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D12.3

FURTHER INTEGRATION OF RESEARCH INFRASTRUCTURES RELATED TO TERRESTRIAL ECOSYSTEM RESEARCH

INCLUDING RECOMMENDATIONS ON CO-LOCATING RESEARCH SITES ON NATIONAL AND INTERNATIONAL LEVEL

WORK PACKAGE 12 – A FRAMEWORK FOR ENVIRONMENTAL LITERACY

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ABSTRACT

This study analyses the existing European landscape of Research Infrastructures in the terrestrial domain from different perspectives: underlying scientific concepts, relation to Grand Challenges, potentials of co-location, and coverage in national roadmaps/national research concepts of terrestrial ecosystem and biodiversity research. It outlines the perspectives of cooperation and concludes that seven further steps are necessary to achieve the desired degree of integration and cooperation.

- Core variables (for observation and experimentation) supporting essential indicators for ecosystem function, as well as Grand Challenge related essential carbon and biodiversity variables, should be developed, listed and their measurements standardized among Research Infrastructures.
- For those core variables, core competences of Research Infrastructures should be defined and used in cross-RI services in order to avoid doubling efforts and diverging standards.
- For the described cross-RI cooperation, advanced governance models for need to be developed.
- National roadmaps should be designed towards integrated approaches serving the broad scientific and societal spectrum in a comprehensive way.
- Co-location of observations by different Research Infrastructures and between observations and experiments is a straightforward strategy and should formally be developed towards "Cooperative ENVRI Master Sites" (CEMS).
- Data interoperability needs to be further developed.
- A proper strategic framework has to be established beyond the usual runtime of EC projects to support clustering over at least a decade for the process addressed in this report. ENVRIplus can be seen here as a guiding example.

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TERMINOLOGY

A complete project terminology can be also found online at:

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PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

TABLE OF CONTENTS

1. INTRODUCTION

Understanding structure and function of terrestrial ecosystems is an important field in science since it provides an integration scale in our scientific understanding from subatomic structures to the universe. Ecosystem science has therefore the same status as particle physics, genetics and physiology of organisms or astronomy. Furthermore, as the basic sciences of physiology and genetics are key foundations of the applied science of medicine, so ecosystem science provides basic input into applied fields such as environmental sciences and agronomy. The exploitation of resources and ecosystem services has resulted in a series of anthropogenically-induced changes in the environment, that now threaten ecosystem integrity, therefore increasing ecological risks for human wellbeing and societal functioning. Long-term protection against possible ecological risks (the precautionary principle) have therefore a legitimate rationale for ecological integrity and sustainable development. The European countries together with the European Commission have identified the environmental challenges in general and started to build in the framework of the European Strategic Forum for Research Infrastructures (ESFRI) large scale environmental Research Infrastructures which also cover ocean, atmosphere and solid earth (in the context of this document called ENVRIs or simply RIs; see also the ENVRI community platform http://envri.eu/about/). ENVRIs enable better understanding of ecosystems' response to climate change and related extreme events, land use changes and losses of biodiversity and reduce ecological risks by providing knowledge from observations. In addition to tackling societal environmental challenges, ENVRIs provide data and state-of-the-art facilities for researchers to stay at the forefront of new scientific developments and to push our ecological knowledge further to ultimately address the complex scientific questions related to the understanding of the Earth System. Unfortunately, the ESFRI process for developing the ENVRIs in the terrestrial ecosystem and biodiversity domain has lacked an integrated top-down steering principle resulting in a complex and fragmented landscape of several landmark infrastructures, projects and advanced communities. Other large ecological research and observation networks, namely CERN in China, TERN in Australia and NEON in the United States are more integrated and through that may yield greater value to investment costs, greater ecological understanding, and better access to different facilities and data. Furthermore, this effectively reduces research costs and possible duplications of efforts. Increasing the coherence, complementarities and synergies among the ENVRIs, as initiated by the EU-supported cluster projects ENVRI (2011-2014) and ENVRIplus (2015-2019), is thus a necessity.

1.1 SCOPE OF THIS REPORT

The basic question of this report is how a comprehensive and efficient cooperation among those ENVRIs focused on terrestrial ecosystem and biodiversity can be realized to further reduce the fragmented research landscape building on the successful first round of amalgamation over the last decade that has resulted in the current RIs. **This report is not intending to provide a final solution, but to induce a discussion process among involved scientists, RI managers, stakeholders from national governments, the ESFRI and the European Commission.**

1.2 CURRENT LANDSCAPE OF TERRESTRIAL ENVIRONMENTAL RESEARCH INFRASTRUCTURES

The European Research Infrastructures analysed in this report are defined from the ESFRI Process and comprise ESFRI Landmarks (ICOS ERIC, Lifewatch ERIC), ESFRI Projects (AnaEE), and ESFRI Emerging Projects (eLTER) in the field of ecosystem and biodiversity research. They are mainly based on distributed in-situ networks of field stations. Although AnaEE is part of the Food and Health sector (half of the in-situ sites of AnaEE are crop ecosystems) it is taken into account in this report since it also deals with ecosystems less managed by man and fills a methodological gap in ecosystem sciences, developing standard experiments to predict the changes in ecosystem processes under various environmental pressures. The basic question of this report is how a comprehensive and efficient European landscape of RIs providing all required information for terrestrial ecosystem research and related Grand Challenges can be realized and sustained. The report will focus on the infrastructures that have their own measurement programs (ICOS, eLTER and AnaEE). Lifewatch as a pure e-infrastructure, is considered since its focus in the role of biodiversity on ecosystem functioning covers an important part of ecosystem science. The DANUBIUS RI is not included since its focus (River – Sea Systems) is under development and the interfaces to other RIs need to be better defined in the coming months.

1.3 GENERAL APPROACH

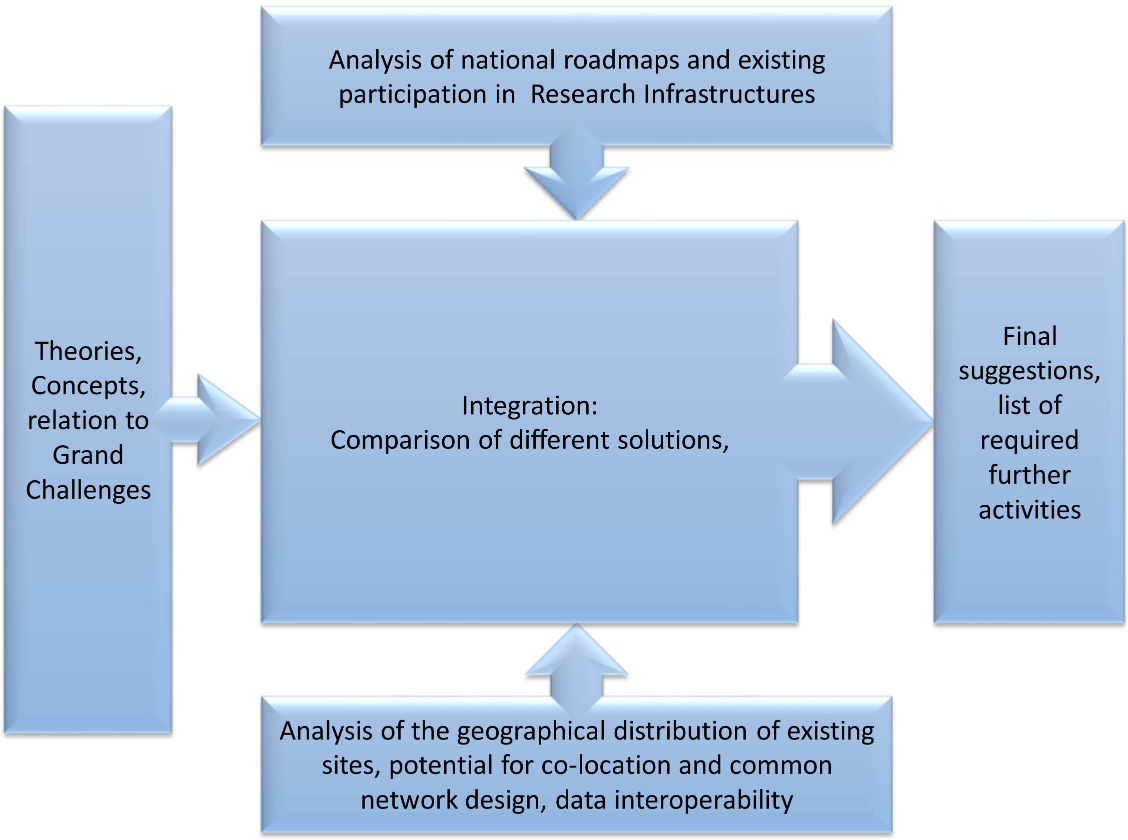

Figure 1: General approach of this study

The report is based on 3 specific analyses:

- A scientific analysis that compares theoretical approaches and grand challenges as the basis for RI concepts.
- An analysis of potential co-location and data interoperability.
- An analysis of different national approaches and existing participation in ENVRIs.

The results of the specific analyses will be integrated by a discussion of possible future solutions leading to final suggestions.

2. ANALYSIS

2.1 CONCEPTUAL BACKGROUND OF ECOSYSTEM RESEARCH

In classical ecosystem science, most studies focussed on organisms in pristine or minimally altered ecosystems and aimed at a basic understanding of natural processes. However, in the dawn of the Anthropocene pristine ecosystems are vanishing and services that ecosystems have provided to humanity since millennia have become vulnerable. This has caused a paradigm shift with important impact on ecological RIs. Current RIs are less in search of a unifying ecosystem theory and more driven by challenges in human-dominated landscapes. The concept of ecological integrity (Leopold 1949) is a good example of this paradigm shift since it is based on the guiding principle of precaution against unspecified ecological risks in the framework of sustainable development (for details see Barkmann and Windhorst 2000). Its aim is to safeguard relevant ecosystem services and preserve the capability to continue self-organized development of systems and services. The self-organizing capacity of ecosystems describes their ability to (a) develop towards a higher degree of self-organization, which is characterized by more complex structures or more efficient functions, or (b) adapt to changing external conditions by keeping the current degree of self-organization. Thus, the result of self-organizing processes in ecosystems is the build-up and the maintenance of complex structures. Several national and international legal agreements on environmental protection have referred to ecological integrity as a key management objective (US Clean Water Act 1972; Rio Declaration 1992). Thereafter, the integrity of ecological systems attracted considerable attention from many ecologists. Because of its normative dimension, it has also drawn the interest of environmental philosophers. In order to apply the concept to environmental indication, Kutsch et al. (2001) pointed out that "contemporary studies of the theoretical bases of environmental indication regard the self-organization of ecological systems as an essential component of ecological integrity" and proposed a way of deriving integrated indicators of biological self-organization from theory and testing them with field data; this was extended to a more comprehensive approach by Müller (2005). Similar approaches have been developed as base for the ECOPAR database which was an iterative and participative process based on expert discussions and input from several communities: LTER-Europe, the Life+ project EnvEurope and the FP7 project ExpeER (Distributed Infrastructure for Experimentation in Ecosystem Research; 2010-2015; www.expeeronline.eu). The concept of the eLTER RI is mainly based on this approach and provides a set of indicators and parameters that are related to ecosystem integrity.

In the most recent development the conceptual focus of some RIs has moved further from the precaution against unspecific ecological risks towards more specific ‘Grand Challenges’ in human-dominated landscapes. The concept of ‘Grand Challenges’ is a political paradigm to define priorities or approaches in research an innovation. Their selection and labelling as ‘Grand’ challenges have been based on normative, political and societal discourses resulting in several inter-related systems with the United Nations’ Sustainable Development Goals (SDGs) being the most universal and prominent system. The SDGs are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. In the framework of the European 2020 strategy, the European Commission identified a range of societal challenges as central priorities for the Horizon 2020 programme. These societal grand challenges are:

- Health, demographic change and wellbeing;
- Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy;
- Secure, clean and efficient energy;
- Smart, green and integrated transport;
- Climate action, environment, resource efficiency and raw materials;
- Europe in a changing world – inclusive, innovative and reflective societies;
- Secure societies – protecting freedom and security of Europe and its citizens.

2.2 RELATION OF ECOSYSTEM RESEARCH TO GRAND CHALLENGES

The paradigm shift in terrestrial ecological research from searching for a unifying ecosystem theory to precaution against unspecific ecological risks and further to specific Grand Challenges (and in addition a shift from ecosystem conservation to preservation of ecosystem services) is common for all ESFRIs in the domain but differs in the degree of being conducted in the basic concept of individual RIs. With the strongest relation to the approach of ecological integrity, eLTER RI is tackling a broad spectrum of ecological challenges, however the theoretical base is starting from understanding ecosystems. AnaEE, providing experiments instead of observations, and with stronger focus on agriculture and food security, is starting a bit more specific from a defined set of ecological and societal challenges and has a more anthropocentric objective in the preservation of ecosystem services, food security as well as specific contributions to bioeconomy.

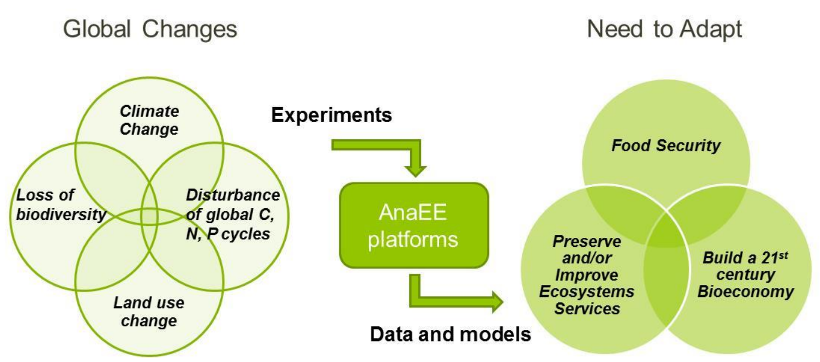

Figure 2: The AnaEE vision: experiments manipulating global changes factors will provide data and feed models to meet current main societal challenges (Source: AnaEE website).

A similarly broad approach characterises the US National Ecological Observatory Network (NEON), whose mission is to “enable understanding and forecasting of the impacts of climate change, land use change, and invasive species on aspects of continental-scale ecology such as biodiversity, biogeochemistry, infectious diseases, and ecohydrology.” (Schimel et al. 2007).

In contrast to eLTER RI, AnaEE and NEON, with their bases in the ecological integrity approach or a broad spectrum of related grand challenges, the Integrated Carbon Observation System (ICOS) is following a cross-domain approach that is directly responding to the Grand Challenge of climate action which is part the UN (SDG 13) as well as the EU system (SC 5) (Ciais et al, 2010).

In the terrestrial ecosystem domain ICOS aims to understand the carbon cycle and to provide necessary information on the land-ecosystem exchange of CO_2, CH_4 and N_2O with the atmosphere (Gielen et al. 2017). This is an essential part of the “full ICOS package” which also includes ocean-atmosphere fluxes and atmospheric concentrations of greenhouse gases. ICOS is, therefore, based in a different parameter system, the “Essential Climate Variables” (ECVs) with a sub-system called “Essential Carbon Variables”. The two systems have been developed under the United Nations Framework Convention on Climate Change (UNFCCC) with strong inputs by the World Meteorological Organisation (WMO) the UN Food and Agriculture Organisation (FAO) and the Group on Earth Observation (GEO) and are documented in the Implementation Plan of the Global Climate Observation System (GCOS). In the context of this study it is important to note, the ICOS can only further develop towards a European pillar of a future global GHG observation system in its current cross-domain array which is clearly described, but comprises only a sub-field of ecosystem science.

LifeWatch *E-Science European Infrastructure for Biodiversity and Ecosystem Research* has, similar to ICOS, a focus on mainly one Grand Challenge – in this case the preservation of biological diversity as defined in the Convention on Biological Diversity. Lifewatch enables knowledge-based solutions to environmental managers by providing access through a pan-European distributed e-Infrastructure to a multitude of sets of data, services and tools. Specific issues related with biodiversity research, the role of biodiversity in ecosystem functioning and conservation are addressed by the construction and operation of Virtual Research Environments (Virtual Laboratories & Decision-support Applications) where integrated models at the meso- or higher scales are executed.

Describing the different conceptual backgrounds and relations to Grand Challenges may be subtle but are essential for the understanding of the genesis of the ENVRIs and the resulting fragmentation. Consequently, for developing creative solutions despite differences in concepts it is beneficial to focus on similarities in their practical approach: all ENVRIs in the terrestrial ecosystem and biodiversity domain (or their parts there) are defining a list of variables that need to be measured as indicators to understand the response of ecosystems to pressure due to changes in climate, land use or species abundance and standardize their observation. NEON has called this “the system engineering approach” (Loescher et al. 2017).

2.3 ANALYSIS OF NATIONAL PARTICIPATION IN RESEARCH INFRASTRUCTURES

Problems to participate in RIs also arise from uneven national roadmap processes and funding instruments and hinder the integrated and robust development of EU RIs. National roadmap processes differ severely between countries, some countries even don’t have an elaborated roadmap yet. Although roadmaps are not a requirement to participate in a RI, they are a proven planning tool to seek in-country support from various sources and sectors of society. Many countries have an in-depth national roadmap process with thorough analyses of the maturity of the respective communities and concepts. Nevertheless, in many cases this process is detached from the ESFRI process and leads to high additional efforts of the national research communities. Furthermore, it leads to country internal competition between RIs. In addition, the term “roadmap” is used for different kinds of roadmaps and roadmap processes with the “ESFRI Roadmap” being only one amongst e.g. national research or RI roadmaps using different rules, procedures and budget thresholds than ESFRI (e.g. German roadmap of the Scientific Council/Wissenschaftsrat). In some cases, the national consortia have, therefore, developed integrated concept for a terrestrial RI that covers several ESFRI landmarks, projects and emerging projects. This chapter will analyse the national roadmaps and will provide some examples for integrated national concepts.

Table 1 shows clearly the problems: only two of the European countries (Italy and Spain) are engaged in all four RIs, few in at least three. Only few countries have integrated concepts for ecosystem/biodiversity research.

Table 1: Country involvement in different ENVRIs (situation as of 22 September 2017).

Country	National Roadmap	AnaEE	ICOS	LTER	Lifewatch	Remark
Austria	✓			EoS		
Belgium	Pending	PP, LoI	EM		EM	
Bulgaria	✓					
Cyprus	Pending					
Czech Republic	✓	PP, LoI	EM			ICTRI
Denmark	✓	PP, LoI	EM			
Estonia	✓	PP	R			
Finland	✓	PP	EM (Host)	EoS		ICTRI
France	✓	PP, LoI (Host)	EM	EoS		
Germany	✓		EM	EoS (Host)		ICTRI
Greece	✓		R	EoS	EM	
Hungary	✓		R			
Iceland	Pending					
Ireland	✓		R, PP			
Israel	✓	PP, LoI		EoS		
Italy	✓	PP	EM	EoS	EM	
Latvia	Pending			EoS		
Lithuania	✓					
Luxemburg	Pending					
Malta	Pending					
Norway	✓	PP	EM			
Poland	✓		R, PP	EoS		

Portugal	Pending		R, PP	EoS	EM	ICTRI
Romania	✓		R	EoS	EM	
Serbia				EoS		
Slovakia	Pending			EoS		
Slovenia	✓			EoS	EM	
Spain	✓	PP	R, PP	EoS	EM	
Sweden	✓	PP	EM			ICTRI
Switzerland	Pending		EO	EoS		
The Netherlands	Pending		EM		EM	
The United Kingdom	Pending	PP, LoI	EM	EoS		
Turkey	✓			(EoS)		

ICOS ERIC and **Lifewatch ERIC**

EM: ERIC Member
EO: ERIC Observer
PP: Participation in Preparatory Phase but not in ERIC
R (for ICOS only): Participation in H2020 INFRADEV Project RINGO as country potentially joining ICOS

AnaEE

PP: Participation in Preparatory Phase
LoI: Letter of Intent for Pre-operational Phase signed

eLTER RI

EoS: Expression of support signed
(EoS): Expression of support expected to be signed

Remarks: ICTRI: this country has in addition to the roadmap an integrated concept for a terrestrial RI.

2.4 EXAMPLES OF NATIONAL CONCEPTS

AUSTRIA

No formal national ESFRI Roadmap for environmental RIs has been developed so far. However, substantive efforts are ongoing to structure and organize the existing pool of ecosystem and biodiversity in-situ research facilities in consultation with the main shareholders, the Ministries for Science and the Environment as well as the National Academy of Sciences (OEAW). The thematic responsibility for ecosystem research was assigned to OEAW in 2011 and rests with the OEAW International Program on Climate Change. As OEAW contractor, the Austrian Society for Long-term Ecological Research inventoried and pooled ecosystem and biodiversity research sites and the institutions in charge of their operation. The basic strategy consists in streamlining a consistent national network with concerted contributions and cost-efficient participation of the most suitable sites in selected European projects, networks and RIs. The concept, strategy, process and site network status are regularly published in a White Paper (Mirtl et al. 2015), comprising priority research themes, greatest potentials, international context and nationally required framework conditions. National foci will be put on high alpine environments and other benchmark ecosystems, climate change and socio-ecological research. The current plan is closely related to the eLTER RI, because the LTER-Austria pool of sites represents the majority of pertinent national infrastructures and the integrated whole systems approach forms a good basis for targeted more specific engagements. Multiple site usage and co-location of RIs have formed a core element of the national strategy from the beginning. Basic site operation will most probably be assigned to eLTER. The organization of involvement in other environmental RIs will be closely aligned with ENVRIplus integrative approach and the emerging formal agreements of eLTER with sister RIs.

BELGIUM

Belgium has a complex science policy landscape with regional and federal authorities, which will evolve further with the ongoing reform of the state and associated transfer of competencies (and budgets) to the regions. Yet, collaborative action of the different authorities has realized two ERIC memberships in the terrestrial environment domain (ICOS and LIFEWATCH) and is preparing for possible participation in a third one (AnaEE, with ERIC application foreseen in 2018). ICOS has the longest history, and started as an initiative of individual research groups. Propelled by European research programs such as Euroflux and its follow-up programs (incl. CARBO-EUROPE IP, GHG-EUROPE), six eddy-covariance flux stations are currently deployed in Belgium, equally distributed across the north and the south, the oldest two covering almost 20 years of continuous operation. Belgium (University of Antwerp) also co-hosts the Ecosystem Thematic Centre (ETC) of ICOS, together with France and Italy. The ETC coordinates the ecosystem network and provides centralised data processing, quality control, support and training to the stations.

The potential contribution to AnaEE is being prepared by the recent funding of novel large-scale facilities at the Universities of Antwerp (Infrared Heating Systems and Mesoscale Ecotron), University of Hasselt (Macroscale Ecotron) and University of Liège at Gembloux (indoor facilities for multidisciplinary study of agricultural ecosystems), the underlying philosophy being that versatile top-of-the-range controlled-environment facilities (some of which in open-air) can best complement the advanced monitoring approach of ICOS to address the grand challenges. Through these RI's, Belgium also consolidates its expertise in climate change impact research.

In LIFEWATCH, a virtual laboratory is constructed for biodiversity research and climatological and environmental impact studies. Spread over the country, several long-term projects have been started by different research centers and universities with financial support of their respective political authorities. In Flanders, INBO (Institute of Nature and Forest Research) and VLIZ (Flanders Marine Institute) have set up sensor networks (e.g. fish and bird tracking), and facilitate data access through data publication and data archeology. In the Wallonia-Brussels federation, the Catholic University of Louvain and the University of Liège/Gembloux use remote sensing imaging and integrated GIS analyses to build geographic datasets of biotic and abiotic factors. At the federal level, RBINS (Royal Belgian Institute of Natural Sciences) develops an Antarctic biodiversity information system and a barcoding facility for organisms and tissues of policy concern in collaboration with RMCA (Royal Museum for Central Africa).

FINLAND

Finland has participated actively in developing the European environmental RIs ever since the first steps to design the ICOS, and later in ACTRIS, AnaEE and eLTER. This has been possible with a strong collaboration between the main organisations hosting the in-situ sites and led to formal agreement to build an Integrated Atmospheric and Earth System RI (INAR RI), under which all these ESFRIs are currently listed in the national RI roadmap. INAR is a core partner in ICOS ERIC, leading the Preparation Phase of ACTRIS RI, and contributing to AnaEE RI and eLTER Emerging RI initiatives, in addition to hosting and coordinating the national nodes of all four RIs.

INAR RI utilizes a multidisciplinary scientific approach, and emphasizes that, in order to understand and find solutions to the Grand Challenges, a deep understanding based on solid scientific knowledge of interactions and complex feedbacks between the atmosphere and Earth system is mandatory. The Finnish concept for terrestrial ecological and environmental RI integration is outlined in the White paper (Bäck et al 2017), where all 7 national organisations hosting or operating environmental observations, together with those organisations using the data and developing the services set up a common framework for future integration.

The backbone of INAR approach are the continuous, comprehensive observations of the environment in highly instrumented, 'flagship' stations, which enables research on multiple interactions in the atmosphere-Earth surface continuum. A key milestone in the Finnish RI development was the establishment of the measurement stations SMEAR I and II (SMEAR = Station for Measuring Ecosystem-Atmosphere Relations) at two University of Helsinki field stations in the beginning of 1990's. The SMEAR stations were designed following the underlying fundamental physical concept of conservation of mass and energy, and they include the up-to-date observation schemes for most of the biogeochemical cycles and their ecological and physical drivers. An essential ingredient in the SMEAR concept is the integration and co-location of different RIs focusing on disciplinary aspects, i.e., actively encouraging joint use of basic infrastructures and human resources, instrument and method development and strategic planning, the main aim of the integration being to improve the scientific value of the research done at these flagship stations.

In addition to SMEAR I and II, two other SMEAR stations are operating in Finland, one station in Tartu, Estonia, and another one in Nanjing, China. Further building of the network is ongoing and likely to be established in the next years in China and Russia. INAR has conceptualized the flagship station design so that it takes benefit from the long experience and tested solutions on how to implement and organize a flagship station in an efficient way. The 'SMEAR-concept' provides a cook-book to establish a comprehensive observational in situ station and sets the basic requirements for the operations.

FRANCE

France terrestrial ecosystem research is developed by Universities and several research institutes among which the Institute of Ecology and Environment of CNRS (Centre national de la Recherche Scientifique) and INRA (Institut National de la Recherche Scientifique) are the main ones. Development of ecosystem RIs has been for a long time under the initiative of individual researchers or laboratories but most of them were only short-term ones. European research programs, such as Euroflux '1996) and its follow-up programs stimulated the building of research platforms, such as the Puechabon eddy-correlation flux tower near Montpellier (2000) and gave incentives for long term operation of such platforms. In 2003, the research ministry started funding the ORE (Observatoires de Recherche en Environnement), local research platforms which have been pooled into SOERE (Systèmes d'Observation, d'Expérimentation et de Recherche en Environnement) according the the type of ecosystem studied: F-ORE-T on forest ecosystems, ACBB on crop- and grasslands, PRO on the use of residual organic products in cultivated ecosystems, GLAPCE on peri-alpine lakes. Other SOERE deal with studies at larger scales like RBV on catchments or RZA on socio-ecological interactions at the regional level.

A national infrastructures roadmap was established in 2008. The CNRS Ecotrons were the only ecosystem infrastructure on that roadmap. ICOS, AnaEE, EMBRC and some observatories were added in 2012. Additional infrastructures related to ecosystem science were added in 2016 (e.g. RECOLNAT, ACTRIS)

Some of the above-mentioned ORE are now part of ESFRI landmarks and projects. In particular, the eddy-correlation sites of F-ORE-T, ACBB and PRO are part of ICOS. Six are main ICOS sites (3 in forests, 3 in arable land and 2 in grasslands) and 7 are associate sites (2 in arable lands, 2 in prairie, 1 in tropical forest, 1 in peatland and one on abandoned land). The French ICOS community also develop a national scientific activity through yearly conferences.

France initiated the AnaEE ESFRI project, leading a design project (2008-2011), a preparatory phase (2012-2016) and currently the Implementation Phase. The involvement in this infrastructure on experimentation and analysis of managed and unmanaged terrestrial and aquatic ecosystems has stimulated the structuration of the French research platforms in this domain across institutes (CNRS, INRA and Universities). An 'Investissement d'Avenir' program (AnaEE-France 2012-2020) supports the development of an RI dedicated to the experimentation on ecosystems mirroring at the national level AnaEE ESFRI. Experimental services and a centralized access to platforms and data are now proposed to the scientific community. These services are based on state of art platforms (30 experimental sites with different levels in environmental control, several analytical and modelling platforms, several shared equipment). The project has also fostered the implementation of an information system for accessing the various resources and structuring the data and data bases and their access for the modelling tools.

France also signed an Expression of Interest in the candidacy of eLTER to enter the ESFRI roadmap. The RZA and RBV platforms , as well as platforms from the Institut des Sciences de l'Univers, would be the main French components of eLTER.

GERMANY

Under the coordination of the Deutsche Forschungsgemeinschaft (DFG) the scientific community in Germany has developed "Long-Term Perspectives and Infrastructure in Terrestrial Research in Germany – A Systemic Approach". This strategy paper aims for an integrated national infrastructure that aims to:

- support systematic, long-term cross-compartment and cross-scale research,
- promote better networking between the different research institutions in Germany than exists at present,
- serve as a basis on which to intensify collaboration with government ministries and agencies at national and federal state level,
- develop methods and services for data availability which deliver in an exemplary way measurement data and research results in a standardised, quality-assured form,
- permit standardisation and harmonisation of research methods and techniques,
- have the potential to be integrated in international research networks.

Recently established networks include the DFG-funded Biodiversity Exploratoriums and iDIV, which take an integrated approach incorporating different disciplines in biodiversity research. The Biodiversity Exploratoriums are internationally linked via LTER-D. In 2008 the Helmholtz Association began to set up TERENO sites, which concentrate on the observation and forecasting of coupled material flows in terrestrial systems in an integrated approach. The aim is to provide long-term data series for the validation of mathematical models, develop new technologies to record important system states, and establish a basis for the development of adaptation strategies in the context of climate and land use change. At some locations TERENO, ICOS-D and LTER-D are merged and measurements are coordinated.

Currently, only ICOS is listed in the national roadmap for RIs. During the most recent national roadmap evaluation the German Center for Biodiversity Monitoring (BioM-D) was not suggested for a roadmap update due to many concerns about the specific feasibility of the concept. For a future roadmap update the different actors may further develop the DFG concept for an integrated terrestrial RI in Germany.

SUMMARY

All of the analysed countries show examples for the integration of the infrastructure (observational sites, experimental facilities, data infrastructure) at the national level. The strategy to connect an integrated national infrastructure to several ENVRIs seems to be beneficial for the national consortia of hosting organisations.

The further steps will now analyse the potential to further develop the integration by co-location and by data inter-operability on the European level.

2.5 CO-LOCATION AND INTEROPERABILITY OF DATA

2.5.1 ANALYSIS OF EXISTING SITE NETWORKS

THE CHALLENGE OF SITE DOCUMENTATION AND MAPPING

The mentioned fragmentation of in-situ ecosystem research and environmental observation has for a long time been reflected in the absence of standardized site documentation and site metadata attributes. While the majority of RIs and networks has individual site documentation systems, which reflect their specific needs and site categories, a comprehensive cross-infrastructure documentation describing multiple use of sites is still missing. Furthermore, the usage of different site names in the different contexts obscures already existing co-location. The usage of sub-sites (parts of sites) or combination of sites as well as over time changing overall site designs add another aspect of complexity.

In this study, technical options for a comprehensive spatial analysis of sites across RIs were explored to detect clusters of sites, where the spatial proximity suggests existing or potential multiple use of (1) the same facilities or (2) facilities located so close to each other, that there might be a potential for combined/joined usage by more than one RI in investigating different aspects of a given ecosystem. The analysis is based on the Dynamic Ecological Information Management System - Site and Dataset Registry (DEIMS-SDR) which was further developed by eLTER H2020 on earlier systems introduced by US LTER. DEIMS-SDR has already been used for site documentation e.g. by EnvEurope (LIFE+), ExpeER (FP7), EcoPotential (H2020) and the global LTER network. It was recently included into the GEO In-situ Task Group activities as an example and trigger for global efforts towards achieving standardized site documentation.

In the context of the FP7 project ExpeER, several in-situ sites networks (ICOS, eLTER, INTERACT, Climmani, FunDivEurope, INCREASE, UNECE ICP IM) were described by a few fundamental DEIMS attributes. In ENVRIplus, these DEIMS datasets were updated for ICOS, AnaEE and InterAct, resulting in a broad availability of site metadata from a large number of RIs, networks and projects, basically reflecting their status around mid 2017.

The dataset was then used to identify “hot spots” (i.e. clusters of sites) for potential multiple usage and/or RI interactions (details of the method described in Box1). It needs to be underpinned that this workflow shows a first analysis of potentials. It shows spatial proximity but does not immediately suggest concrete sites or site clusters for co-location. This will require more detailed and interactive analyses into consideration ecosystem types, climate and terrain attributes, representativi, and underlying scientific questions. Still, this workflow represents a fundamental first step towards an integrated European system of field sites.

Box 1: Technical description of the workflow

In order to be useful for a spatial analysis the datasets had to be aggregated. This was realised by first converting them to .csv-Files so that they could be imported as text-delimited files by the cross-platform free and open-source desktop geographic information system (GIS) application QGIS. The imported files were saved as shapefiles in a working directory. This resulted in a partial loss of information as not every single site provided information about the location.

The shapefiles were then merged into a single shapefile containing all information of the input files and then re-projected to ETRS89 / LAEA Europe (EPSG: 3035). Next the “heat map plugin” was used to create a heat map. A heat map is a graphical representation of data where the individual values contained in a matrix are represented as colours. The Heat map plugin uses Kernel Density Estimation to create a density (heat map) raster of an input point vector layer. The density is calculated based on the number of points in a location, with larger numbers of clustered points resulting in larger values. Heat maps allow easy identification of “hotspots” and clustering of points (QGIS Documentation: http://docs.qgis.org/2.0/de/docs/user_manual/plugins/plugins_heatmap.html).

The purpose of this was to create a raster layer that indicates areas of high spatial density of research locations.

The used parameters for the heat map were:

- Radius : 100000 layer units (i.e. 100km)
- Rows: 500
- Columns: 444
- Kernel Shape: Quartic (bi-weight)
- Output values: Raw values

The units in this heat map represent a probability estimate of there being a point at that location. Each cell will give the number of points within the kernel radius; hence if a cell has a value above two it means that there are two sites or more in this cell. Thus, adjusting the cell size greatly influences the results of this analysis.

Afterwards, all cells with a value above two were extracted and turned into a vector format for easier handling. This layer with the newly generated patches of high site density was intersected with the aggregated layer of sites.

The result of this intersection were the clusters that coincide with the areas of highest of in-situ research facility density.

In order to provide means of querying the data without using a Desktop GIS a browser-based interactive density map was created.

The created aggregated layers (see above) were added to a QGIS map with an OpenStreetMap base map. Then the QGIS plugin “qgis2web” was configured to create an “offline website” that features that display each site name and RI affiliation when clicking on a site. This generates a html site that features a base map with global administrative boundaries, all research site locations and the location of their clusters.

MAPPING SPATIAL PROXIMITY OF RESEARCH INFRASTRUCTURES SITES – FIRST RESULTS

The following maps show the overview of the RIs and networks with a zoom-in to individual sites´ basic metadata (Figure 3), the resulting heat map (Figure 4) and a first map of potential cross-infrastructure sites (Figure 5).

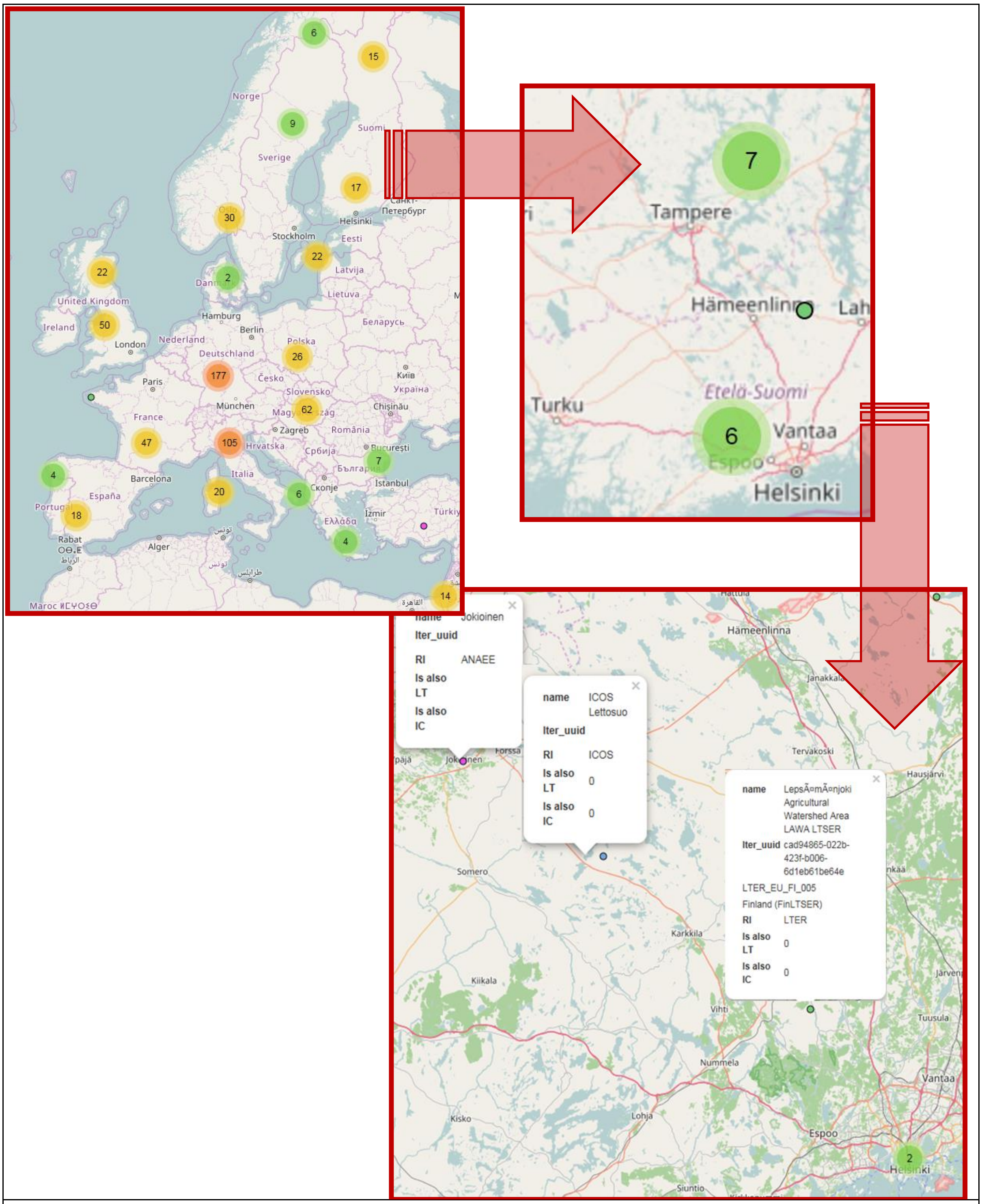

Figure 3: **Top**: Overview map of RI sites. Coloured circles indicate the number of sites in a given cartographic area (dynamically scale-dependent; green: <10; yellow: 10-99; orange: >100). **Centre**: Zoom in to Helsinki area. **Bottom**: Concrete sites and their basic metadata become visible when interactively zooming further in.

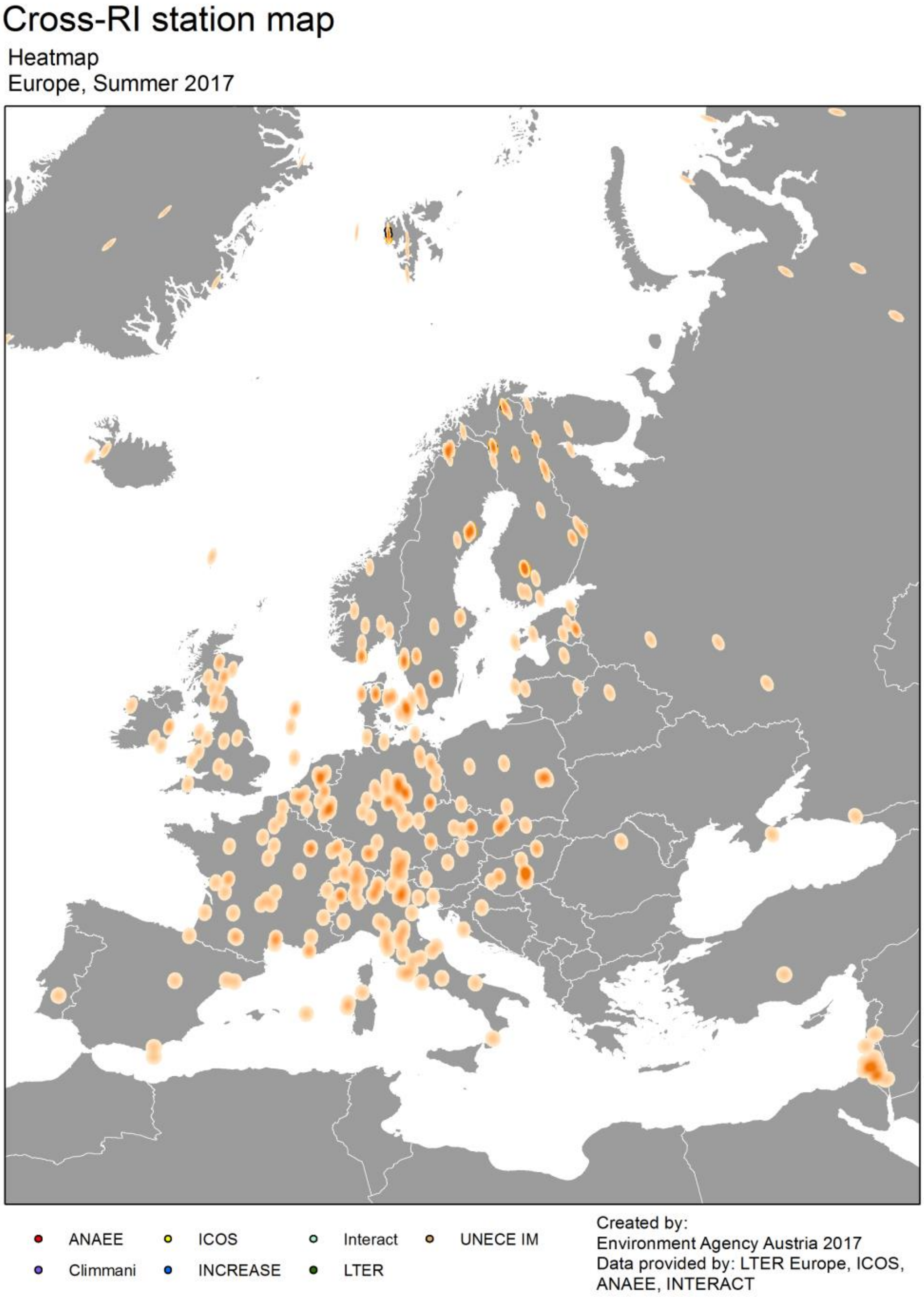

Figure 4: Heat map of existing sites.

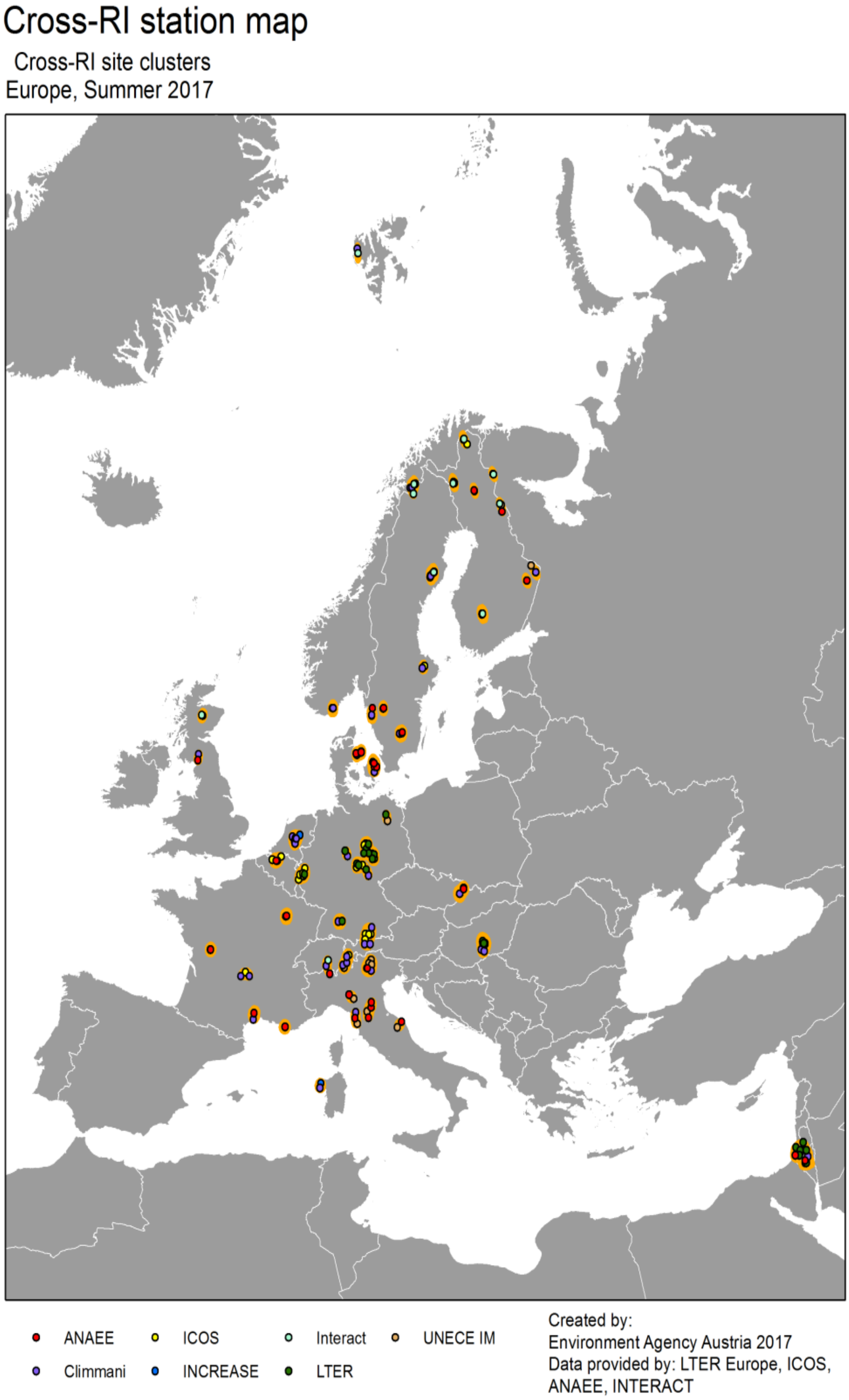

Figure 5: Potential for co-location of ENVRI ecosystem infrastructures.

The results of this study are encouraging. The density of sites in Europe provides a high potential for integration and co-location.

2.5.2 THE HIERARCHICAL CONCEPT OF CO-LOCATION

The analysis so far has shown important features that support the further development of the RIs in the Ecosystem/Biodiversity Domain:

- an integration between the RIs along a practical approach defining a list of variables that need to be observed is possible to achieve despite different conceptual backgrounds,
- there are positive integration experiences from organisation of the national networks,
- a high potential of co-location between RIs is already existing.

In this chapter, the concept of co-location is further developed. The basic principle of this concept builds on the awareness that different scientific or societal questions require different indicators. Consequently, each observational network has its own specific requirements and parameters. While accepting the impracticability of measuring everything everywhere, co-location allows, notwithstanding, high connectivity between different networks and high scientific synergies. This can be achieved by developing existing sites towards common sites where all RIs are present – in the context of this study they are called “Cooperative ENVRI Master Sites” (CEMS) – ensuring a highest level of instrumentation and a cross-calibration between observations (Figure 6).

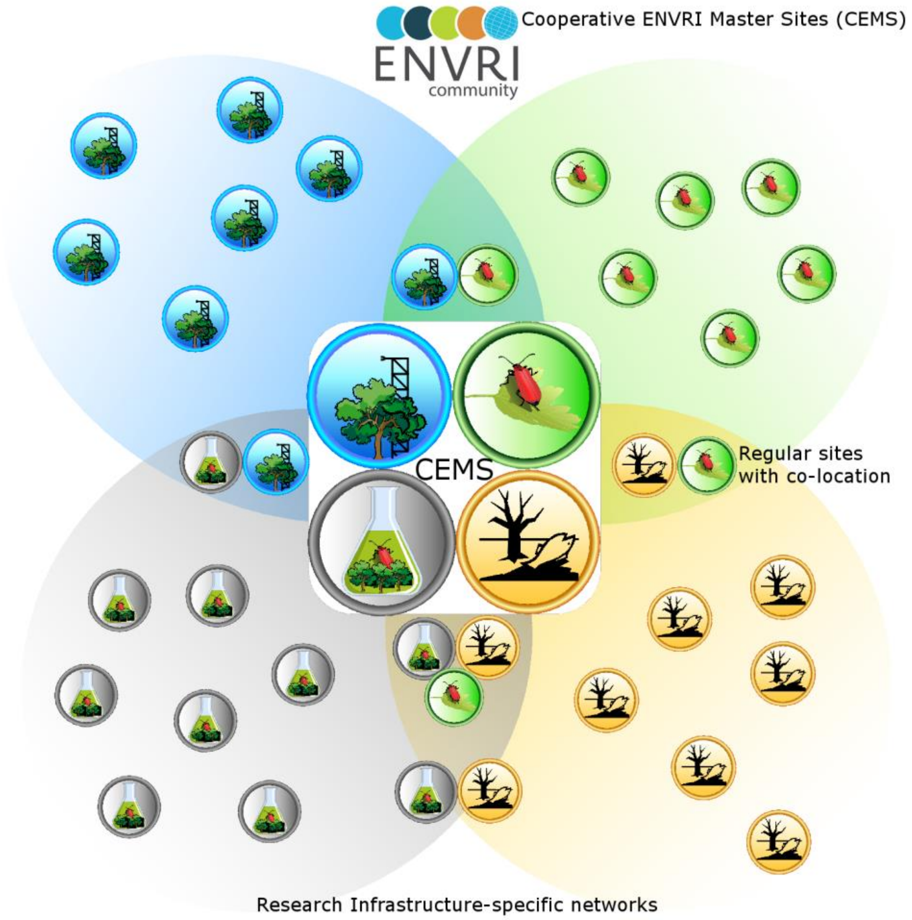

Figure 6: Concept for hierarchical co-location between different RIs in the Ecosystem/Biodiversity domain. Different symbols represent different core measurements from different RIs (blue: flux measurements of greenhouse gases, green: biodiversity observations, grey: experiments, orange: pollution)
Cooperative ENVRI Master Sites (CEMS) are the highest level of scientific integration and co-location.
Co-location between two or three ENVRIs may also be very useful.

The fully instrumented CEMS are run in close cooperation between RIs as backbone for instrument-intensive research. Sites, ideally suited for co-location regarding overall scientific observations but also

in land-use, terrain etc. should be selected between the RIs. CEMS cannot be run by any RI alone and require a cooperation between them. However, they can be condensation cores for integration of different scientific communities and host organisations into national RI consortia.
Besides from the CEMS, each RI will keep its own networks covering its specific scientific scope and related parameters (e.g. eLTER Regular Sites). Occasionally, co-location between two or three infrastructures may be suitable for other sites that will usually not be as intensively instrumented as CEMS.

Box 2: Specific remark about eLTER RI and ICOS

The concept of eLTER RI as provided in the proposal for the roadmap 2018 is very similar to the concept provided here as inter-operational concept between different RIs. This can cause confusion due to the perception that eLTER RI aims to cover the whole spectrum of ecosystem-related observations. Indeed, the basic observation concept of LTER, which is based on Ecosystem Integrity (abiotic focus) and EBVs (biotic focus) as outlined in chapter 2.1 aims at comprehensive understanding of ecosystems which includes also observations on the carbon cycle and impact of climate change on productivity or greenhouse gas emissions from terrestrial ecosystems being the core scientific tasks of the ICOS Ecosystem network.

This conceptual overlap is unavoidable but can be solved on the practical level by cross-RI cooperation (see Chapter 3). Additional observations carried out at by eLTER RI at ICOS sites e.g. on the nitrogen cycle, biodiversity or pollutants will scientifically be extremely valuable for the interpretation of core parameters observed by ICOS while vice versa the ICOS core competence on carbon and greenhouse gas observations provide a valuable input into the eLTER RI.

In addition, the concept of eLTER RI includes regional multi-scale and cross-disciplinary case study areas (eLTSER Platforms), comprising multiple spatially nested smaller scale elements for socio-ecological research that can – inter alia - commonly be used for studies on regional emissions. ICOS is slowly building up socio-ecologic competence and can definitely benefit from cooperation in this field.

2.5.3 REQUIREMENTS OF DATA INTEROPERABILITY

The suggested cooperation requires coordinated data policies among RIs. Since open science and the FAIR data principle is in the genes of the ENVRIs, data characterisation and workflows have to be thoroughly coordinated and harmonised to ensure integration and interoperability of data, applications and other services. The key is interoperating metadata systems using common standards and semantics. The metadata characterises sites, data, services, users and ICT resources (including sensors and detectors). This approach provides end-users a unified method for data discovery and access. It also allows developing improved services by ICT experts.

The common challenges are:

- to select, develop and share data/metadata standards and semantic referential,
- to align semantic referential when different among communities,
- to develop distributed and interoperable data/metadata information systems,
- to facilitate data discovery and use, and to provide integrated end-user information technology to access heterogeneous data sources,

- to develop data mining tools in ecosystem sciences,
- to make data identifiable and citable by extending the use DOI and by developing dataset description and publication,
- to facilitate discovery of software services and their composition,
- to optimize data processing and to develop common models, rules and guidance for research data workflow documentation,
- to characterise users and build a community evolving from current RI communities,
- to characterise ICT resources (including sensors and detectors) to allow virtualisation of the environment (for instance onto Grid- or Cloud-based platforms) such that data and information management and analysis is optimised in use of resources and energy usage,
- to facilitate the connection of users, composed software services, appropriate data and necessary resources in order to meet end-user requirements.

The H2020 cluster project ENVRIplus is currently supporting Environmental RIs in their endeavours to achieve data interoperability. ICOS has built its data life cycle based on the so-called ENVRI Reference Model, eLTER already follows the same pathway in the current IA project. LifeWatch ERIC follows an ORCHESTRA-based architecture model in tight collaboration with the European Open Science Cloud initiative. The following overarching principles should be applied by all RIs:

- Simple but effective. Scientists should be able to optimize the data pipeline from distributed data generators to storage in an easy but effective way, generating appropriate metadata at all stages to allow later access to information on provenance and curation.
- Interdisciplinary but with common rules. Semantic management is required to address the complex and diverging data models and conceptual frameworks used by different science and monitoring domains. Common rules for workflow and tool documentation are essential.
- Rich tools but low learning curves for application. Common access is required to tools including software services that can connect to heterogeneous datasets and be composed within workflows to form an appropriate application instance. Effective re-use of workflows requires the existence of repositories for workflow curation, which depend in turn on high quality contextual metadata.
- Data driven but traceable and citable. The necessity to trace the provenance of data and tools implies recording of the temporal aspects of relationships between datasets, between datasets and services, between datasets and persons or organisations, etc. Both data and tools must be citable.
- Scientist-centred but with a high quality of user experience (QoE). Scientific users require an environment where virtualised access is provided for interdisciplinary interoperation. It is assumed the end-user researchers are expert in their own domains and will wish to have easy access.
- Extensible yet robust. Available resources evolve over time; RIs must be able to federate over a disparate set of resources and services and survive changes in that set. This implies elastic scalability of processing, data storage, and networking linked with increasing user demands.
- Providing appropriate trust, security and privacy as well as concerning sensitivity of data.

Although generally research data (and at least some of the associated software) is open, there is a need to (a) allow for embargo periods to permit prior publication; (b) protect privacy if individual persons are somehow identified; (c) carry through interoperation trust/security/privacy parameters from one domain to another.

3. INTEGRATION

3.1 AN INTEGRATING GUIDING CONCEPT

The analysis has shown that the different terrestrial RIs clustered within ENVRI have a high potential of scientific cooperation, co-location and data interoperability. As pointed out in 2.2, the way forward is defining a list of variables that need to be measured as indicators and related them to the expertise of individual ENVRIs. This necessity can be further explained exemplarily by the overlap between the concepts regarding variables related to ecosystem productivity: for the grand challenge guided ECV (Essential Climate Variables) viewpoint the global land sink of CO_2 is crucial. Thus, the CO_2 exchange between terrestrial ecosystems and the atmosphere is a core variable of the ICOS ecosystem program and thoroughly standardized there. However, the same parameter can be integrated into the ecosystem integrity concept as an important ecosystem service and therefore is also a core eLTER parameter. It is obvious that this service is dependent on ecosystem integrity and vice-versa endangered by the impact of climate change.

The fact that key features of ecosystem integrity related to the function of ecosystems (gross and net primary production, biological control of water fluxes, biomass and soil carbon storage) are also Essential Carbon Variables or are based on the same parameters measured or that variables of ecosystem structure in the ecosystem integrity concept are also Essential Biodiversity Variables opens the path to an overarching guiding concept for cooperation between ENVRIs in the terrestrial ecosystem and biodiversity domain: a detailed revision of indicators and variables from all conceptual approaches should result in a comprehensive parameter set that defines observational networks as well as experiments. The responsibility for the observation of these parameters, related standardization, data processing, data quality control and data integration should then be distributed among the RIs according to their core competences. This would unlock an enormous synergy potential. However, there are some obstacles in the governance.

3.2 CONCLUSIONS ON GOVERNANCE

The current reality in the terrestrial ecosystem and biodiversity domain is a modular system of ENVRIs, which emerged over the past decade. These represent important building blocks, but overall, they are far from the level of integration needed to provide the desired cooperation and interoperability. Theoretically, there are two principle approaches that could be followed for progressing to the next level:

1.) DOMAIN-WISE STRUCTURAL INTEGRATION (FIGURE 7)

Following this model would target to a legal structure where all in-situ infrastructures per domain are coordinated by one European legal entity. The existing RIs would be merged into this new structure. The (hypothetical) "European Ecosystem RI" would comprise several Thematic Centres for e.g. experiments, flux measurements, biodiversity observations. The tasks of these Thematic Centres would comprise e.g. standardisation, data processing and data quality checks. On top of this, an ensemble of thematic e-infrastructures related to specific grand challenges would be established or further developed. LifeWatch can be seen as a prototype of such an e-infrastructure. There would be a large task in building a cross-domain data integration system that enables data access to all available data streams.

Advantages: from a domain viewpoint, a simple and logic solution that mirrors the already existing integration on national level in some countries. The fragmented landscape would be overcome since membership in this infrastructure would be "one for all" and countries would not have to decide between 4 - 6 memberships in the domain. Furthermore, it would open a process for building-up an optimised network of observational and experimental sites.

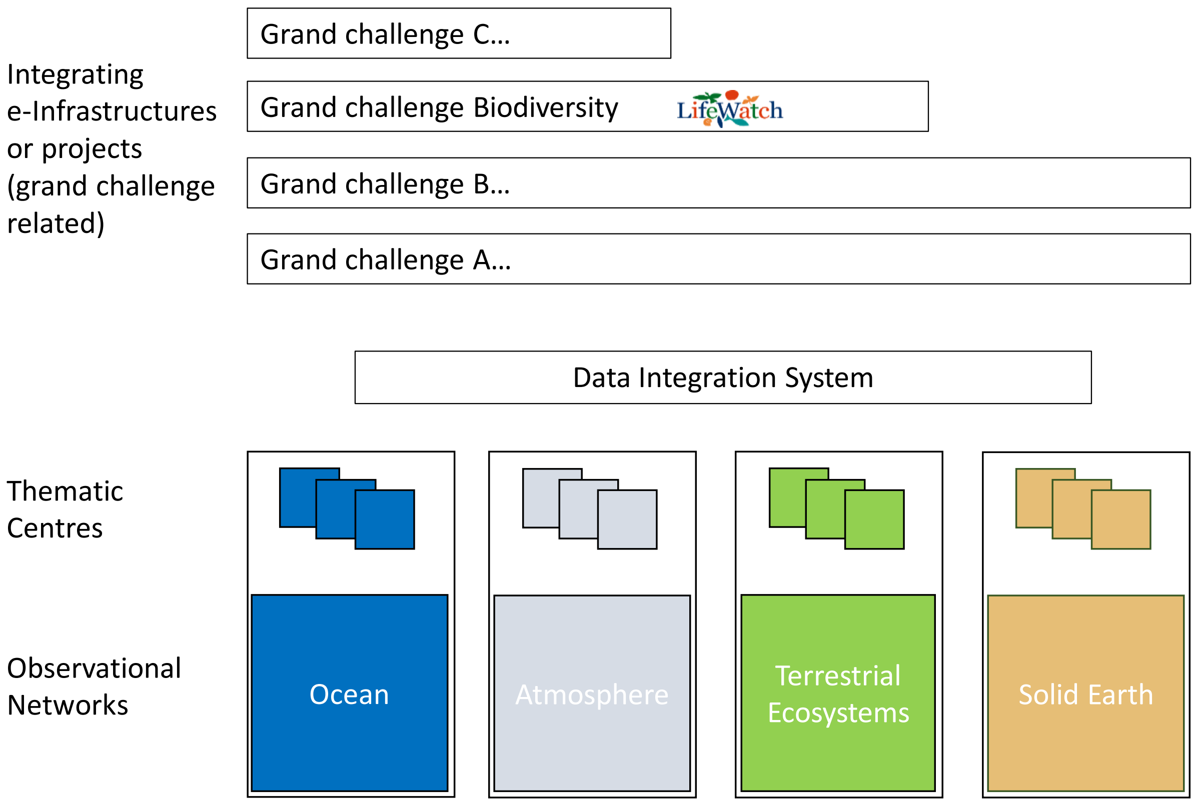

Figure 7: revised legal and administrative structure where all in-situ infrastructures in each domain are coordinated by one European legal entity while cross-domain scientific integration is achieved by specialised e-infrastructures.

Disadvantages: given the already achieved maturity of the existing RIs this solution seems unrealistic since it would require a complete organisational turnaround. The given governance mechanisms in ESFRI have not been built for a strong leadership. They rather support bottom-up initiatives out of the science community. Furthermore, the internal integration of the cross-domain RIs, such as ICOS would be destroyed. Thus, it needs a very convincing concept to break apart one of the most advanced and successful RIs and with that weaken the strong European position in a global carbon and greenhouse gas observation system that ICOS has already achieved.

It can clearly be concluded that the disadvantages of this approach are larger than its possible advantages and thus this way of integration is not supported in the ENVRI community.

2.) IN-DEPTH COOPERATION OF STRUCTURALLY INDEPENDENT ENTITIES (FIGURE 8)

This approach would build on the existing infrastructures and deepen the existing cooperation in co-location, methodological standardisation and data interoperability that has already started in ENVRIplus. Platforms such as GEOSS could be used for common metadata catalogues.

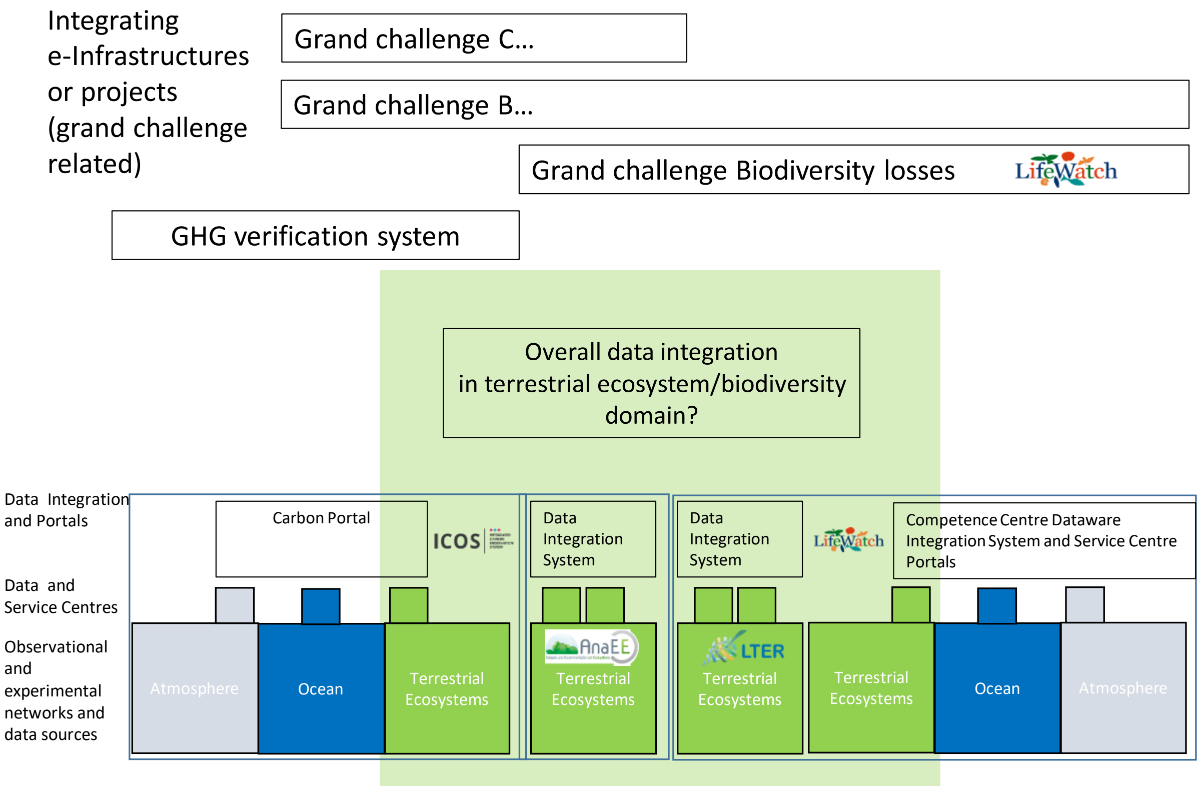

Figure 8: further cooperation and integration building on existing RIs.

Advantages: no large organisational changes at this stage necessary. Cross-domain infrastructures could continue their internal integration and continue to work towards respective grand challenges. Single infrastructures could respond in a much more agile way to upcoming new demands.

Risks: the coverage of single RIs could continue to be insufficient (see Table 1) while the competition on membership (on the European level) and resources (on the national level) would continue. Cross-RI harmonisation could remain to be difficult if parallel data flows for similar parameters (e.g.

ecosystem flux measurements) would be created and specific expertise of RIs was not utilized by the others due to incomplete membership coverage.

The second solution is the more realistic one but the challenge to overcome its shortcomings and provide a globally competitive solution needs further development of the current system. The first requirement is a trustful cooperation where each RI provides a clearly defined indispensable part to a bigger entity that can only be achieved on a level playing field.

This field needs furthermore clear descriptions of scientific, methodological and technical core competences of each of the single RIs in order to avoid doubling efforts. While the ICOS Ecosystem Thematic Centre e.g. has a world-leading position in the processing and quality assurance and control of eddy covariance based flux measurements, AnaEE has the same position in facilitating experiments and eLTER RI in integrating N cycle and biodiversity observations, research on other pollutants/drivers and socio-ecological interactions. LifeWatch ERIC operates to integrate access to distributed biodiversity data resources, to provide services for analysis, modelling and visualization, and to enable Virtual Research Environments (VRE) for Scientific cooperation and experimentation. To overcome competition and parallel competences a cross-Research-Infrastructure system of services needs to be built. It would unlock enormous resources if e.g. all eddy covariance flux sites related to any RIs in Europe could be serviced by the ICOS Ecosystem Thematic Centre while major experiments are facilitated by AnaEE.

As stated above, the core task is cataloguing the indicators and resulting parameters. This requires a huge community effort and would result in a clear definition of the niches of the different RIs and with that a clear description of the European Research Area in the domain.

Co-location should then be promoted and guided by a common concept including common protocols for measurements and standardized processes for labelling sites in specific networks. As suggested above, collocated sites should be named “Common ENVRI Master Sites” and the maintenance shared between RI. Less equipped sites could be run by single infrastructure according to their specific mission.

Unfortunately, the current organisation of the ENVRIs bears some obstacle to achieving these cross-research-infrastructure services (see also Chabbi and Loescher 2017). Services or other activities outside the membership countries of an ERIC or an ESFRI project are currently very difficult. On the other hand, the incentives to participate in several RIs related to terrestrial ecosystems are not very high. Therefore, a thorough discussion process with the ESFRI strategic working group and the national ministries and research institutions should develop governance scenarios to further develop the currently insufficient system. Furthermore, the current development of the European Open Science Cloud (EOSC) may be useful to improve the underlying data infrastructure.

4. SUMMARY AND OUTLOOK

The study has showed that the existing European landscape of RIs in the terrestrial domain is sufficient to support a broad scientific spectrum and research related to numerous societal Grand Challenges. Nevertheless, six further steps are necessary to achieve the desired degree of integration and cooperation.

- **Core variables** (for observation and experimentation) supporting essential indicators for ecosystem function as well as Grand Challenge related essential carbon and biodiversity variables should be developed, listed and their measurements standardized among RIs.
- For those core variables, **core competences of RIs** should be defined and used in cross-RI services in order to avoid doubling efforts and diverging standards.
- For the described cross-RI cooperation **advanced governance models** need to be developed.
- **National roadmaps** should be designed towards integrated approaches serving the broad scientific and societal spectrum in a comprehensive way.
- **Co-location** of observations from different RIs and between observations and experiments is a straightforward strategy and should formally be developed towards "**Cooperative ENVRI Master Sites**" (CEMS).
- **Data interoperability** needs to be further developed.
- A proper **strategic framework** has to be established beyond the usual runtime of EC projects to support clustering over at least a decade for the process addressed in this report. ENVRIplus can be seen here as a guiding example.

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