PROJECT FINAL REPORT

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1 Final publishable summary report

1.1 Executive Summary

The ExpeER facilities were reviewed, and were determined to have good levels of capacity with respect to meteorological observations, soil physical parameters, atmospheric analyses and autotrophic organisms, though experimental manipulations, biodiversity studies, hydrology and soil characterization could be improved. There is a need to increase the number of ecosystems to enhance comparisons between similar ecosystems in different climatic zones, and the availability of analytical and ecotron platforms is insufficient.

In order to gain scientific value from integration of research infrastructure, it is essential that data are collected in comparable ways. This is much easier if common protocols are used. The ExpeER project identified a priority set of ecological measurables for protocol development in consultation with the community, developed the protocols through a process of testing and refinement, and disseminated them through the website and training events.

Providing a common framework to document site information and data is needed to allow for a sufficient and seamless exchange of information. Focusing on sufficient meta-information and building a common semantic framework is needed to reach this goal. ExpeER worked on the enhancement of scientific cooperation and reuse of data and information by offering an overview on sites, datasets and persons, delivered through a web catalogue service.

A quantitative overview of *in situ* networks, projects and processes relevant for ExpeER was elaborated and documented in a database and visualised in a MindMap. Several meetings of the Related Sites Group were used to gather feedback on the ExpeER concepts and vision. ExpeER contributes to key processes related to RI development in ecosystem research notably AnaEE (http://www.anaee.com/), a distributed research infrastructure for experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems.

ExpeER developed the tools necessary for the internal and external communication (logo, website, flyer, Facebook page, monthly bulletins, posters, presentation templates and two brochures: presentation of ExpeER, ExpeER results). Communication with ExpeER end-users and institutions supporting science was done through distribution of flyers, mails, brochures and through the organisation or participation to meetings and conferences. A specific investment was done to promote transnational access activities.

A total of 1617 transnational access (TA) days (*i.e.* working days) were provided during the project, with 106 projects/visits taking place, and TA users coming from 20 different countries (EU and non-EU Member states). TA projects covered a wide range of topics and research themes, with the large proportion of visits taking place in forest ecosystem types (63%), followed by agricultural (17%), peatland (11%), grassland (8%), and coastal (1%). A total of 25 scientific publications have been produced thus far by TA users/projects, with 9 scientific peer-reviewed journal papers, and 16 conference proceedings (oral and poster presentations).

In recent years, rapid technological developments created new opportunities to overcome some of the critical limitations in understanding ecosystem processes, allowing for an improved monitoring of processes at a range of scales from laboratory to the field or region, providing opportunities for improved non-invasive monitoring and for transdisciplinary data integration. ExpeER tested and evaluated a set of these new measurement techniques, from DNA-re-sequencing to optical remote sensing.

ExpeER clarified how techniques and setups in ecological experiments that manipulate climate, CO_2, and/or study aspects of biodiversity can be improved. The advances concerned a range of techniques and approaches used in global change research and will be of benefit to the research community, improving the relevance and reliability of experimental ecology.

Three ecosystem models (CoupModel, JULES and LPJ-GUESS) were applied across European transects (>1000 grid cells) plus grid cells containing all ExpeER sites using relevant global / regional / modelling databases. The vegetation process representations in each model were then evaluated by comparing the simulated outputs from each model to observed GPP and water budgets. A web-based modelling toolbox was developed including model descriptions, evaluations of their strengths and weaknesses, and model outputs for the grid cell applications as well as for five example sites.

Two frameworks, one based on variational data assimilation and one based on a combination of Markov Chain Monte Carlo based parameter estimation and sequential data assimilation, for the upscaling of water, energy and carbon fluxes were developed and successfully tested, showing the feasibility of the approaches. Two frameworks for upscaling of biodiversity, an empirical based approach and wavelet analysis, were tested at the small catchment scale and the larger regional scale. Finally, it was evaluated whether fluorescence data hold important information for ecosystem modelling.

1.2 Summary description of project context and objectives

Ecosystem research is increasingly vital to address policy issues facing Europe and the globe, from nitrogen deposition to global carbon fluxes and climate change. Yet European infrastructures that address such research and monitoring challenges are badly fragmented and uncoordinated.

ExpeER brings together major observational, experimental, analytical and modelling facilities in ecosystem science in Europe: under the same umbrella, and with a common vision, ExpeER forms a key contribution to structuring and improving the European Research Area (ERA) within terrestrial ecosystem research. The ExpeER Integrated Infrastructure enables integrated studies to forecast the impacts of climate change, land use change and biodiversity loss in terrestrial ecosystems.

ExpeER builds on an ambitious plan for networking research groups and facilities. The joint research activities provides a common framework and roadmap for improving the quality, interaction, and individual as well as joint performance, of these infrastructures in a durable and sustainable manner. ExpeER provides a framework for increased use and exploitation of the unique facilities through a strong and coordinated programme for Transnational Access to the infrastructures. Extensive outreach and collaboration with related networks, infrastructures as well as potential funding bodies ensures that ExpeER contributes with its key experiences to the shaping and designing of future research networks and infrastructures, and that it aims to get full support from all stakeholders in reaching its long-term objectives.

1.3 Description of the main S&T results/foregrounds

WP1 Analysis of current resources and roadmap for the EXPEER integrated infrastructure

The ExpeER research network is comprised of four types of research infrastructure distributed across 31 facilities within 13 European countries. Of these, 28 are highly instrumented experimental field sites or highly instrumented observational field sites, 1 Ecotron (on closed during the ExpeER project) and 2 Analytical Facilities which provide state of the art controlled environment facilities and analytical equipment for ecosystem research. Questionnaire feed-back from site managers revealed strengths and weaknesses within the network, from which areas for improvement were identified.

The questionnaire responses indicated that the ExpeER sites are located within seven climatic zones, including humid subtropical, oceanic, continental, semiarid, subtropical (dry), subarctic, and highland with annual rainfall and mean annual air temperature ranging from 500 - 2500 mm and 3 – 17°C, respectively. However, the ExpeER sites do not cover all ecosystem and climate zones, and forest ecosystems are over-represented compared to the other land uses in Europe. The information for each site was divided into 9 categories and synthesised graphically using radial diagrams to help characterise the main focus of research at each site. For illustration, three agricultural and three forest sites have been combined in figures 1A and 1B respectively. More environment and vegetation parameters are analysed at the agricultural sites (Fig 1A) compared with the forest sites, which are mainly observational (no manipulations; Fig 1B), In general, many sites have good technical services and conduct a broad range of meteorological and soil measurements, but many were lacking laboratory space for collaborative work. In addition, it was apparent that the extent of the experimental manipulations together with a range of other measurements, including hydrology, local atmosphere and biodiversity, could be expanded. There also appeared to be a bias in favour of studies on autotrophic organisms (mostly plants) compared with heterotrophic communities.

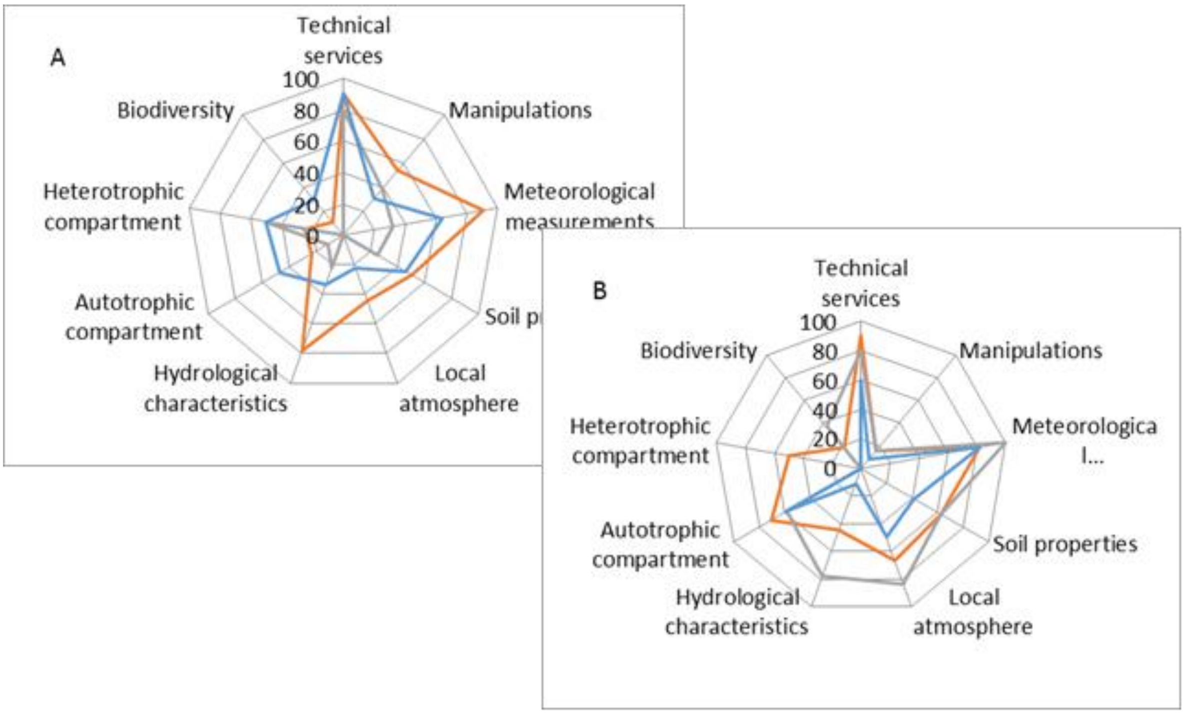

Figure 1. A: Agriculture: Orange: Harz Tereno (Germany), Blue: Rothamsted (England), Gray: Apelsvoll (Norway) and B, Forest; Orange: Hyytiälä (Finland), Gray: Zöbelboden (Austria), Blue: Hesse (France)

In addition, the time resolution of different measured parameters at the sites was examined. For illustration, figure 2 shows the number of sites recording data on various categories of organisms. Most sites record the essential meteorological parameters, but hydrological measurements (drainage) at many of the sites are missing, an important component of most ecosystem models. The ability to manipulate climatic factors and other drivers of ecosystem development is shown in figure 3. Many ExpeER sites are largely observational but about 70 manipulations of ecosystem drivers are carried out at some sites (Fig 3). The data indicate that land use, irrigation/drought, soil management (*e.g.* cultivations) and fertiliser/manure applications were the most common experimental treatments imposed at the sites (Fig 3). Less common were manipulations of atmospheric variables, biodiversity, temperature and drainage; no manipulations of ozone, salinity or radiation were conducted in situ. For climate change research, these variables are highly relevant and can truly help validate the estimates of earth responses and feed-back mechanisms. However, considering the European diversity of climate and ecosystems, the manipulation of some important drivers (*e.g.* temperature) is not conducted at enough sites to allow conclusions to be drawn at the continent level.

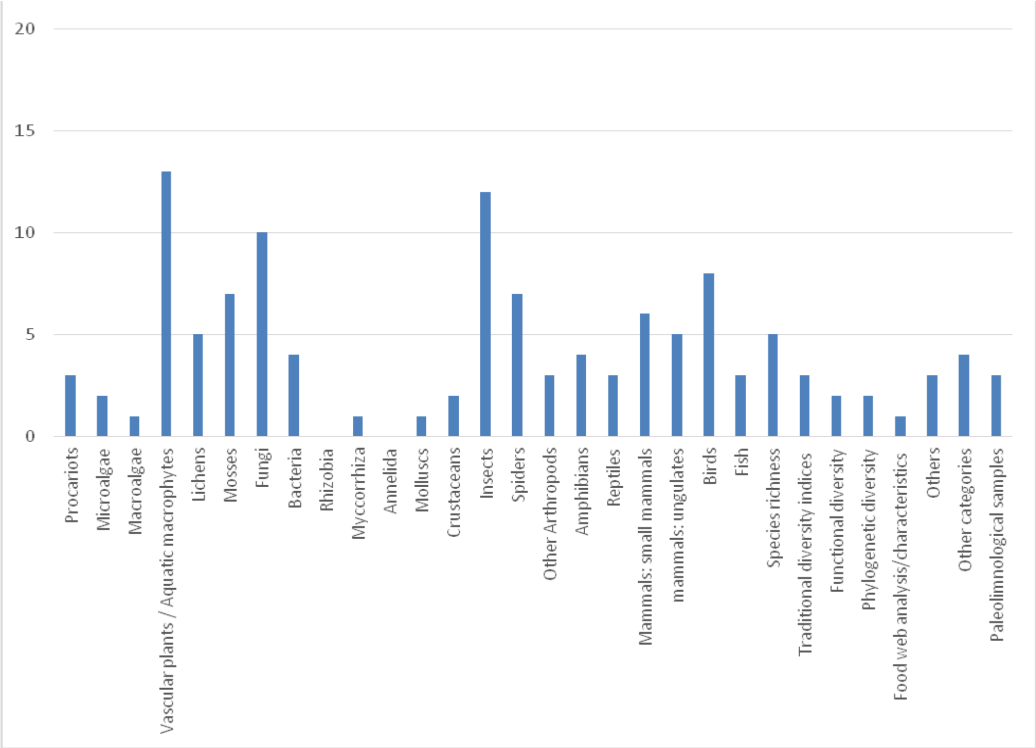

Figure 2. Number of ExpeER sites conducting biodiversity measurement on specific categories of organisms (Traditional diversity indices: Shannon, Simpson, etc.; Food web analysis/characteristics: length, connectivity, etc.)

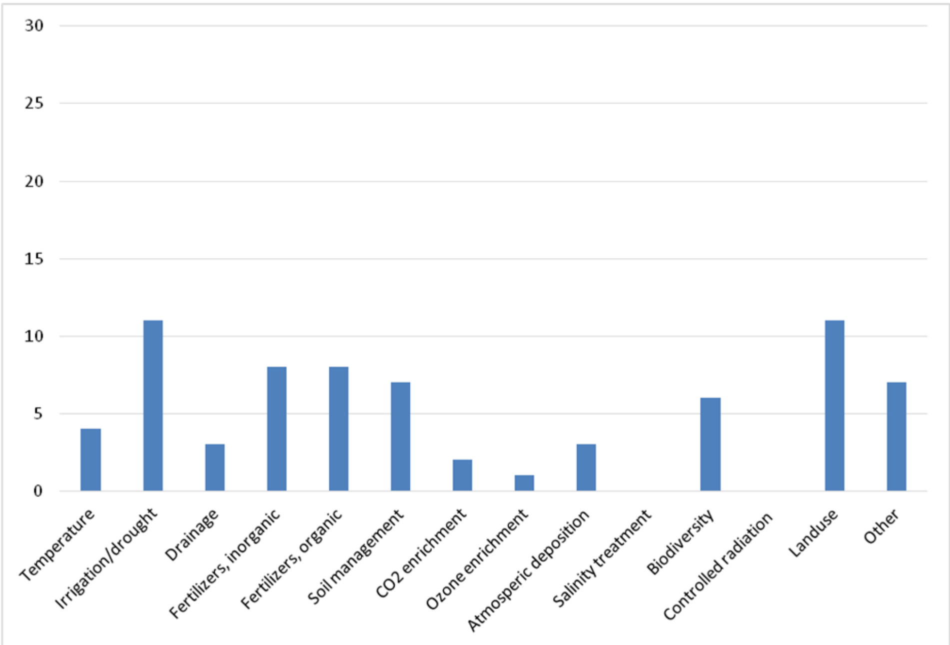

Figure 3. Number of ExpeER in situ sites manipulating various ecosystem drivers. (Controlled radiation includes light intensity and spectrum treatment).

Based on the work of WP1, there is a clear need to further develop the research network established within the ExpeER project.

WP2 Standardization of core variables and protocols

The objective of the WP was to select, develop, train and disseminate a suite of protocols for ecosystem measurement that could be conducted across European research infrastructures, in order to enable to collection of more harmonized data than is currently the case. The approach was to select protocols to measure data that are important indicators of the state of ecosystems, that would be relevant to the ExpeER network, and have not already been covered by international standard approaches. Relevance to ecosystem function was judged against the framework of 'ecological integrity' comprising both ecosystem structures (with biotic diversity and abiotic heterogeneity as high level components) and ecosystem processes (with budgets of energy, matter and water as high level components).

A long list of 58 measurables for terrestrial systems was prepared by reviewing current practices. This list was filtered to retain those considered important to ecosystem integrity; those relevant to a wide range of study sites; those being easily executed and inexpensive; and not already covered by major international standards. The list was sent to all ExpeER partners for prioritisation, which was finalised at the ExpeER meeting of February 2012. This short list comprised, leaf area index, plant biomass, soil macrofauna, soil moisture, soil nutrients (NPS concentration), soil organic matter, soil respiration, evapotranspiration, land use type and phenology. In addition, cross reference was to be made to the ExpeER metadata standards, so that data collected using these protocols on ExpeER sites would be accessible to the wider research community.

Draft protocols were developed for these by subject experts between March – June 2012, which were tested in August 2012 during a 5 day field course in central Italy. The experience was used to refine the protocols. Two training courses were held which were targeted at non-ExpeER staff, again in Rome (May 2013) and Amsterdam (August 2013). Feedback from these courses were used to refine both individual protocols and the protocol set as a whole; there was some re-organisation of protocols, and the protocol for phenology was not taken forward as it became clear the International Phenological Gardens (Chmielewski, 2008) already provides an appropriate protocol.

A set of seven protocols were published, reflecting a broad range of ecological functions. Instructions for metadata recording were also provided.

Ecological functions	**Protocol**
Matter storage	Above ground biomass
Matter loss, nutrient cycling	Decomposition
Habitat diversity, habitat management	Land use and management
Energy capture	Leaf area index
Faunal diversity	Soil macrofaunal diversity
Matter storage, element concentration	Soil organic matter – C & N stocks
Metabolic efficiency	Greenhouse gas emissions from soils

Table 1. Set of seven protocols, reflecting a broad range of ecological functions

Image 1. Practical lesson of biomass sampling in grassland during the SAéPER course in Amsterdam

WP3 Information management and data access

ExpeER WP3 has worked on the extension of the metadata system DEIMS to cover the needs of both, the experimental and the observational communities. This includes the export of metadata to achieve ILTER compliance and export in ISO1915 to achieve INSPIRE compliance. This work has included the integration of web browser metadata and maps data viewers (*e.g.* a pilot map view in DEIMS) to give greater visibility to data from both communities.

An important task in achieving semantic interoperability across data providers and scientific domains is the development of the common vocabulary for the community. This work was based on the extension of the thesaurus EnvThes in order to cover both domains, experimental and observational, and restructuring the root concepts and hierarchy in order to facilitate mapping to the conceptual model of Observation and Measurement (ISO19156).

In order to provide improved knowledge for the environmental management and to support the development and implementation of targeted and evidence based environmental policies at European scale, information on the status and trends of ecosystems as well as on the underlying processes is needed. To enable this, a broad variety of data is generated by research sites and communities adding up to a common data pool used to analyse the effects of drivers and pressures along European scale environmental gradients and experimental treatments. Nevertheless, still a number of challenges need to be addressed when integrating these data. Despite harmonisation efforts by various research infrastructure initiatives and networks, still a lot of data heterogeneity exists across borders of different scientific domains or research infrastructures. In addition to the variety of disciplines involved, data management still shows a high level of diversity - ranging from single data centres to dislocated data storages at single institutes or research groups. Also different data formats, descriptions or reference lists are used by the different communities.

Based on the requirements, ExpeER focused on the development of a common semantic framework and the provision of site meta-information. These activities were in line with the identified objectives of the work package. Building a common vocabulary is needed as a semantic basis for the integration. This does not only concern the technical aspects of managing the thesaurus and the content aspects of developing the concepts and structure but moreover also the social aspects of developing governance which allows the development and use beyond the runtime of the project. The work was based on EnvThes, a SKOS/RDF thesaurus dealing with the long term ecological observation domain, which was extended to include concepts dealing with long term experimentation and agricultural treatments used in this context. The work resulted in a total of about 2.500 terms collected and described in EnvThes. Interlinks to other existing thesauri and controlled vocabulary were established.

To allow delivery of data descriptions using the controlled vocabulary, the metadata system DEIMS was extended. This also allows for the demonstration of pilot map by using OpenLayers, an open source library, and OGS WMS technologies to allow basic viewing of underlying geospatial data.

The pilot map interface focused on the development of standards-based provision of geo-spatial information integrated with the meta-information platform providing information about the long-term observation and monitoring sites. The pilot map interface was utilized to provide an integrated framework for evaluating ecosystem service potential under different scenarios.

The original work plan assumed that the standards most suitable for the ExpeER project would fall within the realm of Open Geospatial Consortium (OGC) ISO/TC211 geospatial standards such as the WMS standard used for map viewer delivery. However, sticking to the original WP3 plan would involve the deployment of geospatial software, for both metadata management and demonstration of map services. However, results from the Task 3.1 Metadata Framework showed that Ecological Metadata Language (EML) is a second important standard for the ExpeER community, running experimental and observational ecological research sites. Extending the ISO/TC211 metadata standard with EML will generate compliance with other communities (US-LTER, LTER-Europe), helping scientists to make use of synergies and allowing the use of the existing DEIMS web cataloguing tools for dissemination.

From this work programme the following main results have been achieved:

- Establishing the metadata framework to link between the ExpeER communities leading to compatible standards for the ExpeER developments and beyond.
- Robust and O&M compliant structure of the root concepts of EnvThes, which will enable an easy application of the conceptual model for INSPIRE compliant data services.
- Extension of EnvThes towards a controlled vocabulary as well for ecological monitoring as for experimental ecology, thus enhancing the semantic interoperability of data of the two sub communities.
- Establishment of semantic interoperability between the controlled vocabulary (EnvThes) and the tool guiding the setup of LTER sites (ECOPAR).
- Extension of EnvThes towards the semantic needs coming from AnaEE France, covering agriculture and experimental ecology.
- Enhancement of the applicability of units by adding their dimensions and thus helping to understand the meaning of the units.
- Removal of diverging semantics between EnvThes and the metadata system of DEIMS which is derived from the missing live link between those two components of the ExpeER architecture.

Based on these achievements the integration and publishing of information and data from the long term ecological observation and experimentation domain will continue. Within ExpeER important steps in the further development of EnvThes and the metadata platform DEIMS have been done which will continue beyond ExpeER as additional data are produced and described within this framework.

WP4 Creating a sustainable network

A comprehensive database of networks, projects, infrastructure, strategic processes and funding mechanisms was elaborated based on input from the ExpeER community and bilateral interviews with relevant co-ordinators and stakeholders. The elements of the resulting database (deliverable D4.1) were first clustered, then prioritized and graphically illustrated in a mind map of the strategic environment of ExpeER, forming the strategic environment for ExpeER in the European Research Area.

ExpeER supported joint expert groups mainly in the field of IT and standardization / harmonization, resulting in co-operations and the joint use of priority parameter lists and site documentations in ExpeER, EnvEurope/LIFE+, LTER-Europe and the global ILTER.

Discussion about the ExpeER identity and vision was facilitated in order to create the basis for the elaboration of funding options. This resulted in the concept that the building blocks of ExpeER (AnaEE and LTER-Europe) shall be implemented as separate, but closely interacting and jointly lobbying elements of the European Research Infrastructures in the field of ecosystem research (projects and proposals in ESFRI and H2020). A scheme for interactions with other RIs as well as supporting services and user groups was developed (e.g. the ESFRI AnaEE http://www.anaee.com/).

WP5 Communication and dissemination

After providing a communication plan, WP5 developed the tools necessary for the internal and external communication of ExpeER (logo, website, flyer, facebook page, monthly bulletins, posters, presentation templates and two brochures (ExpeER, ExpeER results). The first brochure (64 pages) was sent to 400 partners and stakeholder and distributed at various conferences. The final Results brochure (54 pages, 400 copies) is distributed at meeting and on the web.

In order to communicate with ExpeER end-users and institutions supporting science, the following efforts were made:

1) Maintaining of continuous contact with over 1500 potential end-users of the ExpeER products, including national ESFRI representatives, headquarters of Academies of Sciences, big research institutes, other infra projects, site managers of LTER and other scientific and monitoring networks, FP7 projects coordinators and scientists;

2) Learning of the opinions about ExpeER products and desirable results aimed at improving the products;

3) Broad distribution of TNA calls for the more efficient use of ExpeER infrastructure and related budget;

4) Keeping informed the ESFRI national representatives in order to support ExpeER partners in development of experimentation infrastructure based on National Roadmaps.

The ExpeER conference took place on 23-24 September 2015. Close to 100 participants from all over the world attended the conference, including 23 speakers and 13 poster presenters. Various domains were covered, among which forest, soil sciences, agriculture, hydrology, economy, and modeling. The presentations focused on the following topics: “research infrastructures to address the global change”, “linking in natura to in vitro experimentation”, “new tools to meet new challenges” and “data access and modeling”. 11 keynote speakers provided their insight on these issues. Major output of the ExpeER project were also presented. The presentations were complemented by 3 sessions of poster display and a concluding plenary session of open discussion. The conference proceedings and the ExpeER brochure focusing on the project’s sites were handed out during the conference (D5.4). Most of the presentations from the conference were made available on the conference website,

In addition, it was decided to have some results of the conference, completed by additional complementary chapters, published by an international publisher. CRC Press (Francis & Taylor) reviewed the proposed content of the book and accepted its publication, which is planned for the beginning of 2016.

WP6 Management of the calls for Access

The ExpeER Call for TA was opened in June 2011 and came to a close on 31st January, 2015. The TA call was a continuously open mechanism, attracting researchers from throughout Europe by offering access to 29 state-of-the-art research infrastructures across Europe.

TA visitors were offered financial support to contribute to subsistence and travel expenses incurred during TA visits. TA visitors were asked, on a volunteer basis, to provide an informal account of their TA experience, via the TA User Feedback form, which was subsequently uploaded onto the ExpeER website.

At the close of the call, the ExpeER Coordination Team had received 93 full applications, of which 13 were deemed ineligible to receive financial support following review (*i.e.* rejected after scientific evaluation). In addition, 28 "fast track" applications were received, of which 2 did not pass the evaluation stage. In total, 106 TA projects were accepted and took place during the entire time in which the call was open (45-months).

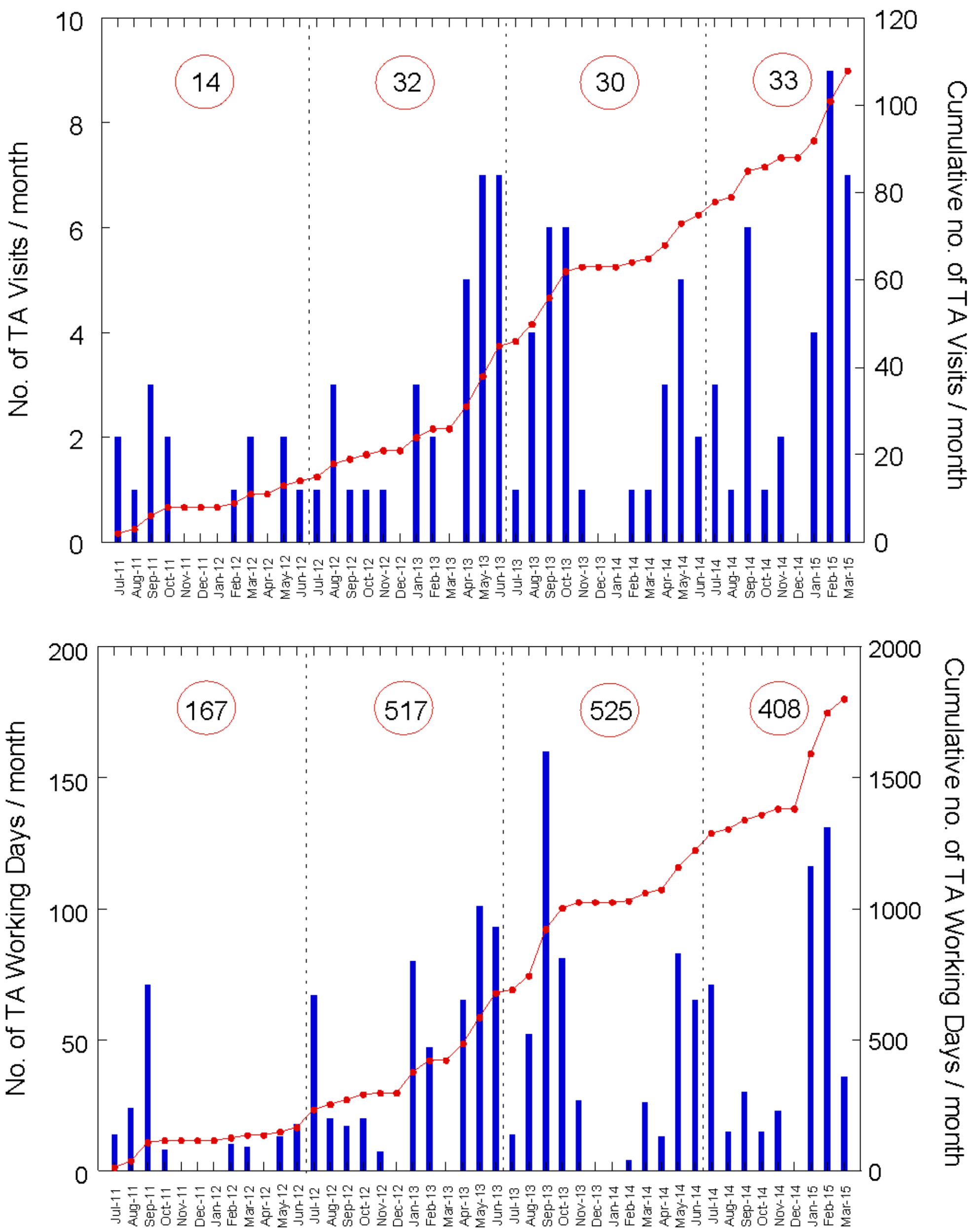

Figure 4. TA activity throughout the ExpeER project: number of TA visits per month and cumulative total (top) and number of TA working days per month and cumulative total (bottom). Yearly totals are shown in red circles.

TA Site Name	Min. quantity of TA to be provided	Number of TA Visits	Nº TA Days Used	% TA Days Used
Apelsvoll, Norway	29	0	0	0
Braila Islands, Romania	57	0	0	0
Seehornwald, Switzerland	22	0	0	0
Therwil, Switzerland	22	0	0	0
Moor House, UK	90	1	3	3%
Lusignan, France	120	2	10	8%
Tatra Windstorm, Slovakia	264	2	25	10%
Hesse, France	57	2	7	12%
Hartz, Germany	64	2	12	19%
Ecosylve, France	36	2	9	25%
Eifel, Germany	120	3	36	30%
Roma-Lecceto, Italy	61	3	39	64%
Whim, UK	120	9	99	83%
Beano, Italy	25	4	23	92%
Rothamsted, UK	32	5	30	94%
Fruska gora, Serbia	75	5	75	100%
Hyytiala, Finland	168	10	172	102%
Jena, Germany	72	4	74	103%
Molecular Ecology Lab, Italy	48	4	50	104%
Tetto Frati, Italy	43	4	47	109%
Achenkirch, Austria	58	4	71	122%
Puechabon, France	41	3	51	124%
Negev, Israel	124	12	156	126%
Donana, Spain	67	5	85	127%
Biogeochemistry Lab, France	80	4	110	138%
Zöbelboden, Austria	15	4	21	140%
Höglwald Forest, Germany	140	6	205	146%
Klausenleopoldsdorf, Austria	33	2	49	149%
Montpellier Ecotron, France	98	9	158	161%

Table 2. Summary of TA activity across ExpeER sites, including number of visits, number of TA days used, and the % of TA days used as per DoW (as per updated figures 2nd July, 2014). TA sites are ranked in order of % TA days used.

A total of 1617 TA days were provided, with the average length of TA visits being 15 days, and the average TA user reimbursement was of 2570,55€.

Scientific output from the TA programme includes scientific journal publications and conference proceedings, covering a wide range of topics as reflected by the variety of TA applications/visits. To date, we have been informed of 25 published items resulting from ExpeER TA visits/activities. Nine of these are scientific journal publications (*i.e.* peer-reviewed) and the remaining 16 are conference proceedings (*i.e.* posters and oral presentations).

WP7 Develop and test new methods to overcome current limitations in understanding ecosystem processes

In the last years, technologies for ecosystem monitoring and exploration have made enormous progress, now providing new options for ecosystem research. Within WP7, a set of new and emerging technologies in ecosystem science was tested and the potential to overcome some of the current limitations in the understanding of ecosystem processes was evaluated. The WP comprised of four individual tasks representing technologies for specific process-scales of interest.

The first technology that was tested is the Next generation DNA re-sequencing technologies in elucidating the soil biodiversity. Changes in the availability of water within soil environments can result in changes in the abundance of bacterial taxa. Given that bacteria are the main drivers of biogeochemical cycles within the soil, changes in the ecology of these organisms has the potential to change the cycles of essential nutrients such as carbon, nitrogen and phosphorous. However, the vast majority of soil bacteria have not been identified and their function is not well understood due to difficulties in culturing them within a lab environment. Task 7.1 used metagenomics and metabarcoding, two DNA-based methods to assess diversity and abundance of bacterial taxa and functions. These methods involve the extraction of DNA from soil samples, effectively sampling the entire soil microbial community. DNA was then sequenced using high throughput sequencing methods and processed using bioinformatic pipelines. These programs cluster each DNA sequence by their similarity, and then compare each cluster with existing databases of taxonomic or functional marker genes, enabling the identification of the taxa and functions present within a community, and their proportional abundances.

Two contrasting manipulated ecosystem approaches were selected for the testing of these methods, one long term drought site, and another set of three sites treated with biochar (a potential carbon sequestration method, also associated with increase soil fertility, aeration and water holding capacity). Whilst bacterial species richness from alpha diversity showed no significant difference between treatments at any site, fungal richness in the UK was significantly increased by biochar after one year. Community composition analysis indicated significant changes in both presence and abundance of bacterial operational taxonomic units (OTUs) in the UK and Italy. For the French site, significant differences were observed in rare bacterial OTUs, but the same taxa dominated with and without biochar. Significant impacts of biochar were revealed for community structures, with the bacterial phyla *Acidobacteria, Actinobacteria* (family *Microbacteriaceae*), and the fungal taxa *Inocybe*, *Myrothecium*, *Thelephoraceae*, *Cortinaraceae* and *Bolbitaceae* displaying the largest shifts in abundance. These changes suggest an ecological and functional shift towards a soil that was more copiotrophic, with large consequences for long-term soil and plant processes. Overall, this report gives a tantalising view of the soil microbiome at contrasting sites across Europe, that more research on our understanding of the soil microbiome is warranted and that permanent addition of biochar to the soil may have significant and as yet, unpredictable impacts on soil microbial diversity.

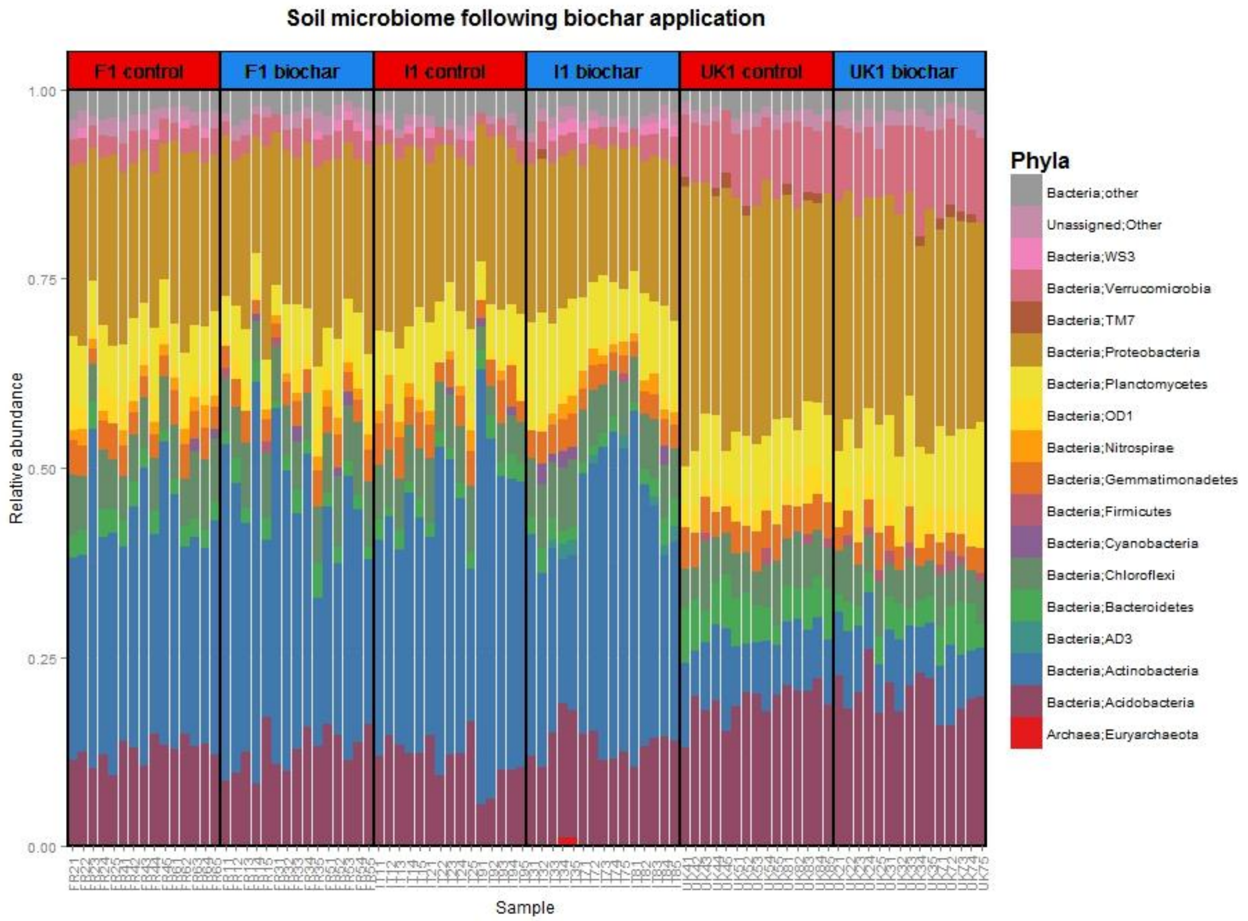

Figure 5. phylum level shifts in bacteria due to treatment. F = France, I = Italy, UK= UK. Blue and red column headers denote treatment, with control samples in blue and biochar samples in red.

Comparison of the differences between treatments showed no difference in the alpha diversity, a measure of the number of different taxa or functions present. Therefore, neither biochar nor drought had any impact on the number of different organisms present. However, analysis using beta diversity measures, which take both the identity and the abundance of each category into account, showed a tentative effect of biochar application on community structure, although no difference in abundance in functional abundance was detected. Our follow up study specifically targeting biochar showed significant changes in the structure of microbial communities due to treatment, illustrating the potential for NGS methods to detect taxa specific changes in abundance. Whilst both metagenomic and metabarcoding methods prove useful, we recommend future studies utilise greater levels of replication to increase the resolution of results, enabling the detection of smaller shifts in diversity of both taxa and functional marker genes.

The second technology we focused on is advanced spectroscopic and spectromicroscopic imaging and mapping to study soil interface architecture and function. One of the approaches developed during ExpeER was the combined exploitation of research infrastructures at field and laboratory scale. We used samples from a field experiment carried out at one of the ExpeER field sites (SOERE ACBB Lusignan) to test the influence of different water contents at field scale on decomposition processes by using stable isotope analyses. The nanoscale analyses of these samples gave us the opportunity to further develop nanoscale investigation using NanoSIMS by using morphological characterisation of the organic matter investigated by NanoSIMS (Rumpel *et al*., 2015). The combination of well-designed field experiments and the use of analytical research infrastructures allowed us to develop new hypothesis concerning the mechanisms of soil organic matter formation under field conditions.

We improved the correlative evaluation of small scale environmental processes using different spectromicroscopic techniques including NanoSIMS. We also tested the developed protocols and methods successfully on other environmental samples including plant tissues and microorganisms. We were thus successful in the development of new methods to study in more detail the biogeochemical processes which determine major elemental cycles at ecosystem to global scales (*e.g.* C, N and P cycle).

The third technology being tested in ExpeER is combining wireless sensor networks, mobile geophysical platforms, and cosmic ray moisture sensors to observe the complex hydrological feedbacks at the field scale. Soil moisture is one of the critical state variables in the terrestrial environment determining both the storage of water in the soil and the generation of runoff processes. An adequate knowledge of soil moisture distribution and related hydrological feedback mechanisms at the landscape level is a fundamental precondition for improved model predictions and system understanding. A critical current scale gap in soil moisture monitoring exists between the availability of point measurements using in-situ sensors and remotely sensed estimates of soil moisture covering larger areas. Recent advances in soil moisture monitoring technologies promise to overcome this scale gap. Within the course of the project three of these innovative technologies have been evaluated: mobile geophysical platforms using electromagnetics (EMI), wireless soil moisture sensor networks, and Cosmic Ray Soil Moisture Sensors (CRS).

Electromagnetic induction (EMI) measurements offer large potential for field-scale mapping of various soil properties and states including soil moisture (θ). Limitations to the use of EMI for estimating any of these properties exist, due to the ambiguous relationship between the measured apparent electrical conductivity (ECa) and the properties of interest. To further investigate the potential of EMI for field-scale mapping of θ, three different EMI sensors have been tested. By conducting repeated EMI campaigns on a hillslope site where the soil moisture distribution was known in detail from a wireless soil moisture monitoring network, it could be shown, that due the varying role of soil properties during different hydrological regimes the relationship between ECa and θ may change over time, clearly limiting the use of EMI for estimating θ (Martini *et al*., 2015a).

CRS is a new promising method for measuring the integral soil water content at the field scale. By combining of a wireless soil moisture sensor network and CRS the applicability of CRS technology under humid forest conditions was tested. It could be shown that the large amount of hydrogen in the litter layer can potentially reduce the accuracy of the soil water content estimation (Bogena *et al*., 2013).

Lastly, ExpeER focused on the hyperspectral remote sensing to assess the relationship between plant primary production and phenology. This task strived to explore the performance of a multispectral camera to assess a year-around phenological cycle along with associated physiological variables. In order to fulfil this task a multispectral camera (Mini MCA Tetracam, Inc.) was installed on a 4-m height platform, facing a typical Mediterranean landscape, about 300 m apart, almost horizontally. The camera has five spectral bands cantered at the green (550 nm), red (670 nm), red-edge (740 and 780 nm), and NIR (860 nm) spectral regions, with band width of 10 nm. The sixth band was converted into the incident light sensor (ILS) that gathers the down-welling radiation at the respective spectral bands. The ILS was connected to the camera by an optical cable and was looking upwards to the sky. In addition, for comparison, a regular digital RGB camera was also installed and obtained images in the same time on the same landscape. Since the multispectral camera was observing a sloped area, pixel size ranged from 7 to16 cm as a function of the distance from the camera. Images were taken hourly from 10:00 am till 13:00 pm, in an automatic exposure mode, and WiFi-transferred to the remote laboratory for processing. The “best” image of the day was used for calculating several spectral indices (*e.g.*, NDVI, red-edge inflection points) for each day. Cloudless images were further used for time series analysis. Physiological measurements were carried out in each season on 24 selected trees (six individuals of each of the four dominant species, mainly Phillyrea latifolia, Olea europaea, Quercus calliprinos, Pistacia lentiscus) in order to understand the physiological state of the monitored trees and shrubs. In this regard, water potential, stomata conductance, and chlorophyll concentration measurements were performed by the standard protocols. Results show that the multispectral camera was able to assess the yearly phenological cycles for each species. In general, these cycles fit well the physiological measurements. It is concluded the multispectral camera has a significant added value over the digital RGB camera for evaluating phenology of different species.

WP8 Development of improved environmental control techniques and new experimental approaches

This work package (WP8) was envisaged as a logical sequence of steps: (i) identifying shortcomings in current experimental approaches used in global change research, (ii) designing new approaches and developing algorithms to resolve these, (iii) testing the proposed solutions in pilot experiments when relevant, and (iv) finalising all designs.

Many techniques exist for experimentally warming ecosystems, and most of them were addressed in this work package. We analysed whether fully or partly enclosing ecosystems in greenhouses, ecotrons or open top chambers (OTCs) led to deviations in tissue temperatures compared to natural warming (De Boeck *et al*. 2012a). We found that the different radiation environment inside greenhouses or ecotrons did not produce large leaf temperature deviations, provided the design avoids insufficient ventilation and significant radiation blockage by the structure. Drastic wind speed reductions inside OTCs approximately doubled the actual (canopy) warming compared to earlier reported increases in air temperature provided by this technique – which is manageable as long as canopy temperatures are recorded (which they rarely are) to quantify the actual achieved warming.

Another warming technique looked into is the transportation of entire monoliths (intact vegetation and soil) to another location that differs in climate. Research carried out in the frame of this WP revealed that soil temperatures are actually increased significantly more than the air temperature. To remedy this artefact, we developed several improvements to lysimeters that house the monoliths. The use of metal plates in a water bath that is in direct contact with the underlying soil and insulation shields at the top led to a significant reduction of the excess soil warming.

A final warming technique addressed here were infrared heating devices. These warm surfaces rather than the air and therefore have the distinct advantage that they can be deployed in the open air because of the reduced energy demands compared to air warming. We focused on two important issues, the first of which is that changing vapour pressure differences associated with infrared heating (caused by higher temperature differences between leaf and air) lead to increased evapotranspiration. We made a full quantification of how transpiration rates are affected by infrared heating by making use of environmental physics and found increases in water loss in the range of 11.5 to 15% for a one degree warming (De Boeck *et al*. 2012b). Two possible workarounds were proposed: adding water to the soil (feasible in any experiment) or increasing the air humidity (a technically more complex solution). A secondary conclusion was that this 'drying' artefact is less of a concern when simulating heat waves as these are naturally drier, which is not accounted for when warming air at ambient relative humidity. In the case of heat waves, using infrared heating could thus be considered advantageous compared to air temperature warming. The second issue addressed in WP8 was the control of the administered infrared heating. The major problem was that current control methods maintain the amount the canopy warms versus control plots at a constant level (*e.g.* +3 °C), which also implies that plant responses to conditions that differ in the warmed plots are filtered out. We devised a method that resolves this and that allows the user to input any climate scenario based on air temperatures, which is another improvement. The novel control is based on energy balance equations and was successfully tested both *in silico* and *in natura*.

Figure 6. Set-up to test a new infrared heater control based on the energy balance (Antwerp, Belgium)

Apart from warming methods, we also addressed another variable important in global change ecology, namely CO_2 addition in the field. Inspired by an ESF workshop on planning the next generation of elevated CO_2 experiments, weaknesses and limitations were analysed and the use of Computational Fluid Dynamics (CFD) was chosen as a means to make CO_2 enrichment technologies more effective and more cost efficient. New control algorithms (PID) were developed and were tested on a dedicated control unit. In a computer simulation with one of these algorithms, it was demonstrated that stable CO_2 gradients can be produced in which vegetation can be exposed to a range of CO_2 concentrations at the same time, which is a major advancement relative to classical FACE systems. Field tests furthermore suggest that it is possible to obtain a consistent gradient of CO_2 concentrations under different wind directions and wind speed conditions.

A third focus in WP 8 was the design of new approaches for experimental ecosystems. Specifically, two main topics were addressed: constructing physical analogue models of larger scale systems and testing the reproducibility of results between laboratories. The first topic involved building a miniaturised model land system which is materially closed and energetically open, just as the Earth (Milcu *et al*. 2012). Different CO_2 emission scenarios were simulated and the biotic C feedbacks between land and atmosphere were estimated. Subsequently, this land-only system was also coupled to an artificial ocean with dissolved inorganic carbon, equilibrated with the atmosphere at prescribed CO_2 levels. For the second main topic, a test was carried out in several labs throughout Europe to see whether the reproducibility of results between laboratories would increase when controlled systematic heterogeneity was incorporated. Experiments were conducted in growth chambers and in greenhouses. Introduced heterogeneity was biotic (plant species) or abiotic (soil texture patches). The results are currently being analysed.

Finally, WP 8 also focused on designing future climate change and biodiversity experiments. Ideas and analyses of current knowledge were collected through workshops involving various ExpeER participants. One paper was written on challenges and opportunities that arise in global change experiments, which focused on a wide range of problems (*e.g.* soil heterogeneity, interdependencies, the stepwise nature of many imposed treatments, etc.), and how to overcome them (De Boeck *et al*. 2015). Another study focused on how biotic interactions and feedback effects are dealt with in manipulation experiments. Finally, we field-tested two new techniques for biodiversity research, of which one proved truly feasible, namely a method to rapidly characterise species interactions in plant communities.

Overall, we think that WP 8 was successful in yielding several advancements spanning a range of techniques and approaches used in global change research.

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WP9 Development of ecosystem models and provision of a model toolkit

Data was collected from relevant global/regional/modelling databases as well as from five experimental sites and adapted to three different whole-ecosystem models (CoupModel, JULES and LPJ-GUESS) creating a data library for a North-South and an East-West European transect with > 100 grid cells. In addition, data was collected for all grid cells containing ExpeER sites. The parameters for these applications provide a starting-point for user application of each model to each ExpeER site. The simulation outputs for each grid provided a baseline for comparing the model performance as input data are refined using site-specific data provided by the site users.

A detailed inter-comparison of the model outputs has been carried out based on the results from the model application across the transects, which formed the basis for assessing and reviewing of model strengths and weaknesses, as well as for testing models against long-term experimental data at selected sites. A particular aim was to evaluate and improve the vegetation process representations within each model. This work is in the process of being summarized in scientific publications.

The three models were applied for a number of different sites within ExpeER. Some of those were detailed applications using a lot of site-specific data also to enable a systematic approach to constrain model parameters based on the data available from the various sites. In two cases, models were furthermore successfully applied to different experimental treatment data (Brandbjerg – Denmark: Ambient conditions, warming and extended summer drought; Lusignan – France: grass mowing and grazing). Some others are preliminary setups to enable further work in later stages when also more detailed information will be available. For the Rollesbroich (Germany), a close collaboration with WP10 was established enabling the application of five different models to this site. Output data in the form of eddy co-variance flux data generated through work performed in WP10 were used as input to calibrate the models used in WP9. For the Plynlimon (United Kingdom) site, two long-term records of runoff were used to initiate a calibration on evapotranspiration from different land use and for Yatir site (Israel) used eddy flux during 10 years to initiate a similar calibration on evaporation and CO_2 fluxes. The output from these model applications is in the process of being summarized in various scientific publications.

A major aim of WP9 was to develop a modelling toolbox for site owners, scientists and young investigators to get much easier access to models, parameter settings and documentation. The model toolbox has been developed and is available online (direct link: http://michaelmi.nateko.lu.se/) – Figure 7

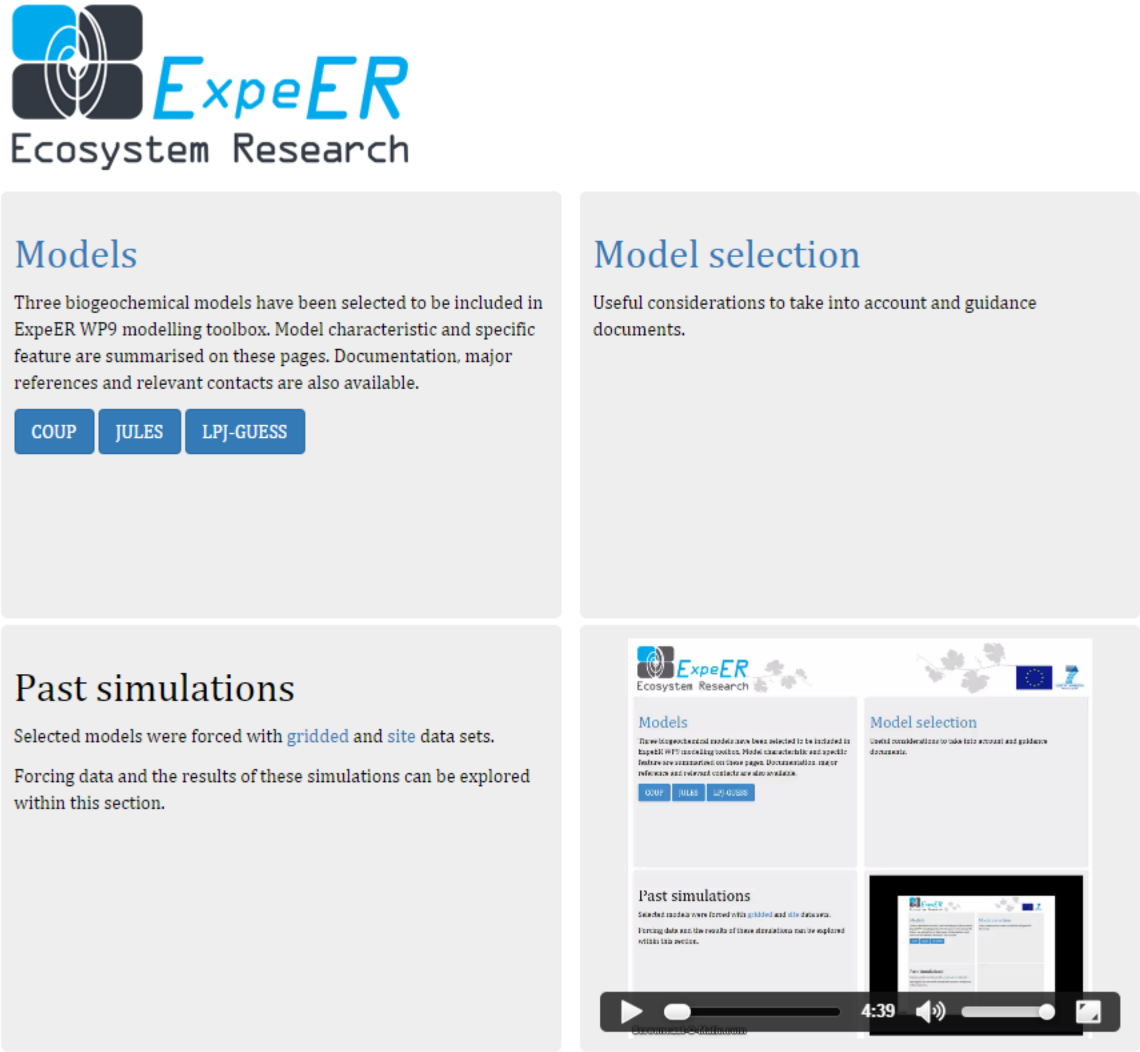

Figure 7. Toolbox webpage showing navigation for Models, Model Selection and Past Simulations.

The toolbox is constructed around three whole-ecosystem models, which can be used to simulate ecosystem functioning and processes in response to experimental manipulation of forcing functions ranging from climate variables to land use management practices. These models (COUP, LPJ-GUESS and JULES) were selected to cover a range of spatial scales and process detail in their simulated outputs (Table 3). The modelling toolbox includes links to enhanced ecosystem models representing hydrological, biogeochemical and dynamic vegetation components and evaluation tools to provide scientific testing of hypotheses and extrapolation of results from the experiments. The modelling toolbox presents or links to all relevant model documentation including design, links to data and parameter settings and model outputs, manuals and instructions (theoretical basis, user guide, variables, inputs and outputs and model connections). The use of the toolbox was demonstrated through involvement of site researchers and users at a workshop training course in September 2014, and the toolbox has also been presented at the ExpeER International Conference in Paris 24-25 September 2014, as well as at the ExpeER Related Sites Group (RSG) Meeting in Vienna 17 February 2015.

	COUP	LPJ-GUESS	JULES
Purpose - Features	Quantification of basic hydrological and biological processes in the soil plant atmosphere system. The model simulates soil water and heat processes in many types of soils.	Dynamic global vegetation model for simulation of interactions between climate, atmospheric burdens of trace gases and vegetation, biogeochemical cycles and trace gas exchange.	Process-based model that simulates the fluxes of carbon, water, energy and momentum between the land surface and the atmosphere.
Scale – Spatial Unit	Spatial resolution: plot. However model can be run in distributed model representing any region.	10 minutes (Europe) or 0.5 degree (globe). May also be applied at stand or plot scale.	Typically 1km for the UK or 0.5 degree (globe) but may also be applied at stand or plot scale.

Table 3. Summary of whole-ecosystem models in the WP9 Modelling Toolbox

WP10 Development of upscaling and data interpretations methods of biogeochemical and ecological processes

We developed frameworks for upscaling of local measurements made by ecosystem infrastructure, like for example net ecosystem exchange (NEE), to larger scales like catchments and even continents. The work focused on two different approaches for doing the upscaling. One approach was a hybrid methodology, where ecosystem parameters first were estimated with help of measured time series of NEE using the Markov Chain Monte Carlo methodology of $DREAM_{(ZS)}$ (Laloy and Vrugt, 2012; Ter Braak and Vrugt, 2008). The advantage of this methodology is that it is not limited to Gaussian distributions and can also be applied for very non-linear simulation models. However, this methodology is very CPU-intensive and could only be applied for single sites. Selected were four sites with different plant function types (PFT). NEE-time series obtained by eddy covariance measurements at those sites were used for parameter estimation. Verification of parameter estimates made for a certain PFT with NEE-time series measured at other sites of the same PFT, showed that the characterization of NEE was considerably improved. In a next step, parameter estimates were applied to improve NEE simulations for the entire Rur catchment. Therefore, updated parameters were assigned to all grid cells under consideration of the parameter uncertainty. It was found that NEE- and LAI-characterization for the catchment improved with help of the estimated ecosystem parameters. At the catchment scale, estimates can potentially be improved further with help of sequential data assimilation. This approach was already tested for the upscaling of hydrological states and water fluxes in the Rur catchment in Germany, again in combination with the CLM model. A first example was the optimization of both model parameters and model states at the Rollesbroich grassland site in the Rur Catchment using soil moisture time series at 41 locations and 3 depths. Different optimization methods were tested; they highlighted a significant improvement of modelled soil moisture for a "verification period" using the parameters optimized for the assimilation window. An upscaling at the Rur catchment with the use of land surface temperature from MODIS at 1 km resolution to optimize few model state variables and parameters was also investigated. The improvement of the modelled latent heat and sensible heat fluxes at few sites remained small which highlights the difficulties of the approach at the basin scale.

The second approach was variational data assimilation in combination with the land surface model ORCHIDEE. Variational data assimilation adjusts model simulation results to measured data by minimizing an objective function that takes into account the uncertainty of initial values for the states and parameters to be adjusted, and differences between model simulations and measured values. Different steps or issues that are usually encountered when upscaling carbon fluxes at large scale with process-based models were analyzed. They concern i) the choice of observations with their information content, ii) the selection of the most sensitive parameters of the model (illustrated with a MORIS sensitivity analysis), iii) the difficulties to find the optimal parameter set linked to the level of model non linearity, iv) the need to assimilate measurements from multiple sites in order to obtain generic parameters (discussion of multiple-site versus single-site optimizations with eddy covariance NEE and LE fluxes) and v) the difficulties to combine data streams of different nature such as carbon fluxes and stocks (for forest). Values were estimated for single sites and also multiple sites, which shared the same PFT. These parameter estimates were used at other sites with the same PFT and it was evaluated to what degree simulation results improved. This approach is very similar to the upscaling approach from the plot to the catchment scale, but in this case the evaluation sites were sometimes located in other continents. It was found that this upscaling methodology improved the reproduction of exchange fluxes of carbon dioxide, water and energy between the land surface and atmosphere. The parameter estimates were also used for projections of changes in net terrestrial carbon storage as function of global temperature change. These projections were compared with simulations with default parameter values. It was found that whereas default parameter values resulted in an almost linear increase in terrestrial carbon storage as function of temperature increase up to 7K, the estimated parameter values resulted in a slower increase of terrestrial carbon storage as function of temperature and even a decrease for global temperature increases larger than 5K-6K. Therefore, projected changes in terrestrial carbon storage were sensitive to the adopted ecosystem parameters.

It was also investigated whether chlorophyll fluorescence (ChF) measurements and photochemical reflectance index (PRI) are promising data to further constrain simulation results with land surface models. At leaf level a high correlation was found between these variables and light use efficiency. However, for the eddy covariance tower footprint and MODIS the correlation between PRI and light use efficiency was much weaker. Surprisingly, for MODIS the PRI-LUE correlation was even slightly higher than for the flux tower.

While it is assumed that ecosystem function and biodiversity are related, evidence is hard to find. In the context of WP10, two sets of studies were undertaken. The first (at TERENO-sites in Germany) related high plant species richness from scales of $0.01m^2$ to catchment to soil moisture, as inferred from measurements of a network of fixed sensors; early indications in scale-dependent relationships between these two variables needs further analysis. The second investigated relationships between phenology and greening of beech forests to environmental drivers at scales of km^2 and above using wavelet analysis, and showed that the greatest influence of particular drivers were seen at particular scales. This kind of study remains difficult, because both biodiversity and ecosystem processes must be measured across the same scales in the same areas, which is very rarely achieved with current technologies. Ecosystem researchers should look to include new technologies, including drones, to provide observational data between the scales of point and small area measurements and data derived from satellites.

1.4 Potential impact, the main dissemination activities and exploitation of results

WP1 Analysis of current resources and roadmap for the EXPEER integrated infrastructure

WP1 outlined a method for comparing existing facilities, finding gaps and synergies as well as scopes for investments in the future. A ranking of facilities based on their technical capacity and scientific performance (number of publications, number of visits, annual investments, etc.) can be used to provide suggestions for the future developments (see. Fig. 16 in the ExpeER Roadmap document). A direct impact of these results is followed up in the AnaEE project (http://www.anaee.com/index.php/) that based on a Multi Criteria Decision Analysis (MCDA) will be applied to similar infrastructures. The ExpeER Roadmap identified further requirements for the managing and administration of pan-European infrastructure for ecosystem research facilities. Necessary steps towards the successful implementation of a pan-European infrastructure for ecosystem research based on the ExpeER results are illustrated in Figure. 8.

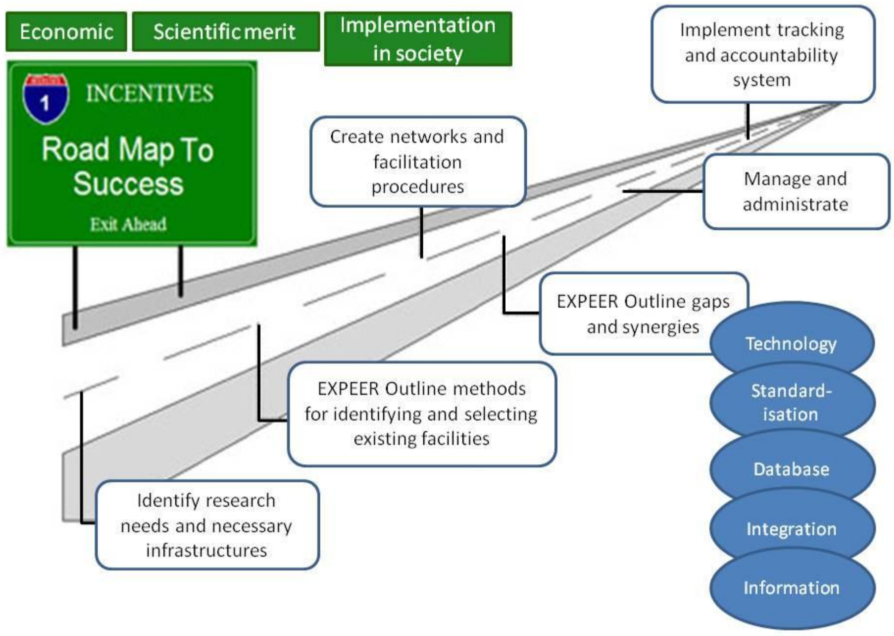

Figure 8. Necessary steps towards a successful implementation of pan-European infrastructure for ecosystem research. Contributions by the ExpeER project in blue and incentives necessary in green (Figure from ExpeER deliverable D 1.3)

Increased and rationalized collaboration between researchers produced the main benefit from ExpeER infrastructures. The possibility to use and access multiple ExpeER research facilities was considered equally beneficial (D1.4).

The dissemination activities include three reports, deliverables D1.1, D1.3 and D1.4 and one work-shop, D1.2. In addition WP1 has contributed to ExpeER brochures and the web-page.

WP2 Standardization of core variables and protocols

The potential impact of this work will be to harmonise data collection across ecosystem infrastructures across the EU and beyond. The major dissemination activities were:

- **Training courses**

Three residential training courses were undertaken. The first, hosted by CNR in Rome in August 2012, was used to trial the draft protocols, and so was aimed at ExpeER staff. The five day course was attended by 25 people, many of whom were both trainers and trainees. The work involved class session and training in forest, grasslands and in the laboratory.

The two five-day courses in 2013 were both aimed at disseminating near-final versions of the protocols to the wider research community. The first, which was again hosted by CNR near Rome in May, focussed on forest systems and was attended by 15 trainees, under the supervision and guidance of 9 trainers. The second, hosted by VUA in Amsterdam in August, had 14 trainees and 9 trainers and focussed on grassland and coastal systems. Both courses included a session on metadata management, covered all protocols, except that soil organic matter was not taught in Amsterdam. Additional demonstrations were provided, to look at more specialist techniques such as eddy covariance (in Rome), and experimental manipulations (Open Top Chambers in Amsterdam). Participants in the courses were mainly PhD students, but also included a number of post-docs, technicians and field-assistants working at European Universities and diverse research institutes such as the Romanian FRMI (Forest Research and Management Institute) and NIOO (Netherlands Institute of

Ecology). In the two training courses, participants of 13 different nationalities, working in 17 different institutions in 8 European countries were trained. Feedback from the trainees was positive.

- **Publication of the protocols**

The protocols have now been published on the ExpeER website

http://www.expeeronline.eu/images/ExpeER-Reports/D2-3.pdf

and a journal publication is being drafted that will explain the protocols and their background to other scientists.

- **Contact with other research networks**

Protocol development is an international activity, not exclusive to ExpeER. The development of this protocol set was closely co-ordinated with the ENV-EUROPE network. Information exchange took place with the US National Ecosystems Observation Network (including a discussion at Portland in 2012), to ensure that there was no incompatibility between the protocols. In 2015, the protocols were brought to the attention of the global Critical Zone Observatory network, to be taken into account as they develop their recommended protocols. The protocols were presented to the Related Sites group meeting in Vienna in 2015.

WP3 Information management and data access

An important aspect of the work in work package 3 has been to ensure that the data standards development and metadata produced aligns with similar data infrastructure developments to ensure reuse of information resources. The work on information management and data access within ExpeER has been aligned with work going on in other European scale projects and initiatives. This has led to a mutual exchange of information and by this also the long-term sustainability of the resulting products. WP3 of ExpeER had co-operations with the following research infrastructures, initiatives, and networks:

- AnaEE (RI) and AnaEE-France (RI) – mainly working on the harmonisation of the semantic work going on in this research infrastructure
- LTER Europe (network) and ILTER (network) – co-operation in the field of metadata on research sites and semantic work. This included also the knowledge and information exchange with several national LTER networks. Participation at a joint workshop with ILTER on the subject of EnvThes and multilingual thesauri.

In addition information and knowledge exchange with the European scale projects EnvEurope, EUDAT, ENVRI and EU BON was performed in order to exchange ideas and promote an open data sharing policy in the field of environmental research.

The communication and exchange of information was done on several ways:

- General information at the plenary sessions of the joint project meetings
- Targeted workshops with related partners were held as physical meetings
- Skype sessions as virtual working meetings on selected subjects of the work plan
- Personal exchange of knowledge and information across the WPs

The web GUI of EnvThes (http://vocabs.lter-europe.net/EnvThesDev.html) and the metadata platform DEIMS (http://data.lter-europe.net/deims) were used for disseminating the results of the working group.

WP4 Creating a sustainable network

Fostered by ExpeER, there are good chances of a successful implementation of its building blocks (AnaEE, LTER-Europe) in a highly co-ordinated manner and as part of a European environmental research infrastructures cluster. This will support highly integrated national ecosystem research infrastructure clusters, their efficient multiple use and the joint development of further services.

WP5 Communication and dissemination

The ExpeER communication activities contributed to the development of the dynamics among the participants of the project and to the success of the transnational access program. The external communication was influential for the recognition of ecosystem science infrastructure and the need to further develop them through ESFRI infrastructures (AnaEE, eLTER). The WP5 dissemination activities (website, brochures, and final conference) are completed by the publication of about 30 articles in scientific journals. The publication by an international publisher of a book (Terrestrial Ecosystem Research Infrastructures: Challenges, New developments and Perspectives, A. Chabbi & J. Roy eds, 2016 Taylor & Francis, ISBN: 978-1-4987-5131-5) following the final ExpeER conference (more than 100 participants from 28 countries) will be a wide ranging synthesis of the international efforts currently underway to develop infrastructures at the service of ecosystem science and its various stakeholders.

WP6 Management of the calls for Access

The TA Coordination Team contributed to the dissemination of ExpeER's TA programme including: direct email(s) to mailing lists, official ExpeER flyer and poster for distribution at conferences, meetings, "Accepted Projects" listed on the ExpeER website, "TA User Experiences" published on the ExpeER website and a workshop of TA users at the 2nd Annual Meeting (Florence).

The majority of TA applicants were experienced researchers (48%), followed by post-doctoral researchers (29%) and post-graduate (*i.e.* PhD) students (22%), with just 1% of applicants classifying themselves as technicians. These data are also reflected in the TA user age, with the majority of applicants aged between 31 – 50 years of age (58%), while younger researchers represented just 17% of all applicants. Male applicants (60%) slightly outnumbered female applicants (40%), while the vast majority of applicants were affiliated with University institutions (68%), while the remainder came from public research organisations (32%).

Approximately 50% of all TA users came from 5 countries: Germany (15%), Spain (9.8%), Italy (9.8%), The Netherlands (8.8%), and the UK (6.9%). The remaining 50% of TA users represented some 15 different countries throughout Europe, EU-Associated states (*e.g.* Israel and Norway) and New Zealand.

ExpeER TA projects covered a range of broad research themes. More than half of all TA visits fell within two main research themes: Ecosystems & Biodiversity (28%) and Global Change and Climate Observation (26%).

Experience from the ExpeER TA will contribute to further development of similar projects in the ecosystem research domain.

WP7 Develop and test new methods to overcome current limitations in understanding ecosystem processes

The research done in WP7 highlighted the added value of the combination of different techniques and sensing technologies to investigate environmental processes at different scales including experimental sites and laboratory setups. The integration of these results supports the European strategy for interdisciplinary environmental research with specific focus on the combination of monitoring and experimentation. The research revealed the potential and also some of the limitations of the investigated technologies and thus contributes to further develop the technologies and corresponding application methods and to promote the application. The main dissemination activities included presentation at national and international conferences as well as scientific publications in international journals.

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- Crème, A., Rumpel, C., Gastal, F., Chabbi, A. (2015) Effect of nitrogen fertilizer replacement by legume on organic matter and phosphorus forms in grassland soil. Plant and soil (under review).
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- Jenkins *et al* (2015). Conversion of grassland to short rotation coppice significantly alters fungal and bacterial communities. In preparation
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WP8 Development of improved environmental control techniques and new experimental approaches

The two papers on identification and solutions of artefacts associated with various warming techniques referred to in section 1.3 (De Boeck *et al*. 2012a,b) were published in top journals and have been cited in 25 other studies since. This implies that the impact so far has been substantial. Furthermore, several researchers have visited UA to learn more about the infrared heating technique (Fig. 8.2): Junliang Zou (UCD School of Biology & Environmental Science, Dublin), Christophe Moni (Bioforsk, Norway), Cécile Vincent-Barbaroux (Université d'Orléans, France), Kris Verheyen and Pieter De Frenne (University of Ghent). The improved control method for infrared heating devices has now been tested successfully and the results will be published as a ready-to-use guide in the near future. This should enable any interested research group to implement our new technique.

The new CO_2 design (GradFACE) developed by CNR has been field tested in collaboration with colleagues from USDA-ARS. The gradient design should strengthen CO_2 studies as they can now more easily explore non-linearities, while the statistical power is increased.

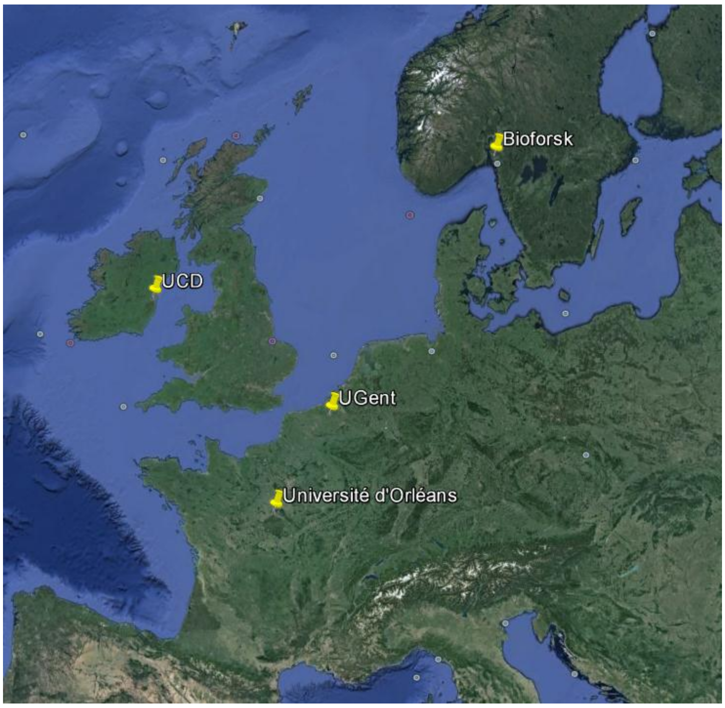

Figure 9. Inventory of consultation on IR warming provided by UA

Regarding the design of new approaches for experimental ecosystems, the paper by Milcu *et al*. (2012) has been cited 11 times. The study into reproducibility was conducted by CNRS in association with 13 other laboratories in France, Germany, Switzerland, England and Italy. The substantial interest shown into collaborating in this project suggests that the study that will be published is likely to be of significant impact.

Finally, part of the work on new generation biodiversity and climate change experiments has been published in a collaborative effort that brought together eight different research groups (De Boeck *et al*. 2015). Other work has been synthesised into two other papers that have been submitted or will be submitted soon. In general, we think that WP 8 has lived up to its promise and resulted in several tangible achievements benefiting the global scientific community.

WP9 Development of ecosystem models and provision of a model toolkit

WP9 has included many aspects of model development and application, which have been or are in the process of being disseminated as scientific publications. One important feature of the model applications was the comparison, evaluation and improvement of the vegetation process representations within each model (references 1 and 2). Another important aspect was the successful application to treatment specific data at individual sites, *e.g.* ambient, mowing and grazing plots at the French Lusignan site (references 3 to 5) and ambient, warming and drought plots at the Danish Brandbjerg site (references 6 and 7).

The Modelling Toolbox was demonstrated through involvement of site researchers and users at a workshop training course in September 2014, and presented at the ExpeER International conference in Paris 24-25 September 2014, as well as at the ExpeER Related Sites Group (RSG) Meeting in Vienna 17 February 2015. The ExpeER modelling toolbox has already proved to be a helpful resource in a project examining differences in water balance between grassland and forest watersheds using long-term data and two different models. The project "Water balance in grassland and forest watersheds" was carried out as part of ExpeER and details are available at:

https://www.kth.se/en/abe/inst/2.12732/grupper/biogeofysik/research/water-balance-1.507367

The modelling toolbox can continue to serve as an easy access to models, parameter settings and documentation for scientists beyond the ExpeER project and could serve as a starting point for further development of modelling toolboxes in future projects.

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WP10 Development of upscaling and data interpretations methods of biogeochemical and ecological processes

Upscaling of measured carbon and water fluxes at infrastructure sites is essential for a better estimate of net carbon and water balances over catchments and continents. Upscaling was in this project achieved by estimating ecosystem parameters specific for plant functional types. It was shown that upscaling is feasible; the estimate of ecosystem parameters improved also at other sites the modelling of the carbon balance. Data assimilation studies, which were used for upscaling, have therefore an important potential to improve estimates of carbon and water balances. The potential of additional data to further constrain these net balances at large scales was also shown. Examples are classical data like biomass production, and novel data like fluorescence. The potential of fluorescence data was investigated in the context of WP10 and demonstrated.

A workshop was given together with WP9 of the ExpeER-project on September 26, 2014 in Paris. It consisted of an overview of model-data fusion methods. Different methods to incorporate measurements in model calculations were presented and a short introduction was given to sequential data assimilation, variational data assimilation, inverse modelling and smoother methods. The common link of these methods to Bayes theorem was also discussed. Afterwards sequential data assimilation methods and variational data assimilation methods were introduced in more detail, with a focus on land surface models and upscaling of water and carbon fluxes. Special attention was given to the definition of measurement operators. A few examples from the ExpeER-project were given to illustrate the application of the methods. One example concerned the use of neutron counts measured by cosmic ray probe to constrain the water balance for an irrigated cropland. Another example was the assimilation of measured net ecosystem exchanges at eddy covariance flux towers and the posterior upscaling of these assimilation results to derive estimates of net carbon uptakes/releases at the continental scale.

Further dissemination activities included contacts with large scale terrestrial ecosystem research (LTER) sites including a presentation at a workshop of LTER (Vienna, February 2015), and contacts with national infrastructure programs (for example TERENO in Germany).

1.5 Project website

www.expeeronline.eu