ExpeER

Distributed Infrastructure for EXPErimentation in Ecosystem Research

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Contributors: M. Mirtl; S. Klotz; M. Frenzel; T. Parr; M. Forisus; J. Bäck; M. Kertesz; Th. Dirnböck; J. Kobler; C. Beier; A. Asmi

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1. Main conclusions & outlook

There is general agreement about the need for a hierarchy of integrated infrastructure components, covering observational and experimental ecosystem research. The **non-invasive comparative approach** consists in observations and monitoring of a large number of ecosystem types and sites in order to capture and analyse the diversity along gradients through statistical analysis and modelling, whereas the **experimental approach** deals with the manipulation of relevant forcing variables within a restricted number of ecosystem types and sites in order to analyse the cascade of responses at process level and their interactions for understanding modification of ecosystem structures and functions.

ExpeER has catalysed the development and formalization of both approaches at the European scale and contributed to integration efforts. The coupling between the experimental and comparative approach was facilitated by the further development of commonly relevant standards and services in the field of standardization and harmonization of parameters and methods, information management, field methods and ecosystem modelling. This common ground reduces the risk of fragmentation and dispersion of the continental ecosystem research community, specifically also in interaction of ExpeER´s building blocks with related research infrastructures.

An integrated ecosystem research infrastructure composed of the hierarchy of functional entities as represented by the ExpeER pyramid will help "take the pulse of a European continent", because it facilitates the combination of information on environmental drivers and their interactions taken from a smaller scale on a larger scale (extent). To this end, spatially distributed sampling is required to capture the variability in the environmental drivers. Key to such continental-scale studies are infrastructure that include following aspects:

(1) Monitoring or observational data to document status and detect trends (e.g. LTER, ICOS) and large scale monitoring schemes,

(2) Experimental data to enhance mechanistic understanding (e.g. AnaEE),

(3) Analytical and simulation tools for modelling and prediction (e.g. LifeWatch).

This allows for obtaining spatial coverage across large geographic (and environmental) extents and detailed process understanding of the small-scale processes and dynamics driven by them. Key challenges, though, are to combine (or find a compromise) between PI driven (bottom up) and designed networks (which are typically top-down). Processes need to be established to ensure a continuous feedback-loop between these two approaches. Furthermore, data sharing and joint collaboration is crucial, although these seem to be more frequent in designed, federated infrastructures while results of PI driven research are often considered to be the property of the respective PIs.

A key challenge is to transform the current network of mainly PI driven research sites into a harmonized infrastructure, combining top down components with bottom up solutions, both in the field of observation and experimentation:

- Top down components: enabling (1) the functioning as Ecological Observation Networks (EONs) in terms of standardized mechanisms to produce baseline environmental trend data, (2) cross-site comparable ecosystem research on major ecosystem processes, and (3) concerted experimentation on priority questions at the continental scale
- Bottom up (PI driven) solutions: securing scientific flexibility and customized observational and experimental solutions according to the ecological profile of specific sites

Ideally, EONs are linked with long-term ecosystem research networks and experiments (e.g. AnaEE). Embedded in key European projects and processes of research infrastructure development, ExpeER has successfully strived for establishing the building blocks of the “ExpeER infrastructure” in the European research infrastructure landscape. In addition, ExpeER facilitated clarifying the relation amongst these building blocks and many of the other landscape elements in order to organize their interplay.

Figure 1 reflects this envisaged interplay: The **central part** represents the requirement of complementary and interoperable in situ networks for standardized large scale monitoring (e.g. ICOS), natural and socio-ecological systems research (e.g. LTER) and experimentation (e.g. AnaEE). These in situ infrastructures provide data for the infrastructures **above** dealing with modelling, data analysis and workflow automation (LifeWatch, IS-ENES) supporting system understanding, predictions and decision-making. Modelling and analyses feed their parameter requirements back to the data generating units. All RIs should make use of generic supporting e-infrastructures such as EUDAT (**bottom**). Scientific and other user communities (**top**) will benefit from the RIs. A more detailed option for RI collocation of the mentioned components based on the hierarchy of their respective site categories was elaborated.

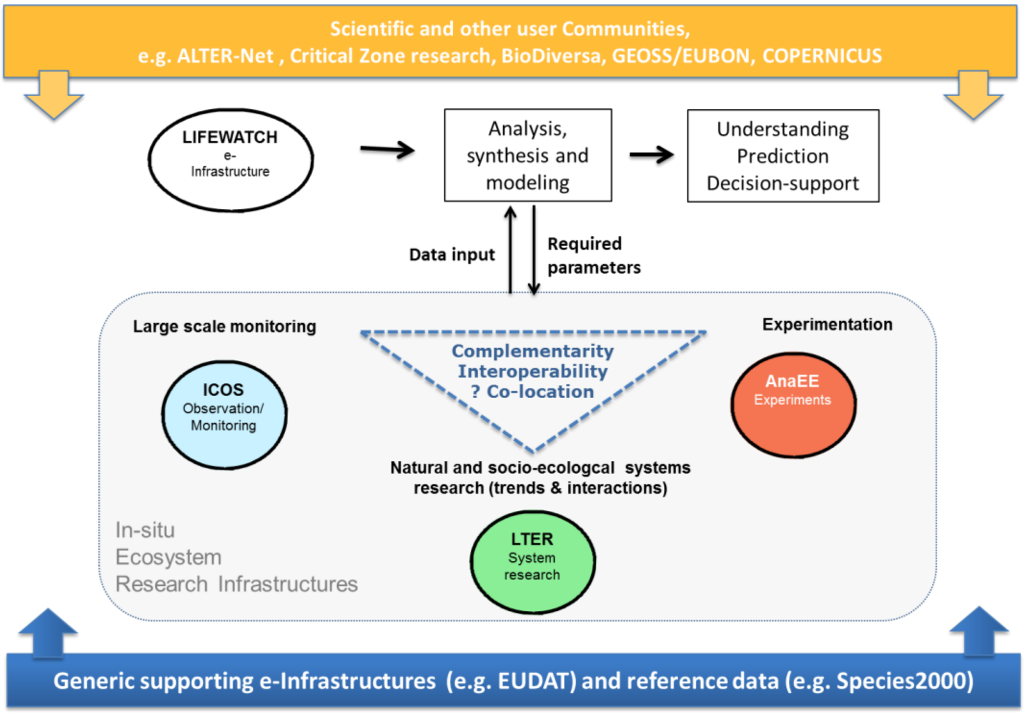

Figure 1: Interaction of in situ ecosystem and biodiversity RIs (central part) with supporting services (bottom, blue) and user communities (top, orange). [from: ESFRI Environmental Strategy Working Group (ENV SWG) start-up meeting for the ESFRI 2030 roadmap, 22 May 2014, Paris]

Specifically for the ExpeER building blocks, key challenges will be i) working in a harmonized way towards specific scientific targets, ii) using centrally provided IT infrastructure and other tools and iii) joining forces in efficient lobbying at the European scale.

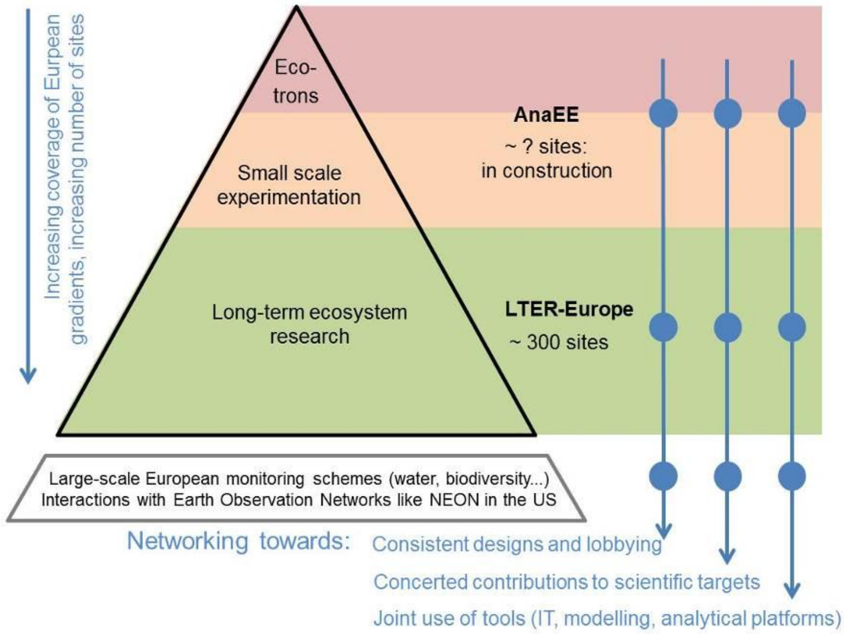

Figure 2: Interactions between the building blocks of ExpeER.

2. Structuring processes and projects

According to the ExpeER Scientific Advisory Board's recommendations, WP 4 group of ExpeER made efforts to clarify relations with key building blocks of the European RI landscape specifically relevant for ExpeER.

In terms of scientific targets AnaEE and LTER would naturally work on a mechanism for a regular and structured exchange about (1) phenomena detected by long-term observation, which should be clarified in targeted experiments and (2) modifications of observational designs for the validation of experimental findings and improvement of input data for ecosystem models.

Regarding the implementation of the "ExpeER infrastructure" substantial progress was made since 2010.

Concerning AnaEE: The ESFRI preparatory project AnaEE (2013-2016) conceptualizes site categories and is currently assessing the results of the first call for sites. AnaEE has finalized MoU with NEON in the United States and established connection with TERN in Australia. Work Package 4 of ExpeER facililtated the production of a MoC draft between AnaEE and LTER-Europe, which was adopted by LTER-Europe and sent to AnaEE on behalf of LTER. The draft can serve as basis for discussions at a later stage or in the context of bigger solutions (e.g. ENVRIplus, see below).

With respect to LTER, Memoranda of Cooperation were achieved between LTER and LifeWatch, EUBON, EUDAT and ALTER-Net. TERN is the Australian LTER sister network of LTER-Europe in the global LTER network, ILTER. LTER-Europe streamlines its network based on the site categories established and consistently applied since 2009, and tests cross-site data analyses in the Horizon 2020 project "eLTER". The eLTER ESFRI proposal was submitted in March 2015. In connection with the ICOS Letter of Support for the eLTER

H2020 project and the eLTER ESFRI infrastructure initiative, discussions about operational links with ICOS were started, specifically concerning the ecosystem component of ICOS.

Both the two above involve in the Horizon2020 environmental research infrastructures cluster project ENVRIplus, which will provide the major framework for developing the “ecosystem and biodiversity domain” in the European research infrastructures landscape. This will be done in close interaction with related RIs or components or RIs such as InterAct and the ICOS ecosystem sites, specifically in the discourse about ideal combinations and collocation of the research infrastructure components, targeted at providing a consistent picture for stakeholders, both nationally and at the European scale.

One of the important changes of framework conditions during the runtime of ExpeER was the increase of processes and projects dedicated to better structure and network the RI landscape. Besides from the formalizing and funding mechanisms (e.g. ESFRI) this category has become a crucial factor for the self-organisation of the RI landscape and is therefore of specific relevance for networking activities. In addition, the ESFRI process and focus itself has been broadened by a more comprehensive view on the entire “RI landscape” and related consultation processes.

Outlook

The scope of ENVRI´s follow-up, “**ENVRIplus**” (Environmental Research Infrastructures providing shared solutions for science and society), was substantially widened in order to support research infrastructures integration in multiple fields. The ENVRIPLUS consortium responded to the Horizon2020 INFRADEV-4 call and brings together the current ESFRI roadmap environmental and associate fields RIs, leading I3 projects, key developing RI networks and specific technical specialist partners to build common synergic solutions for pressing issues in RI construction and implementation.

Both building blocks of the ExpeER infrastructure, AnaEE and LTER-Europe form part of the consortium. The smaller scale experiences of ExpeER with RI integration and networking are reflected in a range of tasks. Supporting tools co-developed by ExpeER will be used in the project.

ENVRIplus has its focus on coordination to structure the scientific community and to reduce the fragmentation in the environmental RI landscape. This becomes practical in the 6 Themes. ENVRIPLUS will boost the up-take of the most advanced technological innovations (Theme 1) and data related services (Theme 2). This will promote efficient research and support new scientific breakthroughs. Providing common guidelines for physical and virtual access (Theme 3) will increase the multidisciplinary use of the RIs. It will, furthermore, increase trust and induce the re-use of the data, products and services of the RIs. New methodological approaches and tools to communicate with users (Theme 3 and 6), new measures to evaluate the socio-economic impacts of the environmental RI (Theme 4), improved training of the RI technicians, managers and users (Theme 5) will foster knowledge transfer and adoption of best practices. By communicating the ENVRIPLUS outcomes within and beyond the environmental RI community (Theme 6) the implementation will be optimized. ENVRIPLUS includes a education and training program for awareness, outreach and knowledge transfer that is targeted to a wide variety of users, beyond those usually reached by the single RIs. Significant opportunities for innovation are rooted in the multidisciplinary component of ENVRIplus and its multicultural context. The importance of social learning does not directly deal with technological potential but will facilitate collaboration and use of products as a base for future innovation. All these efforts are eventually made to support scientists in providing knowledge related to grand environmental challenges, such as climate change, pollution, loss of biodiversity or weather extremes.

3. Key recommendations and risks

From a holistic point of view WP4 of ExpeER fully supports the systems approach in environmental RI development as advocated for in the Environmental Research Infrastructures Strategy report by Asmi et al. (2014): Environmental Sciences are rapidly moving to become one system-level science, mainly because modern science, engineering and society are increasingly faced with complex problems that can only be understood in the context of the full overall system they belong to. There are several reasons and enablers for this shift:

- **Technology push.** Technology innovations on, for instance, detectors and sensors with ever increasing resolution, allow deep observations of scientific phenomena important for the better understanding of a whole system. Connection between these new observations to the whole Earth System requires ways to integrate between the domains. In addition, information technology innovations, such as digitalization of collections, also unlock resources at a systems-level.
- **Demand pull.** The questions scientists are faced with nowadays (not only arising from curiosity, but also from policy like IPCC, IPBES and GEO/GEOSS and societal needs) can simply not be solved using the traditional sources of information. Without access to information from adjacent disciplines, the answers scientists can give will increasingly be partial and incomplete, an therefore less ground breaking or even useful.
- **Globalization.** Like in economics and society, science is experiencing an up-scaling due to globalization. Establishing and managing big data and information repositories often demand an international effort. This can also be observed from the ever-increasing aggregation of research funding, such as ESFRI.
- **Resource integration.** Never before did researchers of so many domains have such a wealth of resources at their disposal. The integration of these worldwide available resources has further fuelled system-level research. An important contribution of e-Science as a system- level science is its potential for integration of information.
- **Science Integration.** These developments in science in general offer an excellent opportunity to approach the Earth as an integrated system, with an eye out to related sciences, such as social sciences and life sciences.

This vision can at the European scale only be implemented by smart interactions between co-located and interoperable RIs in the field of ecosystem, critical zone, socio-ecological and environmental research. The core group for terrestrial ecosystem and biodiversity research in ENVRIplus (ICOS/ecosystems, LTER, AnaEE, InterAct with their in situ facilities and LifeWatch as supporting infrastructure) could act as pivot in this development. In favour of providing realistic suggestions, the following recommendations were collated in consideration of possibilities for realization in the context of existing, just starting or highly probable projects or processes.

3.1. Recommendations

Improve interactions between research infrastructures at the European scale: One of the reasons, why the European Environmental Research Infrastructure Platform (EERIP) has failed, was the combination of necessary self-organization and highly competitive elements within EERIP. Such competitive elements are fostered by a poorly coordinated competitive framework at the European scale, where institutional or national interests can dominate over the greater common good (see risks) in absence of a clearing instance or joint vision.

- Regarding the improved interaction between JPIs and related environmental research infrastructures, the recently started **ENVRIplus project** will **provide a platform for the definition of roles and interactions of individual RIs**. An integrated system of Grand Challenges will be developed on the basis of existing classifications (e.g. EU, US NRC, ICSU). The ENVRI reference model will be expanded by a module describing the procedure of testing individual RIs against this set of Grand Challenges in order to judge the societal relevance.
- More specifically, the **ENVRIplus Board of European Environmental Research Infrastructures (BEERi)** will further develop the common environmental ENVRI strategy and it's implementation actions. The Board seeks balance between the common implementation needs of the infrastructure cluster and the specific implementation needs of individual research infrastructures and domain level.
- To catalyse **transparency of RI interactions**, LTER is preparing a motion in the BEERi context for the "Extension of the ENVRIplus reference model by one module providing a standard procedure (check list, clarification scheme) for defining bilateral RI relations between environmental RIs (in the broader context of the respective domain and the environmental sector as represented by ENVRI). The target is to facilitate MoC developments." Providing a MoC template might be too ambitious in face of specificities of different RI interfaces.
- In terms of scientific targets AnaEE and LTER would naturally work on a mechanism for a **regular and structured exchange** about (1) phenomena detected by long-term observation, which should be clarified in targeted experiments and (2) modifications of observational designs for the validation of experimental findings and improvement of input data for ecosystem models. The ENVRIplus framework and standard procedure might pave the way. Involving the new ClimMani COST action could be an option for an even broader basis for such interactions.
- **Interaction of actual research RIs and larger scale monitoring networks** (observatories): Consider improving the current organisation of observatories, since these together represent in Europe a very large-scale research infrastructure capacity.

Conceptual framework: European environmental research infrastructures with a focus on terrestrial ecosystems are currently developing a common perspective for closer cooperation in technological innovation, data management, in situ networks and access for additional scientific projects. The goal of this cooperation is a better knowledge on the long-term performance of terrestrial ecosystems in a changing world. This requires also a common theoretical understanding of ecosystems which is particularly needed for (1) a common understanding of observed variables based on their theoretical importance as indicators for the functioning of ecosystems and their integrity, (2) a resulting design of observational programmes and technologies, (3) theoretical implications from big data science for understanding of ecosystems, and (4) resulting requirements for data assimilation systems.

- As a follow-up of the ExpeER/WP4 workshop, February 2015, Vienna, a ENVRIplus WP 12 Task 1 workshop should be held to (a) develop a **common theoretical understanding of terrestrial ecosystems** as a base of future cooperation and (b) identify key implications for in situ network integration, interoperability and co-location.
- With respect to **environmental observatories** such conceptual framework touches the following issues:
    - What is a common analytical framework and which empirical models to provide a theoretical framework for monitoring plans?
    - Increase attention for data collection in relation to key research topics.
    - This includes the necessity of a broad scale monitoring system contributing to the sustainability of ecosystem services. What is missing in the design and equipment in the current system?
    - What are adequate spatial and temporal scales and resolutions for studying biodiversity and ecosystems supported by observatories? What size, frequency and granularity in measurements is required, depending on research question?
- Where to add **targeted experimentation**? - Comparable controlled environments for distributed experiments, such as with ecotrons and mesocosms with on-line process measurements.
- The conceptual framework should systematically consider the **requirements of the biodiversity research community** elaborated in the workshop “Investing in Innovative Research for nature and our livelihoods: Strengthening the research strategy to reinforce the ERA on Biodiversity” (11-12 April 2013, Brussels). Numerous of these requirements touch upon RI concepts and design.

Building implementation plans on real conditions: Matter of factly the new European distributed ecosystem RI cannot be built entirely from the scratch, but will need to carefully combine existing facilities and previous investments with concerted upgrades plus new elements, which are currently entirely lacking. This concerns entire RIs (see item above on RI interactions) as well as individual RIs. Both need to build on a reliable picture of existing facilities across countries.

- **Site documentation:** Set up joint site documentation for *in situ* research sites in order to identify overlaps and the ideal basis for the expansion/use of sites by other emerging infrastructures.
    - Recommend building this documentation on the **existing DEIMS** system (http://data.lter-europe.net/deims/), which already contains a big part of European sites and also serving as a global site documentation facility, which is already used for ExpeER, LTER-Europe, the global ILTER, CZOs, EnvEurope and will be the site documentation for a number of emerging H2020 projects.

- Check the RI **coverage and representatives** for data delivery of the major European ecosystem types, environmental zones and socio-ecological regions.
- Focus infrastructure development on **sustainable long-term sites and natural science collections.**
  - Importance of long-term time series to characterize biodiversity/ecosystem change, and the (socio-)ecological profile of a research site (land-use legacy, fisheries)
  - Include short-term projects/activities (e.g. experiments) to be embedded in long-term infrastructures wherever possible.
- Integrate national strategies (roadmaps) for observational and experimental sites
  - responding/contributing to several EU level infrastructures to
  - increase logistical efficiency and scientific interoperability.

Policy of concrete steps and practical interactions: Joint efforts in overlapping fields of activities of individual RIs might have equally strong effects as strategic decisions and integration efforts:

- Mapping of internal data services of observational platforms. Strategies to overcome fragmentation of e-infrastructures should be developed.
- Joint expert groups in priority fields identified by the Related Sites Group and the in situ integration workshop:
  - DEIMS:
    - extend the existing documentation of ecosystem research sites to main RIs
    - Strengthen the data platform, contacts section (--> human component/ researchers)
    - establish a publications section
    - start using DEIMS for the communications aspects addressed in the discussion
  - RI landscape mapping: A team of “dedicated RI co-ordinators” to produce a consensual picture of the landscape.
  - Ecosystem research parameters
    - Build on the achievements of EcoPAR
    - Continue work on priority parameters across environmental RIs
    - Facilitate access to protocols and manuals in order to prevent fragmentation in data incomparability
    - Support „methodological consulting“ of individual sites
  - Mapping of internal data services of in situ RIs (existing, planned) and mutual use. Strategies to overcome fragmentation of actual e-infrastructures should be developed (user driven division of tasks according to use cases provided by in situ RIs such as in EUDAT2020).
  - Joint training activities (mutual invitation/attendance in training activities on field methods, use of standardized protocols, data management, stakeholder interaction, technical equipment)

3.2. Risks

The lapse of time covered by the ExpeER project and concomitant processes were well suited to identify major risks for a successful research infrastructure development and integration at the European scale:

- Strong players pushing developments without consideration of the existing landscape and possible stakeholder irritation:
  - Institutional level: experience has shown, that the complex task of organizing RIs at the national level requires a basic level of national consensus. Even though some institutions might be strong enough to create standalone solutions of substantive size, there is no example in Europe, where such policy lead to durable success
  - Country level: here the above arguments apply in principle. However, the effects might be even more detrimental. If a basic agreement on the interplay and division of tasks amongst RIs cannot be achieved or is neglected by one or a few players, consistent RI integration and implementation across countries cannot succeed at the European Research Area scale.
- Blind competition leads to frictions and unproficient images of the entire domain (stakeholder interaction)
- Stakeholders are not willing to invest consistently across countries, where lacking integration and consensus inhibit achieving a consistent critical mass of individual building blocks across countries. This results in a patchy geopolitical coverage of each individual RI.
- Trade-off between too many single RIs on the one hand and an incomplete coverage of functional niches of ecosystem research on the other (e.g. consistent monitoring AND experimentation AND cross-scale system research)
- Trade-off between centralistic approaches (option to have only one integrated ecosystem & biodiversity RI) on the one hand and limitations of central organization on the other (necessary balance between bottom-up and top-down; necessary specialization).