for a national FinLTSER-type system was recognized by external top-level scientists in both the evaluation reports of 'Water Research in Finland' and 'Ecology and Evolutionary Biology in Finland' 2006-2010 (Academy of Finland 2008 and 2012, respectively). FinLTSER is a formal member network of the European LTER network.

In FinLTSER, the collection of long-term data series at regular intervals using consistent methods takes place at sites that are well-equipped with instrumentation and other facilities to support long-term research and monitoring. LTSEER approach emphasizes long-term information management. Consistent data collection and meticulous data stewardship aim to maintain continuity, integrity and availability of the long-term data series. Information infrastructure supports the use and reuse of data throughout their protracted lifecycles by provisioning access to data and data sharing that are integral for interdisciplinary research collaboration in FinLTSER.

ANNEX 5 lists the current FinLTSER sites and platforms.

ANAEE and AnaEE Finland

AnaEE (Analysis and Experimentation in Ecosystems, <http://www.anaee.com/>) is on the ESFRI roadmap since 2010, and currently in pre-operational phase, led by France (PP funded by EU/FP7, 2011-2016, 13 countries participated in PP). AnaEE is a pan-European research infrastructure for experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems. A key property of all AnaEE platforms is their capacity to do ecosystem-scale manipulations, i.e. experimental testing of ecosystem responses to different human-induced or natural pressures and drivers. The main pressures/drivers that are manipulated are climate change- and ecosystem management- related.

Partners in the pre-operational phase are currently France (host), Belgium, Denmark, Czech Republic, Israel, Italy and Finland. AnaEE-ERIC, when operational, is aiming at providing high quality services in (a) experimental field sites (open field), (b) ecotrons and other in vitro facilities (enclosed platforms), (c) analytical laboratories and (d) modelling facilities. The AnaEE Technology Center is hosted by Denmark, the Analysis and Synthesis Center by Czech Republic, and the Data and Modeling Center by Italy.

AnaEE organized a Call for Expression of Interest for experimental sites in 2014-15, targeting to cover all climate zones and different manipulations of pressures and drivers in the main terrestrial ecosystems in Europe. The call resulted in altogether 38 responses from Finland, including 20 In Natura, 11 In vitro, 6 analytical and 2 modeling facilities. A second round with more specific criteria was done in fall 2015, which resulted to 11 in Natura, 8 in Vitro, 4 Analytical ja 1 Modelling facilities. Site selection is still ongoing in the pre-operational phase.

Table of the Finnish submitted AnaEE platforms in 2015 is in ANNEX 6.

LifeWatch, GBIF and FinBIF, DiSSCo

LifeWatch ERIC (e-Science and Technology European Infrastructure for Biodiversity and Ecosystem Research) was established in March 2017, and is hosted by Spain. LifeWatch advances Biodiversity and Ecosystem Research by including knowledge-based solutions to environmental managers, by providing access to a multitude of sets of data, services and tools enabling the construction and operation of Virtual Research Environments (Virtual Laboratories & Decision-support Applications) where specific issues related with biodiversity, and ecosystem research and preservation are addressed. As LifeWatch is a virtual infrastructure concentrating on biodiversity data, it complements the INAR Ecosystems in situ infrastructures in many ways.

The Global Biodiversity Information Facility (GBIF) is an international open data infrastructure, funded by governments. It allows anyone, anywhere to access data about all types of life on Earth, shared across national boundaries via the Internet. The Finnish Biodiversity Information Facility (FinBIF) is a national data center for biodiversity information. It is set up by the Finnish Museum of Natural History (LUOMUS) through a three-year project in 2015 - 2017. The project is a component of a larger aggregate project Envibase administrated by the Finnish Environment Institute (SYKE). FinBIF develops methods and tools to support e.g. biodiversity monitoring and research. One of the main aims of the project is to promote and apply open data concept. The core information such as taxonomy and location data will be unified, which allows combining data from different data sources to one data warehouse. A new observation and monitoring system as well as a collection management system open to all Finnish collections of natural history are also under development. FinBIF is a national service supporting species-related research, management, teaching, and life-long learning. It collects, archives, and distributes Finnish electronic datasets on biodiversity and provides visualisation and analysis tools in one single portal.

The DiSSCo (Distributed System of Scientific Collections) initiative is aiming for the ESFRI Roadmap 2018 and several Finnish partners have signed a MoU (Luomus, OY, TY, ISY). In DiSSCo, the emphasis is on bio- and geodiversity. At the moment, the process of DiSSCo RI is still in initial phases but there is potential of developing joint activities for example with large historical datasets existing e.g. in eLTER.

ACTRIS and ACTRIS Finland

ACTRIS (Aerosols, Clouds, and Trace Gases Research Infrastructure) is the pan-European initiative that consolidates strategies amongst European partners for observation of aerosols, clouds, and trace gases. Finland (INAR RI Partners) leads the ACTRIS Preparatory Phase Project (2017-2019). When implemented, ACTRIS focuses on producing high-quality observations of clouds and short-lived climate-forcing pollutants (SLCPs). Short-lived atmospheric components have a residence time in the atmosphere from hours to few weeks, which differentiates them from long-lived greenhouse gases. The short lifetimes make their concentrations highly variable in time and space and involve fast processes. The

infrastructure is unique in providing the 4D-variability of reactive trace gases, clouds and of the physical, optical and chemical properties of short-lived atmospheric species.

ACTRIS is a distributed infrastructure consisting of National (observing stations and exploratory platforms) and Central Facilities (Calibration Centres, Data Centre, Head Office) that serve a vast community of users working on models, satellite retrievals, and analysis and forecast systems. Atmospheric predictions of all kinds use complex models that are underpinned by observations. Without high-quality observation data to constrain predictive models, any forecasts of the atmosphere are highly unreliable. Without a ground-truth capability, satellite sensors cannot be accurately validated.

Monitoring sites based on international treaties and authoritative obligations

Data from long-term monitoring sites maintained by the national research institutes complements the data from the highly instrumented research sites, and together with data from remote sensing and national databases, also provides the means for upscaling the information from the site level to regional scales.

The Finnish network for intensive forest monitoring is the largest and most diverse biomonitoring infrastructure in the boreal region, and it combines the expertise from two major research organizations, Luke and SYKE. It includes 12 (partly 14) observation plots located in coniferous forests representing different fertility levels along a climatic gradient. The majority of the plots are located on conventionally managed forests dominated by either Norway spruce or Scots pine. Forest ecosystems are diversely monitored on these plots, with the aim of cause-effect analysis. Deposition of air pollutants, the cycles and leaching fluxes of nutrients, defoliation, abiotic and biotic damage, growth, nutrient status and understorey vegetation are among the attributes monitored. Meteorological measurements are conducted by the Finnish Meteorological Institute. The data gathered since 1995 is stored in a database providing valuable information for further studies. Nine of the plots have been electrified. A forest technician visits all plots monthly for sample collection.

The multidisciplinary International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (UNECE CLTRAP ICP IM) (<http://www.syke.fi/nature/icpim>) quantifies air pollution and climate change effects on the environment through simultaneous physical, chemical and biological monitoring, modelling and scientific review using data from undisturbed well-defined forested catchments. ICP IM is part of the Effects Monitoring Strategy under the Convention on Long-Range Transboundary Air Pollution (LRTAP Convention). ICP IM will also be an essential framework for monitoring of effects of pollutants in the environment under the proposed new National Emission Ceilings Directive (NECD). At present 16 European countries with 44 study sites are involved in ICP IM Programme. The Finnish ICP IM network was established in 1987 and consists of three highly instrumented and intensively monitored research infrastructures (Kotinen, South Finland; Hietajärvi, East Finland and Pallas, North Finland). Several collaborating governmental research institutes and universities are connected to the Finnish ICP IM program: meteorological measurements and monitoring of deposition of air pollutants are carried out by Finnish Meteorological Institute, biomonitoring of forests are carried out by National Resources Centre Finland and monitoring of hydrology, water chemistry and hydrobiology are carried out by Finnish Environment Institute (SYKE), National Resources Institute Finland (Luke) and Universities of Helsinki and Eastern Finland. The international Programme Centre of ICP IM is located in Finnish Environment Institute.

Support, collaboration and networking activities

INTERACT 2

INTERACT is an infrastructure project funded by EU H2020. It is a circum-arctic network of currently 76 terrestrial field bases in northern Europe, Russia, US, Canada, Greenland, Iceland, the Faroe Islands and Scotland as well as stations in northern alpine areas. INTERACT seeks to build capacity for research and monitoring in the European Arctic and beyond, and is offering access to numerous research stations through the Transnational Access program.

The project has a main objective to build capacity for identifying, understanding, predicting and responding to diverse environmental changes throughout the wide environmental and land-use envelopes of the Arctic. INTERACT is multidisciplinary: together, the stations in INTERACT host thousands of scientists from around the world who work on projects within the fields of glaciology, permafrost, climate, ecology, biodiversity and biogeochemical cycling, including the human dimension. The INTERACT stations also host and facilitate many international single-discipline networks and aid training by hosting summer schools.

INTERACT station managers and researchers have established partnerships that are developing more efficient networks of sensors to measure changing environmental conditions and the partnerships are also making data storage and accessibility more efficient. New communities of researchers are being offered access to Arctic terrestrial infrastructures while local stakeholders as well as major international organizations are involved in interactions with the infrastructures. The trans-national access component is crucial to building capacity for research in the European Arctic and beyond.

EU-PolarNet

EU-PolarNet is an EU funded consortium of expertise and infrastructure for polar research, including both Arctic and Antarctic. Seventeen countries are represented by 22 of Europe's internationally-respected multi-disciplinary research institutions. EU-PolarNet aims to improve co-ordination between EU member polar research institutions building on existing networks to create a resource orientated infrastructure access and usage plan. This plan would allow for the co-ordination of data and infrastructure between all the partner organizations. EU-PolarNet will develop an integrated EU Polar research programme by identifying short and long-term scientific needs and optimising the use of co-ordinated Polar infrastructure for multi-platform science missions whilst fostering trans-disciplinary collaboration on Polar research.

ENVRI

ENVRI is a cluster of major (ESFRI level) research infrastructures (RI) around European Environmental and Earth System sciences. This cluster is aimed towards common development of RI services in the environmental domain, improving the ability of these services to work on interdisciplinary grand societal challenges. These activities have been supported by several European Commission funded projects, as well as other similar activities.

ENVRIplus was a EC funded project (2016-2019) driven by 3 overarching goals: 1) favouring cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment to an increasing number of users outside the RIs. It aimed to improve Earth observation monitoring systems and strategies, including actions towards harmonization and innovation, to generate common solutions to many shared information technology and data related challenges, to harmonize policies for access and provide strategies

for knowledge transfer amongst RIs. ENVRIplus also developed guidelines to enhance trans-disciplinary use of data and data-products together with e-infrastructures and coordinated actions to improve communication and cooperation, addressing Environmental RIs at all levels. 21 European RIs were partners in ENVRIplus, including LTER and AnaEE, represented by their European coordinators.

ENVRI-FAIR (ENVironmental Research Infrastructures building Fair services Accessible for society, Innovation and Research) is the follow-up project and the connection of the ENVRI cluster to the European Open Science Cloud (EOSC). The aim of the project is that all participating RIs have built a set of FAIR data services which enhance the efficiency and productivity of researchers, support innovation, enable data- and knowledge-based decisions and connect the ENVRI Cluster to the EOSC. This means that ENVRI-FAIR will develop further the common standards and policies for data life cycle, cataloguing, curation, provenance and service provision within ENVRI RIs and develop and implement in each RI the necessary tools and adopt an open approach to sharing data and software. It will also include improving skills of personnel in the RIs to develop and maintain the FAIR infrastructures through extensive training programs and increasing the potential for innovation of each RI by establishing a specific ENVRI-FAIR service catalogue section in the EOSC catalogue. One important aspect is establishment of cohesion with global RI landscape, incl. RI clusters and regional/international initiatives in the environmental sector.

Large (historical and current) datasets and collections: LUKE VMI as an example

The National Forest Inventory NFI of Luke is a monitoring system that produces information concerning national and regional

- forest resources - volume, growth and quality of growing stock,
- land use structure and forest ownership,
- forest health,
- biodiversity of forests, and
- forest carbon stocks and their changes.

The national forest inventories form an unique time series of the development of forests in Finland: The first NFI in Finland was carried out already in 1920's (NFI1 1921–1924). It was among the first inventories in the world based on statistical sampling. Since then NFIs have been made regularly in 5–10 years cycles.

Forest resource information produced by NFIs are based on extensive field measurements. In first inventories, lines through the country were surveyed but in recent inventories systematic sampling and field plot measurements (totally 60 000 plots) have been used. The field plots are located in clusters that form a regular network over the whole country. The multi-source NFI utilizes several data sources: field measurements, satellite images and digital maps. With this method, forest statistics and thematic maps can be produced for any given area.

ANNEX 2. Examples from elsewhere

i. TERN (Australia)

TERN (Terrestrial Ecosystem Research Network, tern.org.au) is a continent-wise coordinated research infrastructure in Australia and New Zealand. It consists of components such as i) ecological plot-based facilities (AusPlots, Australian Transect Network, Long Term Ecological Research Network, OzFlux and Australian SuperSite Network), ii) biophysical data collection facilities (AusCover, Soil and Landscape Grid, Australian Coastal Ecosystems Facility (ACEF)), iii) storing, accessing and discovering data (Data Discovery Portal, Eco-informatics Facility, Advanced Ecological Knowledge and Observation System) and iv) analysing, modelling and synthesizing data and information (Ecosystem Modelling and Scaling Infrastructure Facility, Australian Centre for Ecological Analysis and Synthesis).

TERN's infrastructure is designed to examine Australian ecosystems and ecosystem processes at different scales from targeted monitoring at the local level, through to surveillance monitoring at regional scales, through to continental scale observation and modelling. TERN delivers: i) Ecosystem data and the programs to collect it including plot data from surveillance and targeted monitoring programs; gas, energy, and nutrient exchanges; remote sensing data; modelled data products about soil, climate, and landscape attributes; and vegetation and soil samples for physical analysis; ii) Tools for the research community including national consistent field methods, data collection apps, and data publishing tools; and iii) Data infrastructure that supports discovery, access, and re-use of ecosystem data collected by TERN and others. The key areas are climate, land, biodiversity, and data. Below is illustration of the different scales in spatial coverage and data richness that TERN addresses.

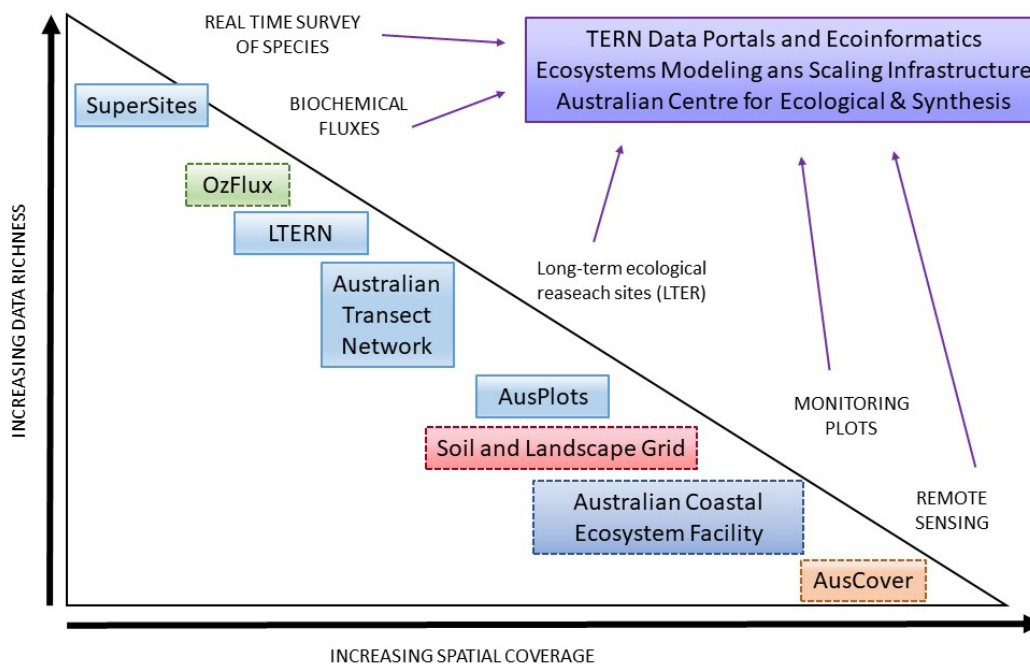


Figure A2.1. The TERN spatial coverage and data richness. Figure from Lowe et al. 2017.

ii. TERENO (Germany)

TERENO (Terrestrial Environmental Observatories, www.tereno.net/overview-en?set_language=en) is an interdisciplinary and long-term research programme involving six Helmholtz Association Centers.

TERENO spans an Earth observation network across Germany that extends from the North German lowlands to the Bavarian Alps. This unique large-scale project aims to catalogue the long-term ecological, social and economic impact of global change at regional level. The main goal of the infrastructure measure TERENO will be to create observation platforms on the basis of an interdisciplinary and long-term aimed research program with a close cooperation between several facilities of the Helmholtz-Gemeinschaft for the investigation of consequences of Global Change for terrestrial ecosystems and the socioeconomic implications. TERENO will provide long-term statistical series of system variables for the analysis and prognosis of Global Change consequences using integrated model systems, which will be used to derive efficient prevention, mitigation and adaptation strategies.

TERENO Vision and Challenge

Predicting terrestrial processes from remote information



Courtesy of TERENO

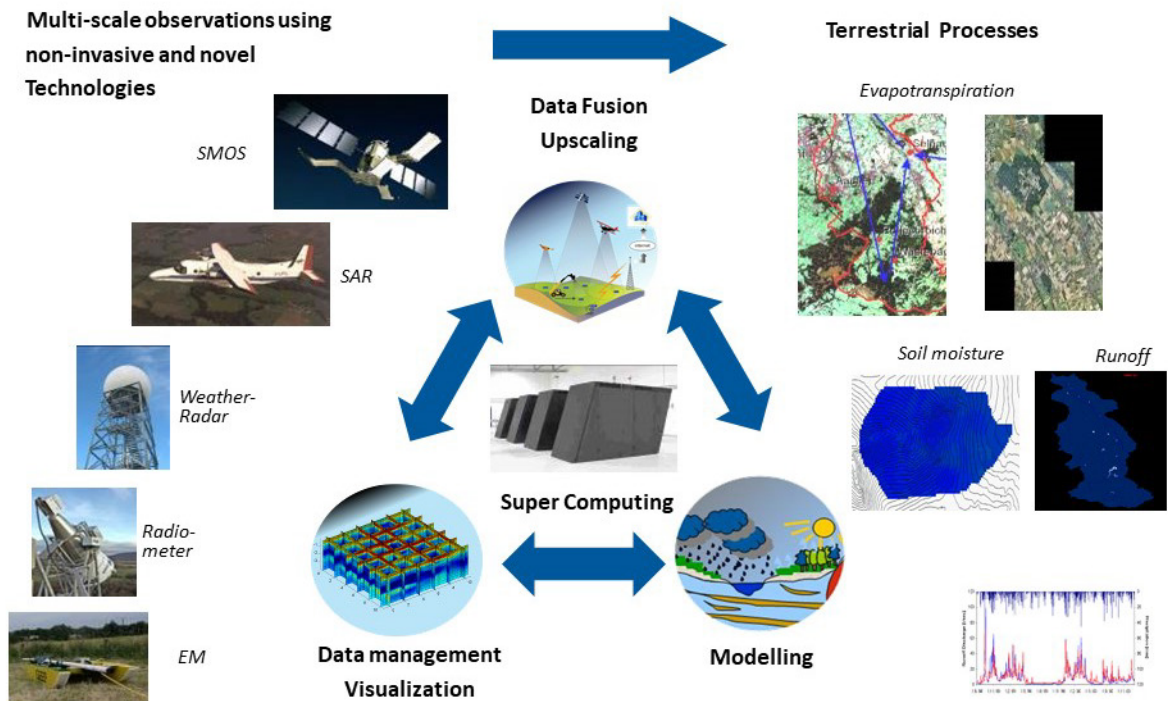


Figure A2.2. The TERENO vision and challenge. Figure from TERENO.

The homogeneous long-term data sets provided by TERENO will significantly foster the validation, advancement and integration of terrestrial models (e.g. groundwater and soil water balance models, regional climate and weather prognostic models, air quality models, runoff and forest/agronomic models as well as diversity and socioeconomic models). Integrated model systems will significantly support the management of agronomic and forest ecosystems (e.g. optimisation of irrigation systems as well as development of warning systems for extreme weather occurrences and flooding, integrated control systems of water management constructions, and monitoring systems for air, groundwater and surface water quality).

The terrestrial observatories have to be operated on a long-term basis (at least for a decade), in order to facilitate the determination and quantification of environmental changes. Through cooperations with other networks the national observatory network will continuously be extended in the following on a European and global level. For the first phase these regions in Germany have been identified: Site A: The Eifel/Lower Rhine Valley Observatory (coordination: FZJ); Site B: The Harz/Central German Low-

land Observatory (coordination: UFZ); Site C: The Bavarian Alps/pre-Alps Observatory (coordination: KIT and HMGU); Site D: The German Lowland Observatory (coordination: GFZ).

iii. SITES (Sweden)

Swedish Infrastructure for Ecosystem Science (SITES, www.fieldsites.se/en) is a national coordinated infrastructure for terrestrial and limnological field research. It contributes to the strengthening of Swedish research based on measurements and experiments conducted in the field. The SITES initiative is funded by the Swedish Research Council and the five partner organizations, i.e. the University of Gothenburg, the Swedish Polar Research Institute, Swedish University of Agricultural Sciences, Stockholm University and Uppsala University. The Swedish University of Agricultural Sciences (SLU) is the host and coordinator of SITES.

SITES consists of nine research stations which are distributed all over Sweden covering the different landscapes and climatic regions. These include agricultural land, forests, mountains areas, wetlands, several type of inland waters, boreal catchments, tundra ecosystems etc.

SITES was founded in 2012 after Council for Research Infrastructures (RFI) at the Swedish Research Council (VR) conducted an investigation on the current status of research stations and other field-based infrastructures for ecological and environmental research on terrestrial and freshwater environments. An international evaluation panel selected nine stations to be funded. Among them are the three stations (Skogaryd, Erken and Svartberget) with high focus on water related monitoring and experimental work located at different climate zones and with different types of soils. The priority group also includes Abisko which is a station with a somewhat broader spectrum of activities located in the mountains area. Abisko has long lasting experience from being an internationally well recognized field station, hosting scientists from all over the world. Furthermore, two stations with extensive agricultural experimental research are included. They add to the network access to large areas with soils for experimental work and have both extensive databases related to relevant soil and weather parameters. Lönnstorp is located in the south and Röbbäcksdalen is located in the north, by that also covering different soil and climate zones. SITES has during its first operational years developed three core structures: SITES WATER, SITES AQUANET and SITES SPECTRAL.

ANNEX 3. University Research stations (RESTAT) in 2018

- Husö Biological Station, Åbo Academy
(<http://www.abo.fi/fakultet/en/husobiologiskastation>)
- Hyytiälä Forestry Field Station, University of Helsinki
(<http://www.helsinki.fi/hyytiala/english/index.htm>)
- Kilpisjärvi Biological Station, University of Helsinki
(<http://www.helsinki.fi/kilpis/english/>)
- Konnevesi Research Station, University of Jyväskylä
(<https://www.jyu.fi/bioenv/en/konnevesi>)
- Lammi Biological Station, University of Helsinki
(<http://www.helsinki.fi/lammi/english.html>)
- Kevo Subarctic Research Institute, University of Turku
(<http://www.utu.fi/en/units/cerut/kevo/Pages/home.aspx>)
- Oulanka Research Station, University of Oulu
(<http://www.oulu.fi/oulankaresearchstation/>)
- Archipelago Research Institute, University of Turku
(<http://www.utu.fi/en/units/cerut/archipelago-research-institute/Pages/home.aspx>)
- Tvärminne Zoological Station, University of Helsinki
(<http://luoto.tvarminne.helsinki.fi/english/>)
- Värriö Subarctic Research Station, University of Helsinki
(<http://www.atm.helsinki.fi/varrio/fi/>)

ANNEX 4. ICOS ecosystem stations in 2018

Class 1 Ecosystem stations

- SMEAR II Hyytiälä - Southern boreal pine forest (UH) (labelled)
- Sodankylä forest (Pallas-Sodankylä GAW) - Northern boreal pine forest (FMI)

Class 2 Ecosystem stations (labeled)

- Siikaneva - Southern boreal fen (UEF, UH) (labelled)
- Lompolojänkkä - Northern boreal fen (FMI)

Associated Class 3 supporting ecosystem stations

- Kenttäröva - Northern spruce forest (FMI)
- SMEAR I Värriö - Subarctic pine forest (UH) (labelled)
- Kuivajärvi - Boreal Lake (UH)
- Lettosuo - Forestry-drained peatland (FMI, UH) (labelled)
- SMEAR III Helsinki - Urban environment (UH)

ANNEX 5. FinLTSER sites and platforms in 2018

- Western Gulf of Finland LTER-site WelFin
University of Helsinki, [Tvärminne Zoological Station](#)
- Helsinki Metropolitan Area, HMA-LTSER
Aalto University, [Department of Built Environment](#)
University of Helsinki, [Department of Environmental Sciences](#)
- Lepsämäenjoki Agricultural Watershed Area LAWA LTSER
University of Helsinki, [Department of Agricultural Sciences](#)
- Lammi LTER, Southern Boreal Aquatic and Terrestrial Long Term Ecological Research Area
University of Helsinki, [Lammi Biological Station](#)
- Päijänne LTER site
University of Jyväskylä, [Department of Biological and Environmental Science](#)
- Hyytiälä SMEAR II LTER
University of Helsinki, [Department of Forest Sciences](#)
- Bothnian Bay LTSER platform
University of Oulu, [Department of Genetics and Physiology](#)
- Pallas-Sodankylä LTER observatory
Finnish Meteorological Institute, [Arctic Research](#)
- Northern LTSER platform
University of Oulu, [Oulanka Research Station](#)
University of Helsinki, [Kilpisjärvi Biological Station](#), [Värriö Subarctic Research Station](#)
University of Turku, [Kevo Research Station](#)

ANNEX 6. Submitted AnaEE Platforms in 2015

NOTE: these are not confirmed platforms, the review process of their suitability and feasibility is still ongoing in 2019.

In Natura: 11 platforms

- 3 Boreal forests, peatlands (UHEL/Hyytiälä, UEF/Joensuu, FMI/Lettosuo)
- 4 Arctic stations (UTu/Kevo, FMI/Pallas & Sodankylä, UO/Oulanka)
- 2 Inland waters (JyU/Konnevesi, UHEL/Lammi)
- 2 Northern Agriculture (UHEL/Viikki, LUKE/Jokioinen)

In Vitro: 8 platforms

- 4 Universities (ÅA/Husö, UOulu/Oulu, UEF/Kuopio, UHEL/Algolab)
- 4 LUKE (Kainuu fisheries, Suonenjoki, Joensuu dasotrons, Maaninka SIMU)

Analytical: 4 platforms

- Finnish Museum of Natural History (Dating lab)
- Finnish Food Safety Authority EVIRA
- Indirect open-circuit respiratory calorimeters/Minkiö barn
- LUKE Oulu

Modeling: 1 platform

- Combined ProTree and GHG inventory tool



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