Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
doi: http://dx.doi.org/10.5424/fs/2013223-03675

Forest Systems 2013 22(3): 535-545
ISSN: 2171-5068
eISSN: 2171-9845

Towards integration of research and monitoring at forest ecosystems in Europe

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Abstract

Aim of study: The main aim of the work was to summarize availability, quality and comparability of on-going European Research and Monitoring Networks (ERMN), based on the results of a COST FP0903 Action questionnaire carried out in September 2010 and May 2012.

Area of study: The COST Action FP0903 involves 29 European countries and 4 non-COST institutions from USA, Morocco and Tunisia. In this study, the total of 22 replies to the questionnaire from 18 countries were included.

Materials and methods: Based on the feedback from the Action FP0903 countries, the most popular European Networks were identified. Thereafter, the access to the network database, available quality assurance/quality control procedures and publication were described. Finally, the so-called “Supersites” concept, defined as a “highly instrumented research infrastructure, for both research and monitoring of soil-plant-atmosphere interactions” was discussed.

Main results: The result of the survey indicate that the vast majority of the Action FP0903 countries participate in the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forest (ICP Forest). The multi-disciplinary International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICPIM) is the second most widespread forest programme.

Research highlights: To fully understand biochemical cycles in forest ecosystems, long-term monitoring is needed. Hence, a network of “Supersites”, is proposed. The application of the above infrastructure can be an effective way to attain a better integration of research and monitoring networks at forest sites in Europe.

Key words: supersites; European Research Monitoring Networks; harmonization; forest.

Introduction

From the different terrestrial ecosystems, forests are the most important as they constitute a substantial part of the Earth’s surface – about 3 953 million ha which is about 30% of the total Earth surface (FAO, 2006). From this perspective it seems reasonable that substantial research is conducted in forests. Globally,

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Received: 26-10-12. Accepted: 05-09-13.

forest ecosystems are considered a carbon (C) sink (Dixon *et al.*, 1994; Grace, 2001; Janssens *et al.*, 2005; Luyssaert *et al.*, 2010), which means that C, in the form of carbon dioxide (CO_2), is absorbed from the atmosphere and stored in the aboveground biomass (leaves/needles, branches, stems) and belowground biomass (roots and soil). However, the amount of the absorbed C is significantly influenced by climatic factors (air temperature, precipitation, radiation) (Carrara *et al.*, 2003; Morgenstern *et al.*, 2004; Niu *et al.*, 2012; Valentini, 2000; Valentini, 2002), by air quality (concentrations of CO_2, ozone (O_3) and nitrogen (N) compounds) (Ciais *et al.*, 2010; Schulze *et al.*, 2010; Serengil *et al.*, 2011), by tree species and soil type (Barr *et al.*, 2002; Lai, 2005) and by forest management practice (Jandl *et al.*, 2007).

The Climate Change and Forest Mitigation and Adaptation in a Polluted Environment (MAFor) Action within the frame of the European Cooperation for Science and Technology (COST) programme is dedicated strictly to forest ecosystems. The main objectives of the Action are: (i) increasing understanding of the state and the potential of forest mitigation and adaptation to climate change in a polluted environment and (ii) reconciling process-oriented research, long-term monitoring and applied modelling at comprehensive forest research sites, referred to as Supersites (Paoletti and Tuovinen, 2011). The Action allows to consolidation of knowledge and experience and consequently to reconcile the current knowledge gaps and future emerging research needs in respect to forest ecosystems (Matyssek *et al.*, 2012).

The present estimations of the global C balance of terrestrial ecosystems are uncertain (Houghton, 2003). Furthermore, the predicted significant increases in the greenhouse gases (GHG), such as carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), and of a variety of air pollutants affecting GHG exchange, such as O_3, precipitation of acidic compounds, such as sulphate (SO_4^{2-}) and nitrate (NO_3^-), till the year 2100 (IPCC, 2001) are a subject of wide discussions in the scientific community (Marland, 2008; Marland *et al.*, 2009; Huntingford *et al.*, 2009). Direct measurements and monitoring of the main GHG and a variety of air pollutants are crucial for the verification of climatic scenarios and for the quantification of the impact of air pollution and climate change to natural ecosystems, forests especially. State-of-the-art measurement techniques, such as eddy covariance (EC), relaxed eddy accumulation (REA) and automated chambers, allow research at various spatial and temporal scales. The EC has recently become a world-wide standard and the most frequently applied method in all types of terrestrial ecosystems - from forests (Arain *et al.*, 2003; Aubinet *et al.*, 2001; Baldocchi, 2001; Carrara *et al.*, 2003; Cieslik *et al.*, 2009; IIvesniemi *et al.*, 2009; Launiainen *et al.*, 2005), grasslands, wetlands (Chojnicki *et al.*, 2007; Lund *et al.*, 2010; Sottocornola and Kiely, 2009) to farmlands (Reth *et al.*, 2005).

Currently, the data cross-comparison or upscaling is in most cases difficult as they are obtained from different sources and by different field/laboratory measurement techniques. Furthermore, the temporal and spatial scale and the used measurement techniques and data processing procedures determine the level of precision. In the light of the above facts, there is a crucial need for a mutual integration of existing international research knowledge and databases, with respect to the measurement methodology, database availability and quality assurance/quality control (QA/QC) procedures.

For instance, data compatibility will be improved, if an organization of coordination centres responsible for quality assurance and quality control (QA/QC) (*e.g.* Atmospheric/Ecosystem Thematic Center, Central Analytical Laboratory in the case of the ICOS project), and data processing procedures will be established. Furthermore, if the processing of raw data (as far as it is possible and reasonable), with application of the validation models, is harmonized, the data and results can be better explored. The unification of the data acquisition protocols and the harmonization of the different measurement techniques influence data quality and quantity. All the efforts aimed at attaining the above objectives will improve the quality of the research knowledge in the area of forest ecosystem recognition.

The main aim of this paper is to summarize availability, quality and comparability of on-going European Research and Monitoring Networks (ERMN), based on the results of a COST FP0903 Action questionnaire (see below). A detailed description of the variables in the various ERMNs is given in Danielewska *et al.*, (2013). Moreover, the concept of “Supersites”, defined as highly instrumented research infrastructures in forest ecosystems (Fischer *et al.*, 2011; Matyssek *et al.*, 2012), will be discussed.

Table 1. The European Research and Monitoring Networks (ERMN) working at forest sites and the number of countries answering the COST Action FP0903 questionnaire which participate in the particular ERMNs*

ERMN	Abbreviation	Number of countries
Coordination Action Carbon Observation System	COCOS	1
Global Terrestrial Observing System	GTOS	1
Greenhouse gas management in European land use systems	GHG-Europe	3
Infrastructure for Measurements of the European Carbon Cycle	IMECC	2
Integrated Carbon Observation System	ICOS	3
Integrated non-CO_2 greenhouse gas Observing Systems	InGOS	1
Integrated Project CarboEurope-IP Assessment of the European Terrestrial Carbon Balance	CarboEurope-IP	6
International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems	ICPIM	6
International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests	ICP Forests	15
Monitoring atmospheric composition & climate	MACC	1
The nitrogen cycle and its influence on the European greenhouse gas balance	NitroEurope-IP	7
Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe	EMEP	6
Global Earth Observation and Monitoring of the Atmosphere	GEOMON	1
European Long-Term Ecosystem Research Network	LTER	2
Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems	ECLAIRE	2

* Details on ERMNs selection are in Clarke *et al.,* 2011; Fischer *et al.,* 2011; Danielewska *et al.,* 2013.

European Monitoring and Research Networks

Out of tens of large-scale international ERMNs, only a few are strictly dedicated to forest ecosystems. Forests will face significant changes in climate, air pollution and forest management in the next 100 years, which will influence their productivity, biodiversity and health conditions. Using the information included in different international databases we might quantify the adaptation of forest ecosystems to these changing conditions. The European projects and networks on forest ecosystems, as the main focus of attention, were identified by Clarke *et al.*, 2011; Fischer *et al.*, 2011 and Danielewska *et al.*, 2013, and are presented in Table 1.

In the ERMNs listed in the Table 1, basic environmental variables such as meteorology (*e.g.* air temperature, air humidity, precipitation, radiation) and atmospheric chemistry (*e.g.* O_3, CO_2, H_2O, CH_4 concentration, aerosols, radioactive elements, tracers and heavy metals) are measured (often at part of the plots). Furthermore, additional variables such as tree stand characteristics (*e.g.* diameter at breast height, height, volume, age, social class), soil characteristics (*e.g.* texture, soil profile and horizons, root depth, hydrogen ion exponent (pH), organic carbon (C_{org}) content, soil moisture, water depth, conductivity), forest – atmosphere fluxes (*e.g.* CO_2, H_2O, CH_4, N_2O, and O_3 fluxes), concentrations and fluxes of elements and compounds in deposition and soil water are estimated in the majority of the above ERMNs. Variables can be divided in different physical levels: leaf/needle level [*e.g.* stomatal conductance, water interception, wetness, Leaf Area Index (LAI)], tree level (*e.g.* diameter at breast height, height, volume, age, social class), ending with the tree stand level (*e.g.* number of trees per unit area, phenological observations). From the listed ERMNs, the ICP Forests and ICPIM programmes have the highest number of measured variables most relevant for forest ecosystems.

A detailed description of the measured variables along with the measurement units and the information about particular ERMNs are presented in the meta-database elaborated within the frame COST Action FP0903 and described by Danielewska *et al.*, (2013). The main objective of the meta-database is to integrate the information from the various existing ERMNs already dealing with the effects of different stress factors on forests, including air pollution and climate change. The meta-database is not intended to replace existing databases, but to act as an aid to those seeking to find available information in these databases and thus to assist in improving access to, and the coordination among, the different datasets.

Questionnaire

General overview

In September 2010 and May 2012, a survey was carried out in the COST Action FP0903. The questionnaire was circulated among the Management Committee (MC) and Working Groups (WG) members of the FP0903 Action by the electronic mail. The feedback to the questionnaire included 22 replies from 18 countries. The main purpose of the questionnaire was to obtain information about the availability, quality and comparability of available environmental data on the national scale. The questions were related to the following four topics:

— participation in international and national projects/networks related to the main objectives of COST Action FP0903, *i.e.* the interacting impacts of CO_2 and O_3, exposure, N inputs and extreme weather events on the C, N and water cycles;

— access to the listed databases;

— data harmonization in view of available QA/QC procedures;

— publications which are related to the databases and their availability.

The Action FP0903 has been established in 2009 and involves 29 countries (Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Israel, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom) and 4 non-COST institution from USA, Morocco and Tunisia. The replies to the questionnaire comes from the 62% of the COST Action FP0903 countries. Therefore the obtained survey result can be regarded as a representative for the Action. Furthermore, countries which took part in the survey actively collaborate between each other in frame of the various international and multidisciplinary research projects and networks. They also undertake different research activities and projects with COST colleagues from such Action like: ES0804 (Advancing the Integrated Monitoring of Trace Gas Exchange between Biosphere and Atmosphere), ES0903 (Spectral Sampling Tools for Vegetation Biophysical Parameters and Flux Measurements in Europe) or FP0603 (Forest Management and the Water Cycle). As a result of the above cooperation, countries which contribute to the survey, are closely linked with the environmental research dedicated to forest ecosystems.

Results and discussion

Participation in international and national monitoring networks

The results of the survey in terms of participation of countries in ERMNs is given in Table 1. A vast majority of countries (15 out of 18 countries which answered the questionnaire) participate in the ICP Forests programme, which was established in 1985 and operates under the Convention on Long-range Trans-boundary Air Pollution (LRTAP) of the United Nations Economic Commission for Europe (UNECE) region. The fact that the ICP Forests project enjoys such a high popularity in the COST Action FP0903 and thus in Europe is related, on the one hand, to the particular attention that is paid strictly to forest ecosystems and, on the other hand, to the long-term character of the programme. Furthermore, the research carried out in the frame of the ICP Forests programme focuses also on the better understanding of the cause-effect relationships between the condition of forest eco-systems and anthropogenic as well as natural stress factors (in particular air pollution, although in recent years climate change has been included in the programme).

The ICPIM multi-disciplinary programme is the second most widespread forest programme, which, similarly to the ICP Forests, operates in the frame of the LRTAP Convention. The integrated monitoring approach refers to the simultaneous measurement of physical, chemical and biological properties of an ecosystems over time and across compartments at the same location. Therefore, by the application of the above approach, the investigation of the common interaction between C, N and water cycles in the forest ecosystem is viable. However, from the forest ecosystem perspective, it is equally important to consider productivity, biodiversity and forest health conditions. Therefore, the measurements of the ground level ozone, precipitation of acidic and nutrient compounds, heavy metals concentrations, etc., are necessary and are conducted for example in the frame of the EMEP programme (present in 6 out of 18 countries which answered the questionnaire).

According to the survey results, the CarboEurope-IP and NitroEurope-IP projects were present in 6 and 7 countries, respectively. The above mentioned projects were funded by the European Union, and mainly focused on the C and N cycles in the terrestrial ecosystems such as forests, grasslands, wetlands and croplands. Additionally, the CarboEurope-IP database takes into account factors related to ecosystem management methods such as harvesting, fertilization, grazing etc. Also, the NitroEurope-IP database is a source of additional information related to the soil profile characteristics or biomass C and N concentrations in residues, grain and straw. Since both presented projects led to the creation of a large European monitoring network, the elaborated procedures constitute an integral part of currently in place ERMNs such as InGOS, IMECC, GHG-Europe, ECLAIRE etc. These ongoing projects concentrate on the C, N and GHG balance estimation of terrestrial ecosystems in Europe with respect to natural and anthropogenic drivers such as climate and land use changes. Presently, the long-term perspective of the environmental research is equally important as its multi-disciplinary and science-based aspects. This is especially important in the case of forests, as the changes in these ecosystems can be best described in decade-long time spans.

A majority of available databases, in the domain of environmental research, comes from various international and large scale ERMNs. However, the result of the COST Action FP0903 survey pointed out a group of projects (Table 2), which support the existing networks, by bringing together the research knowledge and experience, available databases and modelling in order to synthesise the knowledge and improve the future climatic prediction. Therefore, the importance of such projects as ClimMani, EnvEurope, Helcome, FO_3REST, or FutMon cannot be neglected. Moreover, one of the characteristics of the environmental research is its complexity in respect to the different interaction between soil-plant-atmosphere compounds. Therefore, the cooperation between a variety of ERMNs and others international and national projects is extremely important.

Access to the listed databases

According to the survey results, international and national databases listed in the survey can be accessed in three main manners: (i) free access, (ii) free access to limited data series (complete access after

Table 2. The international and national projects/networks reported in the COST Action FP0903 survey not included in the WG1 meta-database

International and National Projects/Networks	Abbreviation	Number of countries
Climate Change - Manipulation experiments in terrestrial ecosystems (http://www.climmani.org/)	ClimMani	1
Environmental quality and pressures assessment across Europe (http://www.enveurope.eu/)	EnvEurope	1
Baltic Marine Environment Protection Commission (http://www.helcom.fi/)	Helcome	1
Further Development and Implementation of an EU-level Forest Monitoring System (http://www.futmon.org/)	FutMon	1
Ozone and Climate Change Impacts on French and Italian Forests: Refinement of criteria and thresholds for forest protection (http://www.fo3rest.eu)	FO_3REST	2

authorization) and (iii) access after registration/on request/by authorization (Clarke *et al.*, 2011). The general access procedure assumes that each potential user of the data should specify the required data (GHG-fluxes/concentrations, air and soil chemistry etc.), time period (the yearly, monthly, daily frequency) and measurement station. All of the parameters can be simply selected from the several interactive boxes at the homepages of the database portals for each of the ERMNs. The request is sent to the corresponding Principal Investigator (PI) who manages the datasets from a specific station (or several stations on national level).

The most common data sharing policy assumes that use of the data, which is obtained on request, should be mentioned in the acknowledgements of publications. Each of the data providers can reserve the right to write an individual acknowledgement text, which should be used, in each case of data use. It is also common practice that authors send their draft texts to data providers for comments and acceptance. An overview of the accessibility of the various ERMNs is given in Table 3. Results show that the access to the databases after registration/on request/by authorization is the most common. The registration procedures are related on the one hand to the Internet security issues or on the other hand to the additional communications with users about problems in the data. Accessible data are raw data (such as unprocessed measurements coming from the sensors that need to be elaborated and corrected to obtain the final, useful fluxes, *e.g.* IMECC or CarboEurope-IP) or calculated values (*e.g.* half hourly fluxes).

Data harmonization in view of available QA/QC procedures

To reach data harmonization, there is a need for having QA/QC procedures, both within and between the ERMNs, to enable comparison of used methods and agree upon harmonized procedures. QA/QC procedures assume that all the measured values are subject to a continuous control in order to reach the minimum probability of errors and biases in data series, both systematic (calculation errors) and casual (human factor).

An overview of the availability of QA/QC procedures in the various ERMNs (Table 4) shows that the majority of the presented ERMNs applied the QA/QC procedures for the measurement data calculation. Furthermore, according to the survey, the general QA/QC procedure's aspects and rules, applied in the presented ERMN, come from ICP Forests and ICPIM. Therefore, generally, the QA/QC procedures in relation to every group of parameters assume the following indicators (ICP Forests, 2011):

— Measurement Quality Objectives (MQOs): expected level of precision/accuracy for individual observations;

— Data Quality Limits (DQLs): the minimum acceptable frequency of observations within the MQOs;

— Plausibility Limits (PLs): the range of acceptable values for observations. These have to be updated continuously;

— Data Completeness Limits (DCLs): the minimum acceptable frequency of data within PLs.

Publications

The databases from the 15 selected ERMNs (Table 1), presented in this paper, are a meaningful source of information for the potential of forest ecosystem mitigation and adaptation to climate change in a polluted environment. Moreover, the knowledge and experience gained from a wide variety of environmental measurements have given the researchers the ability to deeply analyze the effects of different stress factors such as air pollution, GHG emission and climate change on the forest ecosystems adaptation and management. The results of the above research are widely published in various national and international journals, reports and conference materials. In the case of national journals, these publications are often (but not always) in the national language, which may reduce their international use. Sometimes a summary in English is provided. A majority of the international publications, related with the main Action goals, are widely available on the Internet. The manuscript can be found by using the popular internet web browser like Web of Knowledge (http://apps.webofknowledge.com/) or Scopus (http://www.scopus.com/home.url). The author name, publication year, name of the journal or only specification of the key words used in the manuscript will be sufficient to find a particular paper. Most often papers, which were written in the frame of the particular ERMNs can be found on the ERMN's web sites. The links that need to be used are listed in Table 5.

Table 3. Accessibility of the European Research and Monitoring Networks (examined in June 2012)

ERMN	Accessibility
COCOS	Free access (http://www.cocos-carbono.org/)
GTOS	Access after registration/on request/by authorization (http://www.gosic.org/ios/GTOS_observing_system.asp)
GHG-Europe	Free access to limited data series (complete access after authorization) (http://www.europe-fluxdata.eu/newtcdc2/ghg-europe_home.aspx)
IMECC	Access after registration/on request/by authorization (http://www.europe-fluxdata.eu/newtcdc2/IMECC-TCDC_home.aspx)
ICOS	Free access (Project in the preparatory phase - database portal not available yet)
InGOS	Free access (Project in the preparatory phase - database portal not available yet)
CarboEurope-IP	Free access to limited data series (complete access after authorization) (http://www.europe-fluxdata.eu/imecc)
ICPIM	Access after registration/on request/by authorization (No direct link to the ICP-IM database; Access after contact with Programme Center) http://www.environment.fi/default.asp?contentid=17110&lan=EN
ICP Forests	Access after registration/on request/by authorization (http://icp-forests.net/page/plots-data)
MACC	Access after registration/on request/by authorization (http://www.gmes-atmosphere.eu/data/)
NitroEurope-IP	Access after registration/on request/by authorization (http://www.nitroeurope.eu/data_ext)
EMEP	Free access (http://tarantula.nilu.no/projects/ccc/emepdata.html)
GEOMON	Free access to limited data series (complete access after authorization) (GEOmon Distributed Data Base (http://geomon.nilu.no/; GEOmon Rapid Delivery Data (ftp://ftp.nilu.no/pub/GEOmon/)
LTER	Free access to limited data series (complete access after authorization) (https://secure.umweltbundesamt.at/eMORIS/jsp/common/login.jsf)
ECLAIRE	Free access (Project in the preparatory phase - database portal not available yet)

Supersites

Presently, scientific communities face a challenge when it comes to describing the influence of anthropogenic and natural stress factors such as air pollution, climate and global climate change on the terrestrial ecosystems, forests especially. A number of the large-scale international research programs and monitoring networks are a source of information about the forest ecology, surface fluxes, atmospheric physics and chemistry, and air quality. These topics are crucial for the future of the forest ecosystems' goods and services, their maintenance and restoration and for predicting terrestrial feedbacks to Earths climatic systems.

The exact estimation and quantification of such processes like CO_2 exchange, ozone uptake, nitrogen and sulphur deposition or acidification have been and presently still are some of the most relevant topics for the scientific community. A key challenge for the next years is to provide a transnational long-term monitoring network for the main GHG like CO_2, CH_4, N_2O, O_3 and other pollutants such as heavy metals. The attainment of the above goal will be possible by the integration of research communities with operational expertise on monitoring and/or research networks as well as process and large-scale modelling (Fischer *et al.*, 2011; Matyssek *et al.*, 2012). Supersites, defined as a highly instrumented research infrastructure, for both research and monitoring of soil-plant-atmosphere interactions, can help attaining of the above goal. The basic concept of the Supersites assumes that the measurement will be realized on several levels, starting from the forest soil through the particular parts of plants to the whole ecosystem. Therefore, there is a need for the application of various measurement techniques, such as chamber technique, eddy covariance, phenological observation and carbon inventory (Paoletti *et al.*, in press). As these techniques

Table 4. Availability of QA/QC procedures in the European Research and Monitoring Networks (examined in June 2012)

ERMN	Availabillty of QA/QC Procedures	
COCOS	Yes	(http://www.cocos-carbono.org/)
GTOS	Yes	(http://gosic.org/)
GHG-Europe	Yes	(http://www.europe-fluxdata.eu/newtcdc2/GHG-Europe_home/Guidelines/Obtaining/geninfo.aspx)
IMECC	Yes	(http://imecc.ipsl.jussieu.fr/web_na3/)
ICOS	No	(Not defined yet)
InGOS	No	(Not defined yet)
CarboEurope-IP	Yes	(http://www.bgc-jena.mpg.de/bgc-processes/ceip/products/protocols.htm)
ICPIM	Yes	(http://www.environment.fi/default.asp?contentid=17110&lan=en)
ICP Forests	Yes	(http://www.icp-forests.org/Manual.htm)
MACC	No	
NitroEurope-IP	Yes	(http://www.nitroeurope.eu/data_ext)
EMEP	Yes	(http://tarantula.nilu.no/projects/ccc/manual/index.html)
GEOMON	Yes	(http://gosic.org/)
LTER	Yes	(http://www.lter-europe.net/document-archive/central/Best%20practice%20guideline%20v3-June1.pdf)
ECLAIRE	No	(Not defined yet)

have their own individual limitations in their application and accuracy, the combined use of them at one site will significantly improve the state of knowledge about the soil sciences, plant physiology, atmospheric studies and their common interaction in forest ecosystems.

A majority of the currently ongoing research and monitoring networks and projects are funded by the European Commission (EC). In addition, the national environmental funding agencies (ministries of environmental protection, agriculture etc.) are fundamental. The existing funding in most cases is limited in time and is mostly a narrow support for scientific research or monitoring projects and programs (Clarke *et al.*, 2011). Therefore, to link different approaches, the Supersites infrastructure concept assumes two levels of measurements. Level II corresponds to the limited number of highly instrumented sites, where the wide variety of environmental variables will be measured (depending on the variable type, the required time resolution of observation to be applied would be continuous, daily-to-monthly, or yearly). Level I includes the less equipped sites for the basic environmental parameters extensive monitoring, but covering larger ecological gradients and providing data with higher spatial resolution. Both measurement levels should be linked with each other in order to make data harmonization and efficient data flow possible (Clarke *et al.*, 2011; Fischer *et al.*, 2011). It is extremely important to combine the research efforts, undertaken in frame of Level II, with the different manipulative experiments such as: influence of the free-air enrichment of CO_2 or/and O_3 for tree stands, warming/heating experiments by using either controlled environmental chambers or whole experimental stands (heating cables, overhead infra red lamps, or indirect heating by the use of removable curtains), increasing N deposition by fertilizing or simulated elevated N deposition or decreasing by removal.

In an environmental monitoring perspective one describes and monitors the current status of natural ecosystems and their biodiversity, productivity or heath conditions, and establishes the future trends in environmental parameters. The scientific research in the frame of the environmental domain is based on the application of the scientific method for defining the natural processes and interaction which take place between the particular components (soil-plant-atmosphere) of every natural ecosystems. Therefore,

Table 5. Links to publications of the various European Research and Monitoring Networks (examined in June 2012)

ERMN	Publications availabillty	
COCOS	No	
GTOS	Yes	(http://wwwfao.org/gtos/pubs.html)
GHG-Europe	Yes	(http://www.ghg-europe.eu/index.php?id=4)
IMECC	No	
ICOS	No	
InGOS	No	
CarboEurope-IP	Yes	(http://www.bgc-jena.mpg.de/bgc-processes/ceip/products/publica–fr.htm)
ICPIM	Yes	(http://www.environment.fi/default.asp?node=6335&lan=en)
ICP Forests	Yes	(http://icp-forests.net/page/publications-3)
MACC	Yes	(http://www.gmes-atmosphere.eu/documents/publications/)
NitroEurope-IP	Yes	(http://www.nitroeurope.eu/dissemination)
EMEP	Yes	(http://www.emep.int/publications.html)
GEOMON	Yes	(http://www.geomon.eu/publications.php)
LTER	No	
ECLAIRE	No	

the integration of these two approaches presented above seems reasonable as it will increase the state of knowledge on the climate change and air pollution impact on forest ecosystem C sequestration and storage, soil chemistry and the water budget (Matyssek *et al.*, 2012; Paoletti *et al.*, in press).

Summary and conclusion

Presently, the quantification of forest ecosystem behaviour in an environment changing in respect to both air pollution and climate is fundamental, even because of the strong impact forests have on the global climate system. The research knowledge about the common interactions between soil-plant-atmosphere systems will be crucial for future forest ecosystem goods and services maintenance, enhancement and restoration. The presently ongoing ERMNs, and the different databases elaborated in the frame of this project, will help to achieve the above goal. The results of the COST FP0903 survey showed that the ERMN databases significantly differ in terms of their accessibility, quality, QA/QC procedure applications and presence in the European countries. There is a crucial need for mutual integration of existing international research knowledge and databases, with respect to measurement methodology, database availability and QA/QC procedures. In order to accomplish this need, the establishment of a common meta-database can be a first step towards integration and harmonization. Equally important will be the new type of research infrastructure in forest ecosystem called "Supersites". By the diversification of the measurements levels between the highly instrumented sites and low-intensity measurement plots the complex interactions between soil-plant-atmosphere systems can be studied more deeply. The process oriented Level II will furnish insight information and can be up-scaled to spatial coverage by using the wide-spread Level I plots.

Acknowledgements

We acknowledge the COST Action FP0903 "Climate Change and Forest Mitigation and Adaptation in a Polluted Environment". Furthermore, the presented paper was elaborated in the frame of the Short Term Scientific Mission (STSM) fellowships with the reference number STSM-FP0903-011011-010860 and STSM-FP0903-060612-016844 financed by the COST Action FP0903. We wish to thank all the scientists and experts contributing to the survey and discussions.

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