Ecological Function and Biodiversity Indicators in European Soils

Reporting

Project Information

ECOFINDERS
Grant agreement ID: 264465
Status
Closed project
Start date
1 January 2011
End date
31 December 2014

Funded under
FP7-ENVIRONMENT
Overall budget
€ 9 985 223,51
EU contribution
€ 6 999 930

INSTITUT NATIONAL DE RECHERCHE POUR L'AGRICULTURE, L'ALIMENTATION ET L'ENVIRONNEMENT
France

Final Report Summary - ECOFINDERS (Ecological Function and Biodiversity Indicators in European Soils)

Executive Summary:
Soils are a major reservoir of biodiversity. The resulting soil functioning provides numerous essential ecosystem services such as: primary production (including agricultural and forestry products), regulation of biogeochemical cycles (with consequences for the climate), water regulation, resistance to diseases and pests and regulation of above-ground biodiversity. However, soils are subjected to many threats, so there is an urgent need to preserve this resource which is not renewable at the Human time scale. The European Commission has launched Soil Thematic Strategy (STS) for promoting sustainable land use. However, scientific and technological knowledge on soil biodiversity and functioning in relation with the above mentioned ecosystem services is required to reach this goal. Especially, knowledge is missing on i) the range of variation of biodiversity according to the soil and climate type and to the land use, ii) the
relationships between soil biodiversity, functioning and ecosystem services, and iii) the impact of the environment variations on this relationship. The goal of EcoFINDERS was to make progresses in these knowledge gaps. Variations of soil biodiversity across Europe according to the soil type, land use and climate were characterized thanks to a European transect soil survey and to five Long Term Observatories (LTOs) representing different soil types, climates, land use and intensification. Major conclusion is that soil biodiversity is mostly driven by soil physical chemical properties and then by the land use; land intensification impacting soil biodiversity through its effects on soil physical chemical properties. Relation between soil biodiversity, functioning and provision of ecosystem services, tested in LTOs, indicated that i) physical properties and consequences for water regulation are impacted by earthworm diversity, ii) nutrient cycling and results on climate regulation are associated with soil biodiversity and new microbial guild have been identified. A set of bioindicators has been proposed. Standardized Operating Procedures (SOPs) for soil sampling and assessment of soil diversity and functions were developed. These SOP have allowed i) comparison of information from the different sites, and ii) building-up data base for interpreting soil biodiversity and bioindicators values according to the soil type, climate and land use. Furthermore, in the context of climatic change, the resistance and resilience (stability) of soil biodiversity-functioning to drought was tested in mesocosm experiments. Results indicate that above-ground diversity positively impacts this stability and results in return in a better plant growth due to a better nutrient cycling.

Quantification of economic value of soil biodiversity and services was assessed by developing appropriate tools and frameworks. Corresponding theoretical and empirical analysis has acknowledged potential trade-offs between services and has stressed the natural insurance value of soil biodiversity. Relations soil biodiversity-functions-services were translated in socio-economic system for a specific service (water regulation) as a study case. Based on expert judgement, EcoFINDERS has further assessed the cost effectiveness of bioindicators. Finally, EcoFINDERS has strongly contributed to i) raise awareness of policy makers, stakeholders and more generally public on the value of soil biodiversity and functioning for services essential to human well-being, ii) education of early-career scientists and iii) relevant communication to the scientific community by peer-reviewed papers and international conferences.

Project Context and Objectives:
Soils represent a major reservoir of biodiversity. This huge biodiversity supports soil functioning and its translation in ecosystem services including: primary production (i.e. agricultural and forestry products); regulation of biogeochemical cycles (with consequences for the climate); water regulation; resistance to diseases and pests; and regulation of above-ground biodiversity. These ecosystem services are essential to Human well-being. However, soil biodiversity and more generally soils are subjected to many threats, so there is an urgent need to preserve this resource which is not renewable at the Human time scale.

Thus, the European Commission (EC) wants to define a policy for the sustainable management of soils and has launched a Soil Thematic Strategy (STS). For developing this strategy, the EC considered that a better knowledge was required on soil biodiversity and functioning in relation with the above mentioned ecosystem services. Indeed, information on soil biodiversity was scarce especially because of difficulties for studying soil biota which are associated with: i) the small size of a significant fraction of them (microorganisms), ii) the arduousness to have access to soil biota in the soil matrix, iii) the high variety of
(i) the arduousness to have access to soil biota in the soil matrix, (ii) the high variety of environmental situations (types of soils, land uses, climates). On top of these difficulties, methodological limitations only allowed until a recent past having a truncated view of soil microbial diversity since we had only access to the so-called culturable microorganisms known to represent less than one percent of the total microbial community. However, progress in molecular strategies, especially possibility to extract DNA directly from soils, are now offering new opportunities for molecular characterization of soils biodiversity without a cultivation step. Finally, very few studies, if any, had encompassed together the analysis of the various groups of organisms making up soil biodiversity, that is to say microbes (archaea, bacteria and fungi) but also micro- and meso-fauna (protozoa, enchytraeids, nematodes, earthworms, collembola). This was a major shortcoming since the different biota interact together and with plant roots through food web chains, and their activities and functioning are necessarily related to these interactions. Knowing soil biodiversity per se, although being a very important task, is not informative enough, and must be complemented with deciphering networks among soil biota and with linking biodiversity to soil functioning and ecosystem services delivered. Furthermore, as soil biodiversity was expected to vary according to environmental drivers related to soil type, climate and land use, the corresponding environmental parameters were also expected to impact - for a given soil - biodiversity, its activities, functioning and provision of ecosystem services. Therefore, monitoring soil quality within the frame of a policy for sustainable land use was requiring, on top of soil biodiversity, an increased knowledge on i) the interconnectivity between soil organisms, ii) the relationships between soil biodiversity and functions, and iii) the impact of environmental parameters and Human activities on the above referred networks and relations.

Thus, goals assigned to EcoFINDERS were to make progress in the knowledge of i) soil biodiversity and its range of variation according to the soil and climate type, and to the land use, ii) relationships between biodiversity, soil functioning and ecosystem services delivered by soils, and the impact of the environment variations on this relationship, iii) interactions between below- and above-ground biodiversity and consequences on soil functioning. The hypotheses made in EcoFINDERS were that environmental parameters (especially soil properties) and intensity of land use may impact soil biodiversity and the relationships between soil biodiversity, soil functions and ecosystem services.

For making progress in the knowledge of soil biodiversity across Europe, a major prerequisite was to develop standardized operating of procedures (SOPs) applied by all partners within the project and aimed at being applied by European countries and EC for its STS. Indeed, it is striking to see that, for long, information from scientific studies was hardly not comparable because of the use of different protocols, making impossible to draw consistent conclusions. Therefore, EcoFINDERS had for major objective to develop SOPs for i) soil sampling to assess soil diversity and functions, ii) DNA extraction from soils and molecular characterisation of microbial diversity, iii) faunal extraction, identification and enumeration. More specifically, EcoFINDERS aimed at i) establishing databases of soil biodiversity in various soils under different pedo-climatic conditions and land uses for monitoring purpose, ii) developing a detailed understanding of the natural and human imposed drivers of soil biodiversity across EU soils, iii) standardising, automating and transferring molecular tools for soil biodiversity analysis (microbes and fauna), with potential for the development of ISO protocols. A major focus of EcoFINDERS was to develop barcoding procedures to enhance molecular identification of faunal species and to assemble a reference library for pyrosequencing of entire soil animal communities. Indeed so far, taxonomic identification of soil fauna relies mostly on morphological observations which are time consuming and require skills only
Fauna relies mostly on morphological observations which are time consuming and require skills only shared by a limited number of experts.

Relationships between biodiversity, soil functioning and ecosystem service were assessed and quantified in connection with soil physical and chemical properties. Regarding physical properties, a specific attention was given to water regulation in relation with soil structure and earthworms' abundance and diversity. A hydrological model has been developed to describe the hydrological effects of earthworm burrowing in response to land use. This model uses field data for density and diameter of macropores and their depth distribution. Regarding chemical properties, EcoFINDERS had for aim to characterize the contribution of soil biodiversity to carbon, nitrogen and phosphorus cycles in relation with nutrient cycling and climate regulation. For that purpose, EcoFINDERS has made methodological development to identify and target functional communities involved. As an example, EcoFINDERS has designed and optimised primers to investigate the diversity of microbial guilds genetically capable to reduce the potent greenhouse gas and ozone depleting agent N2O. Also, EcoFINDERS has quantified the relation between biodiversity and major functions involved in C and N cycles such as organic matter mineralisation and denitrification. Quantitative relations were made between the level of soil biodiversity and activities within C and cycles. Attempts were made to identify microbial communities and function involved in natural soil suppressiveness by following metagenomic approaches.

The interactions between below- and above-ground biodiversity and consequences on soil functioning were addressed with as purposes i) to link soil microbial diversity with soil functioning in terms of organic matter turnover and ii) to assess the resistance and resilience (stability) of soil biodiversity and functioning to climatic change and more specifically to drought. For the first one, assessment was made of soil biodiversity components that drive i) plant diversity and community composition and ii) ecosystem resistance and resilience to pest and pathogen invasions. Nutrient flow and distribution in the entire soil food web has been studied using stable C and N isotopes. For the second, plant species composition was manipulated to study the effect on soil community to test their effects on the response to drought of belowground communities and resulting processes.

Fulfilling the above majors goals of EcoFINDERS has also required the development and standardization of bioindicators that are sensitive, reliable, easy to apply and cost-effective. In that prospect, EcoFINDERS had for objective to identify their range of variations to allow the interpretation of the bioindicators’ values according to the soil type, climate and land use. For monitoring purpose, EcoFINDERS also aimed at mapping threats to soils and soil biodiversity at a European scale.

To address these broad objectives and initial hypotheses, EcoFINDERS has conducted biodiversity research at a range of spatial scales across Europe. Firstly, a network of five field sites across various soil and climatic types has been established, each of the long term observatories (LTOs) included a nested gradient of land use intensity to allow quantification of human and environmental impacts over wide ranging soils and habitats. Secondly, a broader scale European transect soil survey, representing an unprecedented initiative, has been adopted to assess wider variability in biodiversity across European soil and climate gradients. Finally a mesocosm experiment has been set to explicitly examine the mechanisms by which above-ground diversity affects belowground diversity and function.

Convincing policymakers and end users for the relevance of the EC STS require demonstrators of the
Convincing policy makers and end users for the relevance of the EC STS require demonstrators of the added value of the sustainable use of soils in order to preserve their biodiversity and promote ecosystem services delivered. Quantification of the economic values of soil biodiversity and soil ecosystem services was therefore a central goal of EcoFINDERS. This quantification was indeed aiming at delivering information on the added value of a sustainable land use. For that purpose, a conceptual approach to the analysis of the value of soil ecosystem services was followed by linking it to other initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) as well as other ecosystem assessments, such as the UK- National Ecosystem Assessment (NEA). The theoretical and empirical analysis of the soil services has acknowledged potential trade-offs between different services, stressing the natural insurance value of soil biodiversity. The relations soil biodiversity-functions-services were translated in socio-economic system for a specific service (water regulation) as a study case. EcoFINDERS also analysed how soil conservation initiatives, such as payments for soil ecosystem services, can be best designed to conserve soil biodiversity. Lastly, based on expert judgement, EcoFINDERS has assessed the cost effectiveness of bioindicators.

EcoFINDERS had therefore as purpose to i) develop appropriate economic valuation tools, in particular with frameworks assessing the value of soil ecosystem services and associated resilience attributes of soil biodiversity, ii) understand the current institutions under which soil services are governed and the diversity of stakeholder perceptions associated with soil services, iii) assess how economic instruments may help to conserve soil services in a cost-effective way, and iv) identify soil services and biodiversity indicators from a cost-effective way by involving scientists and stakeholders, including land users such as farmers.

Convincing policy makers, stakeholders, end-users and public of the importance of soil biodiversity and soil ecosystem services is requiring a major effort in communication. EcoFINDERS had as a major goal to achieve that communication by various means: i) associating policy makers and stakeholders with scientists to joint events (scientific conferences, panel discussions, stakeholder forum), ii) communications events associating scientists and large public (festival, show room, sampling events), iii) quick wins, iv) dissemination of flyers, publications, v) conferences, etc... On the top of the communication toward policy-makers, stakeholder, public, EcoFINDERS was also aiming to communicate scientific excellence and advances in magazines (peer reviewed papers in a series of Journal including from Nature group, special issue, book chapters and international conferences).

To summarize, EcoFINDERS was aiming to move one step forward in i) the knowledge of soil biodiversity and soil ecosystem services across Europe, ii) delivering standardized operating procedure to assess soil biodiversity and services, iii) proposing a set of cost-effective bioindicators and mapping the threats to soil biodiversity at the European scale, iv) developing strategies for assessing the economic value of soil biodiversity and ecosystem services, and v) promoting the importance of soil biodiversity and ecosystem services to policy-makers, stakeholders and public.

Project Results:

WP1 Biodiversity

The overarching objective of Workpackage 1 is to characterise the biological diversity, distribution and function of soil organisms (micro-, meso- and macrofauna, microbes) across the EU to decipher the relationships between pedoclimatic characteristics, land-use and soil biodiversity. The work involved the deployment of standardised high-throughput molecular and morphological methods, across coordinated sampling campaigns at 5 long term experimental sites covering grassland, arable and woodland transitions (“Long Term Observatories” LTOs, Figure 1a) to specifically address how land use...
transitions (Long Term Observatories - LTOs, Figure 1a) to specifically address how land use intensification alters soil biodiversity; as well as an EU wide distributed sampling (the “transect”, Figure 1b) survey to define broad ranges and controls of soil biodiversity. Additionally a mesocosm experiment was established to assess the role of plant biodiversity in determining climate change responses in soil biodiversity and nutrient fluxes between above and below ground systems.

Over these research platforms a number of standardised methodologies have been applied for the sampling and assessment of soil biodiversity including molecular approaches for microbes (Task 1.1); molecular approaches to assess functional diversity of genes involved in key ecosystem processes such as the nitrogen and carbon cycles (Task 1.2); and molecular and traditional approaches to assess faunal biodiversity (Task 1.3). Many of the developed approaches were also implemented in the mesocosm experiment of Task 1.4. All data arising from the project have been deposited in a bespoke EcoFINDERS database containing biodiversity and soil data from each geo-referenced sample (reported in D1.2).

Task 1.1 focussed on assessing the biological diversity of microbes and understanding the environmental and anthropogenic factors shaping communities; whilst Task 1.3 focussed on fauna but using more traditional approaches towards identification. Following the standardisation of sampling and methodological approaches (with WP3), extensive campaigns of samplings were conducted across the LTO field sites and the transect survey. This involved extensive coordination between partners and across WP’s: from field sampling, dissemination of soils to experts in soil faunal characterisation; nucleic acid extraction and distribution for a range of molecular analyses targeting different elements of microbial taxonomic and functional diversity.

Over 400 soil samples were collected and assessed across Europe as part of the LTOs (reported in D1.1) and transect sampling campaigns (D1.3 and D1.5). A first main outcome of this exercise was that for equivalent resource input progress in evaluating soil biodiversity responses was far more rapid for the evaluation of microbial communities, due to their reliance on molecular tools. Faunal assessments utilising more traditional taxonomic methodologies involved more labour as well as specialist taxonomic skills, and in many instances it has not been possible to provide full inventories for all samples. This highlights the need for more rapid approaches to assess soil fauna – as have been developed in other Workpackages as part of the EcoFINDERS project.

With respect to the molecular methods applied to soil microbes, two different methodologies have been evaluated – a cheap and rapid profiling method (Terminal Restriction Fragment Length Polymorphism, T-RFLP) and modern high throughput sequencing (with WP3) and both approaches were applied to the analyses of bacterial, archaeal, and fungal communities. We found both T-RFLP and high throughput sequencing methods reveal similar patterns in microbial community structure across all the samples assessed. The rapid T-RFLP method is therefore a cost effective means for assessing broad changes in microbial communities, but the sequencing approach allows for more rigorous interpretation of the identities of taxa changing in response to soil or land use factors. With the declining costs of sequencing it is likely that in the future these methods will become more favoured for monitoring purposes. It is noted however that these methods require considerably more time for raw data processing compared with T-RFLP, but the further development of bioinformatic pipelines will likely negate these issues in the future. Whilst efforts were made to standardise the methodologies for high throughput sequencing for this project (particularly adopting 454 technologies), given the rapid increases in technological development with...
(particularly adopting 454 technologies), given the rapid increases in technological development with respect to different platforms, it is not worthwhile developing formal Standard Operating Procedures (SOPs) at this stage (by the close of project the 454 technologies were no longer available being replaced by Illumina systems).

Both the transect and LTO surveys reveal that soil physicochemical conditions and land use are by far the most important drivers of variability in microbial communities above any direct spatial or temporal effects. The new knowledge with respect to understanding these predictable relationships, permits both spatial mapping of soil molecular biodiversity (Figure 2, from D1.5) but also potential predictions of the relative effects of land use or climate change on soil communities. The magnitude of local changes in biodiversity due to land use also is dependent on the type of conversion (e.g. forest to grassland > arable/grass rotation) and the local pedo-climatic context (Table 1). Where land use change results in large differences in soil conditions (such as organic matter, C:N ratio, or pH), then large changes can be expected in the microbial communities. For this reason by far the greatest and consistent effect on all measures of biodiversity was observed at the Berchidda site (forest to grassland). Effects at other sites varied according to taxonomic group and the nature of the land use transition. Relationships between change in biodiversity and soil C storage were explored in D1.6 and with the exception of the grassland improvements at the UK site, most forms of intensification resulted in a decrease in soil organic matter (OM). Establishing the causal relationships underlying these findings describing specific relationships between diversity and soil functionality with respect to C-cycling has been explored alongside this work in WP2. With respect to microbial indicators, we found consistencies in the responses of various microbial groups to soil pedo-climatic gradients, in addition to identifying specific indicator taxa in the LTO analyses of local changes in land use. However the specific indicators are largely related to the local soil conditions and the nature of the land use change. Novel microbial taxa with good potential for use as bioindicators were therefore found – particularly for bacterial taxa such as the acidobacteria, actinomycetes and alphaproteobacteria. However the magnitude direction of change in these taxa is dependent on the local soil/habitat context and the nature of the land use change. These relationships were reported on in the WP1 deliverable reports which have been submitted and are now being worked up into papers (including a broad overview of effects across LTOs, as well as detailed studies on specific effects at each). The analyses of these extensive datasets are now complete and datasets have been deposited in the EcoFINDERS database.

Task 1.2 addressed the diversity and distribution of key microbial genes involved in carbon and nitrogen cycling in soils, and much of this research made use of the soil genetic material collected by partners from the transect, LTO and mesocosm samplings. Work has focused on bacteria/archaeal genes involved in cycling of mineral forms of nitrogen; and also the fungal derived genes involved in the decomposition of plant-derived organic matter. The work has involved the development and optimisation of new functional genetic approaches, including the optimisation of primers and methodologies to characterise key N and C cycling genes prior to application to survey/experiment DNA and RNA. Results point to similar patterns as observed in Task 1.1 in that soil chemical conditions appear to also be a key driver of the diversity of functional genes found in soils and land use can significantly modify functional gene abundance and diversity (Figure 3), with the magnitude of effect being related to the nature of the land use transition in concert with the local pedo-climatic conditions. In addition many new novel fungal functional genes involved in degradation of lignocellulosic material in soil have been found from a transcriptome analysis of soils at the Berchidda LTO.
Task 1.3 was concerned with the assessment of faunal biodiversity using traditional and molecular approaches, and generally focussed on the LTO and transect samplings according to the SOPs developed during the early stage of the project. Across all coordinated samplings there has been continued morphological characterisation of extracted specimens (mites, collembola, enchytraeids, earthworms) to allow quantification of the extent of biodiversity in a range of soils advancing understanding of natural and anthropogenic drivers. Data has been published in deliverable reports (LTO & transect data) and are under preparation for public publications. Whilst the faunal data was not as useful compared with the molecular microbial data for the specific large scale assessment of land use effects at the LTOs, significant new results have been obtained from both the LTO and transect samplings. Many new species have been found and characterised, and the first EU wide maps of enchytraeids (Schmelz et al.) and European earthworms (Rutgers et al.) have been produced and will be part of a Special Issue of Applied Soil Ecology. In parallel, the definition of NOR (Normal Operative Range) of these two oligochaete groups is taking shape. Additionally, a vast collection of enchytraeid species has been obtained with ca. 200 species, 70 of which are new to science. This data is currently being worked up, using an integrative taxonomic approach (morphology plus DNA barcodes developed as part of WP3). Significant new datasets have also been compiled for microarthropod species composition, from both the European transect and selected LTOs. From the transect samples a total of 5352 microarthropods were identified to species or higher taxon. In addition to the information about taxonomic identity two separate tables were provided with summarised information per sample about the life history trait composition of the microarthropod communities and their feeding guilds.

To complement the LTO field studies and European soil transect, an experimental mesocosm experiment has been undertaken in Task 1.4 to empirically examine the chemical, physical and biological interactions and nutrient flows between above and belowground biodiversity in response to climate perturbation. The way that we manage the land can induce significant changes in the productivity, diversity and structure of plant communities, and such changes can, in turn, impact the soil microbial community with feedback consequences for biochemical cycles and plant growth. UOM lead the mesocosm experiment to determine how changes in plant community composition impact soil processes and their stability in the face of simulated drought. Specifically, the diversity of plant communities was manipulated in pots, followed by a drought regime to test how plant diversity affects belowground communities and processes with climate perturbation. Soils were sampled over the course of the drought-recovery regime for a variety of biotic and chemical variables making use of several methodologies and approaches developed in the other WP1 tasks. All datasets are now complete for this experiment including next generation Illumina sequencing of bacterial and fungal communities, soil functional gene analyses, soil mesofauna, soil chemistry and C&N fluxes.

Our results (reported in D1.5) showed that drought impacted the bacterial and fungal community compositions, but that the extent to which microbial community composition changed during the drought depended on the dominant plant species (e.g. Figure 4). Moreover, the drought effect could still be detected two months after ending the drought in the Dactylis and Leontodon dominated the plant communities, showing that the resilience of microbial community also depended on the dominant plant species. Together, these results indicate that changes in the identity of dominant plant species in a plant community can alter the response to and ability to recover from drought, of soil microbial communities. We hypothesised that root traits can explain the above microbial responses to drought. In support, we
Hypothesised that root traits can explain the above microbial responses to drought. In support, we observed linear relationships between root dry matter content (RDMC) and the composition of bacterial, fungal and N2O-reducing microbial communities (Figure 5). The effect of drought on RDMC depended on the dominant plant species, with RDMC increasing in communities dominated by Dactylis and Leontodon under drought. This suggests that the response to drought of microbial community is related to the response of root traits of plant community. These different responses to drought could relate to changes in competition for resources between plant and microbial communities. Indeed, drought modified the relative proportion of different plant species within the communities, especially when Dactylis and Leontodon were the dominant species, and this in turn affected the resilience of the plant community composition to drought (data not shown). Additionally, at the final harvest, the quantity of C and N available in soils was modified by drought and plant community composition, and was correlated to microbial biomass as well some genes’ abundance of microbial community related to N cycle (nosZI, nosZII, AmoA, nirK). This, combined with the observation that nitrate was reduced while aboveground biomass was increased in drought treatments, suggests that plants are stronger competitors for nitrogen than microbes when recovering from the effects of drought.

Overall, the results from this experiment show that plant community composition, in particular the identity of dominant plant species, can modify belowground responses to drought with consequences for ecosystem functioning. Based on these observations, we proposed a conceptual model in which plant community composition both directly, through symbiotic fungi, and indirectly, through changes in soil moisture, carbon, and nitrogen availability, affects microbial community composition (Figure 6). In turn, these changes in microbial community composition have implications for ecosystem functioning, both in terms of C and N cycling, and for the resistance and resilience of plant under climate change. This conceptual framework is currently being tested with structural equation modelling in preparation for a paper on these findings.

WP2 Soil functioning and Ecosystem Services

The objectives for Workpackage 2 were to establish and quantify relationships between soil biodiversity and the delivery of key ecosystem services, covering soil structure maintenance, soil water regulation, carbon sequestration, nitrogen retention, regulation of plant diversity and productivity, and suppression of native and exotic pests and diseases. WP2 has progressed in the understanding of functional biodiversity in soils at three levels: i) filling knowledge gaps in refined analyses of soil biodiversity (with WP1) and soil functioning, using newly developed and standardised tools (WP3), in cooperation with indicator assessment (WP4); ii) compiling existing data by literature review and meta-analysis, revealing land use and soil management impact; iii) establishing quantitative relationships and developing mathematical models for scenario study and guidance on land management, and transferring data to facilitate valuation assessment (WP5).

Change in land use and management can impact massively soil ecosystems. Ecosystem engineers and other functional biodiversity in soils can be influenced directly by such change, and this in turn can affect key soil functions. Yearly field campaigns have been conducted at long-term observation sites (LTOs) across Europe, comparing various land uses that differ in intensity of use: rotation cropping with grassland intervals, reduced tillage, grassland management extensification, and setting aside land. In all campaigns, soil biodiversity was sampled and soil processes were measured on site or in the lab. The work was broken down into tasks that were defined around chemical, physical and biological aspects of soil functioning and ecosystem services derived thereof.
Task 2.1 aimed to assess and quantify regulation of soil structure and soil formation (soil organic matter regulation, soil aggregate formation), and water regulation (retention, supply, and absorption) as affected by soil biodiversity. We performed meta-analysis of literature to provide general quantitative assessment of the effects of changes in land use and land management across a range of successional and extensification transitions (conventionally tilled arable land → no or reduced tillage → grassland → wooded land) on community metrics for earthworms and fungi, two functionally important soil groups. An analysis of the relationships between community change and soil structural properties was also included. The results highlighted a consistent trend of increased earthworm and fungal community abundances and complexity, following transitions to lower intensity and later successional land uses. The greatest changes were seen for early stage transitions, such as introduction of reduced tillage regimes and conversion to grassland from arable land. Not all changes, however, result in positive effects on the assessed community metrics. For example, whether woodland conversion positively or negatively affects community size and complexity depends on woodland type and on changes in soil properties, such as pH, that may occur during conversion. Alterations in soil communities tended to facilitate subsequent changes in soil structure and hydrology. For example, increasing earthworm abundances and functional group composition were shown to be positively correlated with water infiltration rate (dependent on tillage regime and habitat characteristics); while positive changes in fungal biomass measures were positively associated with soil aggregate stability.

LTO field studies showed that minimum tillage (MT) generally increased water infiltration rate, and water holding capacity was enhanced in the topsoil as compared to conventional tillage (CT). Soil aggregate stability was high under permanent grassland, and decreased with tillage frequency. However, the difference between MT and CT was not statistically significant. Water infiltration rates were significantly related to biomass of anecic earthworms that make deep vertical burrows. We manipulated precipitation regimes in a field mesocosm experiment to test whether presence of anecic earthworms (L. terrestris) can mitigate detrimental effects of intense rain events on soil and plants (ryegrass). Aboveground primary production was decreased by such events only in absence of the earthworm. This can be explained, at least partly, by increased water flow into soil through the macropores made by the earthworm. This study is one of the first experimental proofs of a potential insurance value of earthworms in agroecosystems.

A mathematical model was developed to predict water logging conditions and drought stress to crops on the basis of earthworm burrow spatial distribution and volumetric qualities as observed at LTO Lusignan in permanent arable land and grassland. Since biomass and functional group composition in earthworm communities are strongly affected by land use and soil management, this knowledge can now be used to assess the risk to farmers’ incomes as related to cropping strategies.

Functional differences exist between ecological groups of earthworms; however, functional responses could not be demonstrated at all sites and land uses. In general (literature), anecic and epigeic species can enhance water infiltration rates, whereas endogeic species have no such effect. The relationship between earthworms and soil aggregates formation also differed between sites; no generalised regression could be produced here across sites. There were generally positive relationships between earthworm biomass and abundance with soil aggregate size at both Lusignan and Moskanjci. In contrast, there was a trend of decreasing aggregate stability with increasing abundance of endogeic adult earthworms at Lusignan.

These findings raise the potential to manage landscapes to increase ecosystem service provision from soil biota in relation to regulation of soil structure and water flow.
Task 2.2 aimed at assessing and quantifying the relationships between soil biodiversity and chemical aspects of soil functioning and ecosystem services such as the regulation of nitrogen and carbon cycling, soil fertility and primary production (including food web approaches). It was investigated how land use affects soil biodiversity and soil ecosystem functioning by lab and field quantification of nutrient fluxes and trophic interactions.

Field observations comparing minimal (MT) and conventional mouldboard ploughing (CT) tillage showed faster nitrogen mineralization at CT in spring, while more nitrate-N was available under MT in summer; indicating that N availability under MT is better synchronised with crop development. Total soil organic carbon contents depended on tillage and soil depth, and showed depth-tillage interaction after 12 years of soil management. MT soils clearly showed decreasing concentrations of organic carbon downwards along the soil profile, and topsoil C contents tended to be higher than under CT. Similar trends were found for total N, and plant available K.

Drought affected the abundance of ammonia oxidizers and denitrifiers in archaea and bacteria. Average abundances of functional genes for nitrification (amoA of ammonium oxidizing bacteria, AOB) and denitrification (nirS, nirK, nosZI and nosZII) were significantly higher in MT soil than in CT soil in the 0-10 cm layer, except for total Crenarchaeota.

Measurements of soil ability to store or release carbon have been achieved on samples collected at Veluwe, Lancaster and Berchidda LTOs. The functional role of microbial diversity to soil functioning was evaluated with a laboratory microcosm experiment simulating erosion of soil microbial diversity by inoculating in gamma sterilized soil from LTO Lusignan with increasing dilutions of a suspension of the original soil. Decomposition of 13C labelled wheat residues and of indigenous organic matter was assessed during 60 days by measuring 13CO2 and 12CO2 fluxes, respectively. Results show that intensity of the soil respiration was strongly linked to microbial diversity, with the highest values observed when diversity was the greatest. These results highlight the significant role of soil microbial diversity for soil organic matter turnover.

Biological emissions of N2O are mainly controlled by nitrification and denitrification, N2O being a by-product of the first step of nitrification, or an intermediate or end-product in denitrification. Denitrification is the main process of N2O production in soils and the N2O:N2 ratio of denitrification end products can be influenced by several factors depending on soil conditions. Despite the importance of soil microorganisms in the conversion of the different forms of nitrogen, there was yet no consistent view on the significance of microbial biodiversity for soil ecosystem functioning.

Functional redundancy in denitrifier diversity was investigated by a dilution approach similar as described above. A reduction in diversity by dilutions up to 5 orders of magnitude revealed that the diversity of this functional community did not drop drastically with a decrease of about 75% of the measured species richness, as established by high-throughput sequencing. However, this decrease in the denitrifier diversity or in any other microbial guild was sufficient to result in a significant decrease of 4-5 folds in the denitrification activity, indicating a limited functional redundancy. The soil resource level had a significant impact on the shape of the denitrifier diversity-activity relationship.

Altogether, the results showed that biogeochemical cycling in soil can be affected by diversity loss, which highlights the functional consequences of this major threat to soils.

According to the insurance hypothesis, declines in ecosystem functioning due to reduced biodiversity are
According to the insurance hypothesis, declines in ecosystem functioning due to reduced biodiversity are more likely to occur under fluctuating conditions. We hypothesized that denitrifying communities with high genotypic dissimilarity also will have high functional dissimilarity or complementarity, and thus will be more tolerant to extreme conditions. This would result in a broader functional operating range, which we define as the range of environmental conditions under which a community or ecosystem is able to maintain its functions. Results did not establish a straightforward relationship between the functional operating range and a level of biodiversity, but rather showed complex patterns that vary with the community composition and environmental conditions. Phylogenetic diversity and relatedness metrics coincided with genotype richness and the importance of the individual metrics cannot be teased apart. However, diversity was associated with the broadest functional operating range and the highest process rates.

The contribution of microbial populations in determining the potential to act as a sink for N2O was examined for 47 soils across Europe. The soil N2O sink capacity is mostly explained by the abundance and phylogenetic diversity of a newly described N2O reducing microbial group mediating the influence of edaphic factors. Analyses of interactions and niche preference similarities suggest niche differentiation or even competitive interactions between organisms with the different types of N2O reductase. Several recurring communities comprised of co-occurring N2O reducing bacterial genotypes were identified, providing significant indicators of the soil N2O sink capacity across the European soils. Altogether, the results reveal that abundance and phylogenetic diversity of previously unaccounted N2O reducing microorganisms as well as community membership is critical for the soil N2O sink capacity.

While soil management has been shown to affect soil biodiversity in the field, laboratory and greenhouse experiments were conducted to further identify relationships between diversity and nutrient regulation. It was demonstrated that earthworm species differ in their capacity to incorporate crop residues and increase soil C and N contents. Similar species produce dissimilar soil biochemical hotspots, supporting the view that species identity and functional traits are important in investigating biodiversity-function relationships in soil macro-fauna groups. Earthworm-mediated incorporation of fresh surface C in soil resulted in a distinct soil organic matter chemical composition in the drilosphere. Earthworm presence is prerequisite for maintaining an active drilosphere, as soil around burrows from which the earthworm has been experimentally removed is not a distinct microhabitat from bulk soil. It has also been shown that the drilosphere hosts a somewhat distinct protistan community compared to surrounding soil. Also, the impact of reduced microbial diversity on carbon cycling was tested in another bioassay microcosm experiment. The results show a decrease of soil carbon mineralization rate with decreasing soil microbial diversity.

To further assess and quantify the relationship between soil biodiversity and carbon and nutrient cycling, and primary production glasshouse experiments were carried out to test how changes in soil biodiversity in response to environmental change and plant community composition impact a key, but relatively understudied, aspect of soil functioning: the resilience of soil biogeochemical processes and plant growth to drought. This experiment involved taking soils from treatments that had either been subject to simulated drought or not, or where the soil had been conditioned by plant communities dominated by each of two grassland plant species Leontodon hispidus and Dactylis glomerata. These soils were then planted in a reciprocal design with either the conspecific or heterospecific species in monoculture or in competition, and were then exposed to experimental drought. In doing so, we could test for: i) legacy effects of soil treatments (i.e. drought and conditioning by two dominant plant species) on the stability of soil processes and plant growth; and ii) influences of these legacy effects on plant-soil feedbacks and plant competitive interactions. Analysis of the soils confirmed that the first drought modified the microbial community.
Interactions. Analysis of the soils confirmed that the first drought modified the microbial community diversity, as assessed by T-RFLP, without changing soil abiotic properties, including soil C and N, and soil pH. For soil conditioned by both plant species, drought significantly reduced bacterial diversity, as assessed with the Shannon index, but increased that of fungi. Microbial activity following rewetting, assessed by measuring soil respiration, decreased in soils that previously had been subject to drought during the conditioning phase. Given that soil concentrations of soluble C and N and soil microbial biomass did not decrease after rewetting in this treatment, this suggests that the metabolic activity of the microbial community is decreased after a first drought event. This was related to a decrease of plant resilience to drought, as illustrated by the smaller increase of plant biomass after rewetting in soils conditioned with drought, a response which could be related to adaptation of the soil microbial community and altered rates of nutrient cycling. We also found that microbial activity and the plant resilience to drought depended on plant conditioning of soil, plant species identity, and plant competitive interactions. These results suggest that legacy effects of both drought and plant conditioning influence microbial responses to drought with consequences for plant growth. Overall, our findings suggest that legacy effects on soil microbial communities of drought and plant species composition influence the stability of soil processes related to C and N cycling and plant community responses to recurring disturbance events.

Task 2.3 aimed at determining the soil biodiversity components that drive plant diversity and community composition, and ecosystem resistance and resilience to pests and pathogens. Nutrient flow and distribution in the entire soil food web has been studied using stable C, N isotopes. To this extent, greenhouse mesocosm experiments were conducted using soils from chronosequences of set-aside land (Veluwe LTO) in The Netherlands. The study revealed that in long-term abandoned fields (45 yrs) the connectivity between the species groups still reflected that of recently abandoned field communities. All functional groups remained over the course of succession, but their community composition changed and, more importantly, taxa connections became more complex resulting in enhanced network interconnections. A consecutive mesocosm experiment confirmed some of these functional patterns. Results showed that plant roots in long-term abandoned grasslands had been taking up less labelled carbon and nitrogen, which means lower metabolic rate of the plants. The results suggest the above and below ground communities to become more efficient and slower in nutrient use, with increasing fungal dominance in the microbial community. This suggests that natural systems are more robust, since their soil food webs are more interconnected and are driven by efficient use of nutrients.

Studies on disease suppression revealed significant differences in the taxonomic diversity and community composition of rhizosphere fungi between soils which are suppressive for different diseases and between suppressive and conducive soils for a given disease. For Fusarium-wilt disease, taxa such as Plectosphaerella cucumerina, Verticillium sp., Hypocreales, or Fusarium equiseti were relatively more represented in suppressive than in conducive soils. Several species in some of these taxa can act as disease antagonists. However, fungal or bacterial taxonomic groups cannot be used as indicators of suppressive or conducive soils. Suppressive soils are certainly a source of biological control agents, but it is likely that the resistance mechanisms are based on the expression of functional groups of genes shared by fungal or bacterial consortia and whose taxonomic composition may vary from one soil to another.

While protists are mainly considered being bacterivorous, the functional versatility of those that feed on fungi turns out to be very wide. Some amoebae and flagellates can thrive on plant pathogenic fungi...
fungi turns out to be very wide. Some amoebae and flagellates can thrive on plant pathogenic fungi. Molecular data reveal the presence of known fungal feeding protists in all soils investigated, suggesting that this trophic link in food webs is more important than suggested before. Another unknown aspect of protist biotic interactions was observed for earthworm burrows as hotspots of protist activity. Protists numbers generally were high in the ranges of 100,000 individuals per gram soil, with increased numbers in earthworm burrows compared to bulk soil. The overall protist community composition was not affected, however, some individual protist genera were found to be associated with burrows, others with bulk soil. These findings indicate that some protist taxa are closely associated with earthworms, living in their burrows, while others are negatively affected by earthworms and mainly live outside the burrows. This finding could, however, only be obtained by a deep-taxonomic characterization of the protist community enabled by applying a modified enumeration technique that was newly developed.

Task 2.4 aimed to collect data in WP2 and prepare for economic modelling in WP5, in order to assess values of ecosystem services in relation to functional biodiversity in soils. Two approaches have been followed. The most elaborate approach was a “traditional” focus on the relation between soil biodiversity, soil functioning and crop yield, where soil processes were analysed mostly with respect to soil organic matter and nutrients. LTO data were compiled for valuation modelling of targeted ecosystem services. With a fitted quadratic production function, the role of soil organic carbon in the yield of grass was estimated, quantifying that less grass is produced at lower soil organic carbon (SOC) levels. The function also predicts future yields if management would promote SOC. Land conversion to maize from grassland has a positive impact of yields, and continuous maize cropping reduces yields. Therefore crop rotation is beneficial for yields.

While focusing on crop yields, trade-offs with other services were also analysed for. A mixed rotation with cereals and grassland (Lusignan LTO) offers a promising compromise in terms of i) maintaining higher levels of microbial biomass, earthworm biomass and diversity together with ii) maintaining comparable yields for the period to that from a rotation under cereals. These fields also experienced higher cereal yields than continuous cereal production, despite receiving less N fertiliser. We believe this is due to the relatively short time period that Lusignan has run, and that over time, differences may emerge. Soil biodiversity is influenced by land management practices.

The second approach focused on the significance of earthworm burrowing for water infiltration capacity of agricultural soils and forthcoming incidences of water logging in soils during periods of heavy rainfall (likelihood increases with climate change), and the consequences for farmer’s income security as a result of land inaccessibility and loss of crop. Hydrological modelling using site-specific soil and weather conditions data has diagnostically identified the occurrence of circumstances detrimental to cropping. The model can be used in site-specific scenario studies comparing different land use if the relationship with earthworm burrowing intensity is known.

WP3 Developing and Standardising Tools and Procedures for Assessment of Soil Biodiversity

The main goal of WP3 was to establish standardized state-of-the-art morphology-, function- and molecular-based procedures for assessing the diversity and structure of soil-borne communities, including bacteria, fungi, protists, collembolan, enchytraeids, and nematodes. To facilitate these analyses, a comprehensive reference database of genomic barcoding for soil organisms has been established. Utilizing the methodologies developed in WP3, we have produced verified guidelines of standardized methods and protocols. The standard operating procedures developed formed the foundation for the biodiversity surveys of bacteria, fungi, protists and soil invertebrates using samples collected in WP1.
Biodiversity surveys of bacteria, fungi, protists and soil invertebrates using samples collected in WP1. Furthermore, the methods and procedures developed facilitated robust indicator design for use in WP4. Regarding molecular methods, an overarching goal was to develop optimal sampling, high-throughput next generation sequencing, and bioinformatics methods and tools to assess incremental levels of soil organism diversity and to explore ways to integrate this biological complexity into the physical and chemical structure and functioning of soils. For morphology- and function-based methods, we standardized sampling procedures of already existing indicators and developed expert knowledge systems (media interactive identification keys) and trait-based identification approaches, which have been interconnected with molecular identification approaches (in WP1). Research and development in WP3 were based on samples taken at the LTOs and the European transect survey sites. Soil microbial biodiversity was examined at five LTOs situated throughout Europe, encompassing a range of climatic zones, soil types and land uses. The five LTOs were selected to represent a variety of common, European land use types ranging from boreal forest to Mediterranean grassland. Moreover, at each LTO, low and high intensity management treatments were sampled to investigate the effects of land use intensification on soil biodiversity and functioning.

To fulfill WP3 objectives, it was necessary to develop new tools and analytical pipelines to assess the biodiversity of soil organisms in a functional context. This was done by linking biodiversity with morphological and functional data using high-throughput imaging and DNA barcoding approaches, respectively. WP3 aimed to provide guidelines for standardized protocols for soil sampling, DNA extraction, high-throughput genotyping, metagenomics and bioinformatics. WP3 teams developed robust SOPs and analytical pipelines in order to assess the biodiversity of soil organisms in a functional context. This included SOPs for soil and biological samplings, high-throughput phenotyping of micro-, meso- and macrofauna, DNA extraction and storage, and high-throughput genotyping (DNA barcoding) of soil organisms. WP3 also assessed, compared and standardized methods and tools that enable data processing (biometrics, bioinformatics, data basing, data mining). WP3 specifically addressed the following aspects: coordination of LTO access, sampling and storage strategies, DNA extraction and sequencing, and development of a central warehouse (database) to store and organize the results (data/metadata) produced by experiments, LTOs, and modelling.

WP3 was articulated on four tasks:

Task T3.1: Soil sampling, soil storage and inventory of soil metadata. This task includes all aspects of molecular microbial ecology and DNA metabarcoding for the extraction and analysis of whole community diversity by methods of high-throughput environmental genomics of neutral and functional markers (t-RFLP, 454 pyrosequencing, bioinformatics, etc.). The results obtained have been evaluated across different spatial and temporal scales to compare geographic distance, land use and land management. Such measures were carried out to provide the indicators of soil quality for productivity, stability, resistance and resilience needed to prevent tipping points or thresholds being exceeded where functions are lost.

Task T3.2: Morphological and functional tools, including SOP for phenotypic characterisation and identification of microorganisms, Expert knowledge system for identification of soil invertebrates, SOP for functional (soil fauna activity) methods and SOP for trait-based identification of soil invertebrates.

Task T3.3: Establishing high-throughput molecular assays for assessing the structure and diversity of...
Task T3.3: Establishing high-throughput molecular assays for assessing the structure and diversity of soilborne communities. The specific technical objectives were to: i) develop SOPs for unbiased extraction of nucleic acids from mixed communities of soil organisms, including bacteria, archaea, fungi, micro- and mesofauna; ii) test and optimize specific DNA/RNA storage procedures at the centralized GenoSol depository; iii) test and optimize specific sets of PCR primers for comprehensive amplification of target DNA from soil microbes (group-specific PCR).

Task T3.4: Management of databases and modelling. This task addressed the practical arrangements necessary to manage the data collated while the project was running and their subsequent maintenance and long-term curation. An ISO-compliant discovery level metadata catalogue has been maintained centrally, and metadata from partners’ databases have been regularly harvested.

Task 3.1. Soil sampling, soil storage and inventory of soil metadata
The activity developed in this task has been devoted to the optimization of soil sampling strategy and of the procedure of microbial DNA extraction as well as storage, centralisation and dispatching of soil samples, genetic resources and metadata. With the goal to standardize and compare biological indicators of soil fauna and microorganisms along European geographic range of soils it is crucial to optimize and develop a common sampling strategy as well as standardized molecular approaches to characterize their abundance and diversity. In this context, a sampling strategy, developed by the consortium of partners and carried out by the GenoSol platform (INRA), has been set up to provide a single method to assess microbial diversity, specifically bacterial and fungal taxa. Specific sampling methods for earthworms, nematodes, enchytraeids, and microarthropods have been also optimised.

In this project, two types of sampling campaigns have been conducted and managed by this task 3.1:
- Sampling campaign across the different European LTOs at fall and spring 2011 (336 soil samples), with field support in each country (INRA Lusignan for France, UNITO and University of Sassari for Italy, NIOO and WUR for Netherlands, SLU for Sweden, University of Lancaster for United Kingdom). In addition, roots of plants colonized by AMF were sampled in the Lusignan LTO and stored at -80°C in March and September 2011.
- Sampling campaign across European transect with 115 sites during spring and summer 2012 (156 soil samples when considering replicates). For this campaign a preliminary study has been conducted by Teagasc to identify and locate the European sites respecting climatic, land use, and soil properties constraints and representativeness.

The soil samples of the LTOs and of the European Transect dedicated to microbial DNA extraction have been stored at -40°C for a long term in soil conservatory of the Genosol platform. Soil samples have been shipped to the INRA-Arras facilities for the measurements of soil chemical composition. The soil samples have been used to assess the microbial diversity (WP1), together with function and rates of nutrient cycling within soil profiles to compare resilience, turnover, migration and potential and response of communities to changes (WP2). The corresponding DNA samples have been extracted and shipped to several consortium partners for microbial DNA characterization: INRA-Nancy (fungal diversity), INRA-Dijon (AMF diversity and quantification and diversity of fluorescent pseudomonads, quantification of total bacteria, crenarchaea and N-cycling communities, characterization of bacterial diversity), CEH (genetic structure of microbial communities), NIOO (quantification of fungal communities), Wageningen University (quantification of antibiotic producing genes), Cologne University (diversity of Protists).
A database including all information on soil samples (site localisation, land use, climate type, GPS coordinates, sampling date, physico-chemical characteristics and land use) has been created by Teagasc and made available to partners on collaborative platform.

In this task, a specific effort has been devoted to the improvement of the soil DNA extraction procedure. A novel procedure based on the modified protocol of the ISO standard 11063 has been developed to generate high yields of soil fungal, bacterial and archael DNA for community analysis and to upgrade the characterization of soil bacterial and fungal communities by metabarcoding. The corresponding DNA samples have been extracted and shipped to consortium partners for microbial DNA barcode amplification (see Task 3.3) and sequencing by 454 pyrosequencing (in WP3.3). WU received from INRA (Genosol platform) 156 DNA samples from the Ecofinders transect and bio-indicator sites for qPCR-based assessment of putative markers for the ecosystem service disease suppressiveness.

The INRA Genosol platform has also managed the characterization of soil bacterial community diversity by the preparation of 16S rRNA genes libraries, pyrosequencing and bioinformatics analysis. Platform Genosol has also received and stored the 72 soil samples corresponding to the sampling strategy of the six sites dedicated for bioindicators evaluation. DNA from these soils have been extracted and disseminated to partners (INRA Dijon, CEH, Köln University, Wageningen University).

In terms of deliverables and communication, this task has allowed the centralisation and storage of LTO and transect soil samples which represent a very significant resource for the EcoFINDERS consortium and more widely for the European scientific community in soil biological science. Several molecular procedures have been standardised (soil DNA extraction procedure, gene libraries, bioinformatics tools) thanks to technical platform and dispatched among EcoFINDERS partners via technical workshop organised in this WP3 and more widely via academic publications in international scientific journals and congresses.

Task 3.2: Morphological and functional tools

WP3 teams worked with WP1 in optimizing methods for soil sampling, identifying and assessing activity of soil organisms (microorganisms and invertebrates). A series of SOPs for phenotypic characterisation and trait-based identification of soil microbes and invertebrates has been developed through a tight coordination between the consortium partners: i) SOPs for phenotypic characterisation and identification of microorganisms, ii) Expert knowledge system for identification of soil invertebrates, iii) SOPs for functional (soil fauna activity) methods, iv) SOPs for trait-based identification of soil invertebrates. Groups investigated are microorganisms, earthworms, protozoa, enchytraeids, collembola, and nematodes.

Two SOPs were developed for the phenotypic characterization of microbial communities in soils: SOP 1 - Phospholipid fatty acid analysis (PLFA) in soils - and SOP 2 – MicroResp - (Deliverable 3.1). SOP 1 was based on the guideline ISO/DTS 29843-2. Several modifications and improvements were made aiming to shorten the operational time and to standardize the water content of each soil sample to be analysed, making the PLFA identification more reliable. Soils used to test and optimize the SOP were obtained from the spring sampling at each LTO. Data obtained using this SOP and comparing it with the one mentioned in ISO/DTS 29843-2 showed comparable results in terms of the balance of PLFA, but an increase in the total PLFA mass. Moreover, a shorter operational time and a more reliable identification of PLFA was achieved in this SOP. MicroResp previously developed and was tested against 15 soils from 5 LTOs. The SOP worked well and the MicroResp analysis was able to distinguish between the different soils with a
SOP worked well and the MicroResp analysis was able to distinguish between the different soils with a high level of significance, indicating that MicroResp is a highly sensitive method for measuring catabolic activity and functional diversity of microbial communities in soil. Issues related to the pre-treatment of soil, number and identity of carbon substrates used, incubation time and the level of reproducibility were discussed and suggestions for improvement were made. Furthermore recommendations of further steps to develop an ISO guideline based on the developed SOP were made, especially the need to perform an inter-laboratory ring test using the same soils and assay setup. These protocols were developed by IMAR-UC and AU that worked in close collaboration.

Expert knowledge system was built for the identification of soil invertebrates (Deliverable 3.2) a web based interactive platform and aimed at two simultaneous goals: i) to be used by a wide range of target audiences (from general interested public, pre-university students and teachers and graduated, MSc. and PhD students and scientists) according to their needs in terms of identification; ii) to integrate the different groups of soil invertebrates in one single platform, facilitating the identification process of soil samples. The strategy followed was to build an integrative platform incorporating examples of its functionality using three groups of soil invertebrates (Collembola, Lumbricidae and Enchytraeidae), but constructing it in a way that could be easily updated when the information of more soil fauna groups is available. This was fully achieved. The platform created is already being used in the EU, Africa and South America by a wide range of target groups (especially pre-university groups and MSc. and PhD students in a first level taxonomic identification of soil invertebrates – at order and family levels), fulfilling the above mentioned goals of this deliverable. At this stage the platform is allocated at the server of the University of Coimbra and will continue to be updated. The platform was built by IMAR-UC and ECT that collaborated closely during the duration of this sub-task.

The SOP on functional methods (Deliverable 3.3) focused on the in situ evaluation of the soil fauna activity using the bait-lamina method. It was based on an existing draft ISO guideline (ISO/WD 18311) presented to ISO in 2012. The SOP presented here was used in close link to the fall 2012 sampling campaign (Task 4.3) on the five LTOs. The experimental design proposed to be used under ECOFINDERS (number of bait-strips per sample and number of samples per treatment and their spatial arrangement) was tuned after treating all the data received from the five LTOs. Since data from different land-use types was collected, this was used as an intercalibration exercise that contributed to validate the design proposed in this SOP and also used in further discussion of the draft ISO guideline.

SOP for trait-based identification of soil invertebrates (Deliverable 3.4) aimed at promoting a critical discussion concerning the state of the art and new challenges on the area of using ecological/functional traits in soil ecology. To achieve that, a two full-days workshop was organized by IMAR-UC and ECT GmbH and took place on the facilities of ECT GmbH (Flörsheim, Germany) on 17-18 February, 2013. The workshop counted with the participation of 10 members from the EcoFINDERS consortium, plus 8 external researchers that were invited by their expertise in trait-based approaches or management of ecological/trait databases. Experts on soil ecology were divided into three breakout groups to tackling different specific questions related to the objectives of the workshop. The main aim was to analyze which traits are being used in ecological studies, whether they are the most appropriate to study the relations between soil biodiversity and soil processes underlying key ecosystem services (effect traits), and how they are being used to evaluate the effects of environmental stressors on soil fauna communities (response traits). The ultimate goal was to have a step forward on what could be the ideal structure of a trait database, what type of traits should be included and how to gather them, structure and standardize trait data in order to be readily available to soil ecologists and permit to link effect and response traits in a response-effect framework. The conclusions of the workshop are being incorporated into different scientific
Task 3.3: Establishing high-throughput molecular assays for assessing the structure and diversity of soilborne communities

Microbial communities

A range of standardised methodologies were employed throughout the project ranging from traditional taxonomic investigations to complex high-throughput molecular approaches with the aim of determining the relative impact of environmental drivers on different components of soil biodiversity, but also establishing “indicator” approaches with which to monitor changes in soil diversity. Development of high-throughput methodologies based on characterization of DNA now offer unique opportunities for assessing genetic structure and diversity of microbial communities at large scales and in a wide range of environments. Each of these methodologies has advantages and disadvantages that can affect how soil microbial community responses to environmental filters are represented. Although next generation sequencing technologies proffer the most detailed analyses of microbial communities, other molecular methods, such as terminal restriction fragment length polymorphism (T-RFLP) analysis, represent alternative high-throughput options but do not provide the same level of phylogenetic detail. In WP3, we have compared 454 pyrosequencing and T-RFLP analyses to assess their ability to discriminating genetic diversity and structure, in response to land use intensification. The specific technical objectives of Task 3.3 were as follows:

- Sequence the LTO DNA samples by 454 pyrosequencing and generate DNA barcodes;
- Sequence the European transect DNA samples by 454 pyrosequencing and generate DNA barcodes;
- Design and test new primers and PCR amplification procedures for metabarcoding soil fauna (e.g. protists, nematodes, earthworms);
- Perform high-throughput genotyping of soil fauna using 454 pyrosequencing;
- Produce biodiversity indexes and statistics for bacterial and fungal diversity for further analysis in WP1 using the EcoFINDERS bioinformatic workflow.

Extraction of DNA from bacteria, archaea and fungi was optimized in Period 1. In the Period 2, we focused on assessing the most effective DNA extraction method for establishing high throughput DNA barcoding of faunal species, such as nematodes, protists and earthworms. In Period 3, our activity was mainly dedicated to i) sequencing to produce the DNA barcodes corresponding to the various microbial communities and ii) analyzing the datasets to produce the needed biodiversity indexes for WP1.

For pyrosequencing analyses of bacteria, archaea and fungi, both forward and reverse primers included a multiplex identifier (MID) tag, unique to each sample, to discriminate between communities sequenced in a single batch. Prior to amplification, samples were randomised into eight libraries of sixteen. Bacterial 16S rRNA gene fragments were amplified using the primer pair 530F and 803R with Pfu DNA polymerase (Promega, Southampton, UK). Following amplification DNA was purified using the MinElute PCR purification kit (Qiagen, Manchester, UK) and quantified using the PicoGreen staining Kit (Molecular Probes, Paris, France) on a StepOne Real-Time PCR System (Life Technologies, Paisley, UK). Archaeal 16S rRNA genes were amplified with forward primer A364aF and reverse primer A934b using AccuPrime Taq DNA polymerase (Invitrogen, Life Technologies, Paisley, UK). Post-amplification, archaeal 16S amplicons were purified by gel extraction with the QIAquick gel extraction kit (Qiagen, Manchester, UK).
amplicons were purified by gel extraction with the QIAquick gel extraction kit (Qiagen, Manchester, UK), then quantified using the Qubit® dsDNA BR Assay Kit with a Qubit fluorometer (Life Technologies, Paisley, UK). The fungal internal transcribed spacer 2 (ITS2) region was amplified using primers ITS4 and ITS9 which are known to amplify more groups of fungi, especially dikarya (Ascomycota and Basidiomycota), than other more traditional primers. Following amplification, PCR products were purified using a QIAquick PCR purification kit and quantified using Quant-iT PicoGreen dsDNA reagents (Life Technologies, Paisley, UK). For each microbial group, amplicons were then pooled at equimolar concentrations to provide a total of 2 µg DNA in each library. Amplicon pyrosequencing was performed on the GS-FLX 454 Titanium platform (Roche, Basel, Switzerland) by Beckman Coulter Genomics (Danvers, MA, USA) generating a total of 5,446,750 reads (bacteria: 3,001,697; archaea: 966,675 and fungi: 1,478,378). For full details of microbial gene amplifications and sequencing see supplementary information.

Optimized EcoFINDERS bioinformatic pipelines were thus used to generate taxonomic attribution to be used in WP1. Microbial sequences were demultiplexed using mothur v.1.22.2 to allocate sequences to particular samples according to MID tags. Bacterial and archaeal sequences were filtered using mothur, and the fungal ITS2 region was extracted using Fungal ITS extractor v.2. After quality filtering, a total of 3,264,103 reads (1,608,034 bacteria; 663,281 archaea and 992,788 fungi) were retained. For each microbial group, community analysis was performed using the same level of surveying effort for each sample. Bacterial sequences were rarefied to 1,633 sequences per sample, whilst the archaeal and fungal datasets were rarefied to a depth of 500 sequences per sample (for full details on sequence processing see supplementary information). Operational taxonomic units (OTUs) were then generated at 97% similarity for all microbial groups using Usearch v 6.0.307. Phylogenetic assignation was performed on a consensus sequence from each OTU using the Ribosomal Data Project (RDP) database release 10.3 for bacteria and archaea. Whilst the UNITE database release 5.0 was used to classify fungi. The 454 pyrosequencing data generated for this study have been deposited with the Sequence Read Archive (http://www.ncbi.nlm.nih.gov/sra) and are available under project PRJNA254033, accessions SRS652425 through SRS652668.

Results of these analyses are presented in the WP1 section.

DNA barcoding for faunal species
Characterization of the huge soil faunal diversity still relies heavily on the slow and expert-dependent morphological identification. This hampers our ecological understanding of spatial and temporal diversity of many faunal groups, as screening many samples at high taxonomic detail is not a realistic proposition. DNA-based approaches potentially solve this issue, but the development of such methods targeting soil fauna lags far behind that of soil microbes. For that reason, Task 3.3 aimed for the establishment of methodology for high-throughput and high-resolution characterization of soil fauna communities using DNA metabarcoding. Specific objectives were i) to develop such a framework and the molecular markers required as its components, and ii) to establish reference datasets of DNA barcodes required to assign sequence data to particular faunal taxa. The EcoFINDERS consortium has focused on six faunal groups: mites, collembolans, enchytraeids, nematodes, lumbricids and protists. New markers were developed for barcoding of mites, collembolans and enchytraeids. These were applied to generate reference collections of DNA barcodes for species known from agricultural soils and semi-natural grasslands in Europe.

For metabarcoding, we developed a tiered approach, in which a general eukaryotic marker is used to
For metabarcoding, we developed a tiered approach, in which a general eukaryotic marker is used to screen for the presence of different eukaryotic clades and a set of more specific markers is simultaneously analysed to obtain high resolution data for targeted taxonomic groups. We tested our approach using two 454-pyrosequencing runs. Artificially created DNA pools of known composition were analysed to test to which extent the taxonomic composition could successfully be retrieved. Results showed that the majority of taxa was recovered, but that relative abundance of sequences assigned to the different members differed profoundly from what we expected based on added DNA. Another interesting finding was the observation of 40 protist OTUs, while only 8 taxa were added. Many of those closely resemble parasites, which most likely originated as co-extracts from faunal cells (Geisen et al., in review). Furthermore, direct comparisons of morphological and molecular identification approaches, based on the same soil samples, showed a high overlap in the number and identity of observed taxa.

We conclude that high-throughput sequencing has some biases that need to be taken into account in interpreting community structures, but does provide a promising tool for high-throughput screening of faunal taxa present in soils. For the first time, we provide an integrated methodology for molecular screening of a wide range of soil faunal organisms (De Groot et al. in prep). This approach will highly benefit the efficiency of both applied and academic soil faunal surveys in agricultural landscapes.

Task 3.4: Management of databases and modelling

A key facet on the EcoFINDERS project was the integrated and coordinated sampling of soils by multiple partners across Europe, and efficient and tractable databases were required to facilitate storage and wider dissemination of the data to stakeholders. In Task 3.4 we have established the project database, which has been developed to not only store data but provide a user friendly interface for retrieval of data. In the 3rd Period, we have addressed the practical arrangements necessary to manage the data collated in EcoFINDERS project and their subsequent maintenance and long-term curation. The partner consultation was carried out in Period 1, whereas the database design and implementation was performed during Period 2.

CEH was responsible for providing a tractable system and its long term maintenance. An ISO-compliant discovery-level metadata catalogue has been implemented centrally, which was used for regularly harvesting metadata from partners’ datasets. The metadata catalogue is now available externally via the project website. CEH has implemented the EcoFINDERS central warehouse (database) to store and organise the results (data/metadata) produced by experiments, LTOs, trans-European transect and modelling. A user friendly interface has been developed to allow easy extraction of data (and metadata) at both the site level and at the data category level. The database is controlled centrally. The database was created as an MS Access 2007 database, as this provided the most convenient method for storage and development during the lifetime of the project. For long term accessibility an online database would be ideal, or a download option from a data centre with the data tables stored as text files or other non-proprietary file format to ensure that the data are as future proof as possible. To date, the long term future of the database has yet to be decided. The database includes three main sections. Section 1 is for the LTOs, Section 2 for the European transect, and Section 3 for the indicator Long Term Observatories. A detailed description of the database structure is available in Deliverable 3.5.

Originally starting with a small number of T-RFLP datasets from the LTOs samples, the database was extended to include other molecular data and fauna data from the LTO samples, samples from a European
extended to include other molecular data and fauna data from the LTO samples, samples from a European wide transect, and other so-called indicator LTOs sampled for soil biodiversity indicators. The report contains different sections for each experimental type, which detail out the structure and definitions of the tables and data. Data processing was automated as much as possible, using the programming language R for any data reformatting. After any reformatting and importing into the database, the data were recoded with the correct sample identifier before being appended to the correct data table, using a defined process. A series of quality assurance checks were put in place to ensure that errors were not imported into the database. Any changes or modifications made to the database were recorded in a modification log and linked to the data. All data imported into the database contain details on who was responsible for importing data, the date of import and who provided the data. A user friendly front end was created to allow for easy view and extraction of the data without needing any knowledge of how to query a database. A series of menus allows users to navigate between the different datasets, to view data and to export data along with metadata. Tutorials on how to access data through the user interface are available and have been presented at the final EcoFINDERS meeting in Dijon on early December 2014.

In conclusion, WP3 seeks to establish standardized state-of-the-art morphology-, function- and molecular-based procedures for assessing the diversity and structure of soil-borne communities, including bacteria, fungi, protists, collembolan, enchytraeids, and nematodes. To facilitate these analyses, a comprehensive reference database of genomic barcoding for soil organisms has been established. Utilizing the methodologies developed in WP3, we have produced verified guidelines of standardized methods and protocols. The SOPs developed form the foundation for the biodiversity surveys of bacteria, fungi, protists and soil invertebrates for biodiversity surveys carried out in WP1. Furthermore, the methods and procedures developed facilitated robust indicator design for use in WP2 and WP4. Regarding molecular methods, we have developed optimal large-scale sampling for LTOs and the European transect sites, high-throughput 454 sequencing, and bioinformatics pipelines for assessing soil organism diversity. This allowed WP1 to integrate this biological complexity into the physical and chemical properties of soils. For morphology- and function-based methods, we standardized sampling procedures of already existing indicators and developed an expert web-based knowledge database and trait-based identification approaches.

WP4 Evaluating and Developing Indicators for Biodiversity
The two outcomes of WP4 were i) to recommend indicators for soil ecosystem function and indicators for soil biodiversity and ii) to map threats to soil biodiversity.

Potential indicators were tested at LTOs that cover the desired range of European climatic zones and land use options, overlaid in many instances with experimental treatments relevant to climate change and other threats to biodiversity. Six sites were chosen to cover: Atlantic, Continental, Mediterranean and Pannonian climatic zones and arable and grassland land use types. Each site had fully replicated plots of a standard management (control) and an alternative management (treatment). Treatments varied from site to site but were relevant to the land use and the climatic zone (Table 2; Figure 7).

This ensured a wide range of experimental conditions with which to test the sensitivity of the potential indicators. Sampling took place in autumn 2012 and spring/autumn 2013. Results from the samplings are uploaded to the project portal.
A breakdown of the cost effectiveness of the indicators showed the expected trade-off between intensity in the field and intensity in the laboratory. The logistical challenges of two methods, bait lamina and water infiltration, were too great to overcome in this sampling regime and so we would recommend that although they give useful results, directly relevant to ecosystem services and easily interpreted, their inclusion as an indicator would need to be critically evaluated. Ergosterol was a single end-point indicator (fungal biomass) that used similar methodology to PLFA, which would give an indication of fungal biomass but a range of other metrics as well (i.e. different bacterial groups, bacterial: fungal ratio). The resilience assay could not be recommended for use now, simply because it is newly developed and cannot easily be interpreted. An indicator programme cannot be based around a single indicator, as shown by the facts that: no one indicator was able to detect treatment effects at all sites; and that there were different patterns of indicator responses to the different treatments across the sites. Thus a suite of indicators will need to be used. The ENVASSO project made specific recommendations for three indicators (earthworm species, Collembola species and basal respiration) for use in an initial screen when monitoring for changes in soil biodiversity. Based on a combination of the practical results, relevance to the monitoring objectives and relative cost-effectiveness, we recommend an initial suite of six indicators to monitor soil biodiversity and ecosystem function at the European scale, three faunal and three microbial indicators. These are: earthworms, Collembola, nematodes, nitrification, microbial biodiversity by T-RFLP, and extra-cellular enzyme activity. Earthworms are represented by too few species to be a reliable indicator of biodiversity, but they are a very relevant indicator of function with a high utility (provide multiple end-points) and are directly related to ecosystem functions (e.g. water infiltration, decomposition, nutrient cycling and crop productivity). Only earthworms were sensitive to the changes at Lusignan, which actually showed no effects of management in our assessment of LUI. Earthworms, already widely recognised as soil indicators, meso- and micro-fauna, microarthropods and nematodes, are directly influenced by changes to soil structure, soil pore water and atmosphere composition, and soil organic matter. They are also directly related to the ecosystem functions of decomposition and nutrient cycling, have a high utility and are potentially high-throughput (with a move to molecular techniques). We would recommend Collembola as a microarthropod indicator because their trait-based life-history information provides much additional information. Nitrification, although a single end-point assay is directly related to a central ecosystem function. Microbial biodiversity by T-RFLP is a high-throughput process, as could be the assay of extra-cellular enzymes which addresses aspects of carbon, nitrogen, phosphorous and sulfur cycling. Range of variations of the indicators was also assessed across the European soil transect survey set within EcoFINDERS.

There are a number of caveats to this recommendation. So: i) there is a need to identify when indicator results identify a significant change which requires a ‘normal operating range’ or set of reference values against which the indicator value can be compared. At the continental level, for example Europe, then these would be established for realistic set of regions. This is already undertaken by, for example MAES (mapping and assessment of ecosystems and their services - http://biodiversity.europa.eu/maes) ELCE (ecological land classification for Europe), DMEER (digital map of European ecological regions) and the European biogeographical regions; ii) the temporal dynamics of the indicators needs to be taken into account; iii) standardisation is crucial to any monitoring scheme, many of the methods already have agreed ISO formats but a preliminary ring-test between participating laboratories would be a key requirement; iv) the recommended indicators are purely biological, there would need to be link to chemical and physical measurements to give a more complete understanding of the soil conditions; v) the available technology is continually advancing. Even during the lifetime of this project the available technology has
technology is continually advancing. Even during the lifetime of this project the available technology has changed considerably. For example, high-throughput sequencing started out using the Roche 454 system but by the end of the project this was phased out and is no longer in production. The application of metabarcoding approaches has become more prominent, so that the diversity of all groups can be determined from the same sample. As our results showed changes in diversity were not common between microbial and faunal groups, a metabarcoding approach would give an absolute measure of diversity. Developments have also been made in the measurement of environmental DNA (e-DNA, Bohmann et al. 2014. Environmental DNA for wildlife biology and biodiversity monitoring. Trends in Ecology & Evolution 29:485-485) which, if shown to be reliable, would greatly increase the ease of DNA extraction and increase the sample size, thereby making the soil samples far more representative. Changes in technology, however, are only likely to alter the way in which the indicators are determined, rather than change the indicators themselves. Changing from morphological to molecular identification of fauna has been described earlier, but also the superseding of T-RFLP by high-throughput sequencing, for example, would still give a measure of microbial biodiversity.

The three maps (Figures 8 - 10) that resulted from our evaluation of threats to soil biodiversity represent the first attempt to show areas featuring three different components of soil biota under potential threat and, therefore, requiring particular care in coming years. The maps show that the overall distribution of the sensitive areas is similar among the three components of soil biodiversity. For example, the Po Plain and the Netherlands region are particularly sensitive because of intensive human exploitation, i.e. wide-spread use of fertilizers. The south of England showed a high risk due to both soil compaction and potential reduction of organic matter, while the driving force in Spain and southern Italy was the risk of aridity (i.e. climate change) (Figures 8 - 10). Despite the comparable distribution, the level of risk varies among the three categories because of the different weighted potentials associated to the different threats. The extent of areas with high level of risk (Figures 8 - 10) are greater for soil fauna and soil functions compared to soil microorganisms. The reason for this may be the higher capability and flexibility in responding to external pressures typical of soil microorganisms (i.e. bacteria and fungi) thanks to their biological features (Schimel et al. 2007. Microbial stress-response physiology and its implications for ecosystem function. Ecology 88:1386-1394). This reflects the minor scores given to each threat to soil microbes by the experts, and leads some of the regions with high risk in the maps of soil fauna and functions (Figures 9 - 10) to be downgraded to medium-high or medium in the map of soil microorganisms (Figure 8). Of course, such differences need to be taken into account for the development of specific measures aiming at reducing the impact on different components of soil biota. Furthermore, the origins of these differences need to be further investigated in order to identify and understand the threats that define them. This will allow us to better design strategies specifically targeting the potential causes of loss/reduction of soil biodiversity.

WP5 Valuation of Soil Ecosystem Services

A premise of EcoFINDERS is that society values soil ecosystem services to the extent that they fulfil needs or confer satisfaction to humans. WP5 provides the economic valuation and institutional framework for policy making. It is based on the notion that soil biodiversity can be seen as natural capital, and the flow of soil ecosystem services is the “interest” on that capital. WP5 had four main objectives: i) to model the role of soil biodiversity and soil ecosystem services for human well-being, by disentangling the concept of the economic value of soil ecosystem services (c.f. D5.1 D5.3 D5.4) (ii) to shed light on the institutional background on which such values are perceived by individuals and society (c.f. D5.2) iii) to interrogate what kinds of economic incentive measures could be applied that are both effective and perceived with sufficient legitimacy by land owners (c.f. D5.5) and iv) to evaluate cost.
effective and perceived with sufficient legitimacy by land owners (c.f. D5.5) and iv) to evaluate cost-effective indicators of soil biodiversity and ecosystem services (c.f. D5.6). In what follows, the main results associated with these four objectives are described.

The concept and application of the value of soil ecosystem services
WP5 has focused on the idea of economic value of soil biodiversity and ecosystem services. This does not imply that EcoFINDERS reduces the entire idea of value only to an instrumental (anthropocentric) one. However, it has sought to deepen on this aspect of value. For this end, a set of three groups of modelling approaches have been used to better understand the socioeconomic value of soil ecosystem services.

First, an ecological economic stock-flow conceptual framework has been developed that synthesizes the main contributions of the valuation literature on the role of soils as critical natural capital. The framework associates, through specific pathways the biophysical soil system with the economic system and the private vs. social values of soil biodiversity and ecosystem services. This helps map soil functions, services and economic values and allows to identify various categories of economic values associated with soil biodiversity and ecosystem services. The model has offered the important insight that the value of soil biodiversity and ecosystem services stem mostly from its “indirect use value”, generally associated with regulating ecosystem services, and the “natural insurance value”. That is, the model offers an intuitive but robust insight that soil biodiversity can positively affect the average supply of ecosystem services, (e.g. agricultural yield, as provisioning service) and that in addition it can provide reduce the variability of such supply of services up to a given threshold. The latter is the insurance value of biodiversity.

Second, through a theoretical bio-economic model representing the link between soil biota, hydrological processes and the economic value of agricultural production, WP5 has conceptualised how soil biodiversity delivers water regulation services and how these services affect the distribution (mean and variance) of agricultural revenues to a representative farmer. The model can predict how much a farmer is willing to conserve soil biodiversity when he is averse to climate variability, i.e. to variability in water availability. This allows to theoretically ascertain the conditions for optimal soil conservation strategies of risk averse farmers under climatic uncertainty. The model considers that soil biodiversity improves water moisture in the soil. In a stochastic framework accounting for climate variability, this means that soil biodiversity helps to transfer water from humid periods (spring) to dry periods (summer) all along the production process. We have proposed a modelling with linear and with non-linear production processes. The model shows that the critical threshold by which the value of soil related to its insurance value, mainly depends on the cost of investment in soil biodiversity, the productivity of soil biodiversity and land users (e.g. farmers’) risk preferences (how much the farmer likes or dislikes the variation of his production, and thus income variability). The model further reveals the degree of complementarity between soil biodiversity and irrigation from which land use policy implications can be directly derived. For instance, with regard to water use, we predict theoretically that i) irrigation quotas might be preferable to irrigation pricing policies when farmer’s decisions are not sensitive to the cost of irrigation or the cost of soil biodiversity conservation, and ii) soil biodiversity conservation should be coupled to water resource management policies as biodiversity is more difficult to observe and regulate than irrigation.

In addition, the bio-economic model used by WP5 allows for the existence of other sources of hydrological services beneficial for agriculture, such as through irrigation technology. This consideration in the model is important as farmers can insure themselves against climatic variability by using irrigation or/and investing.
Important as farmers can insure themselves against climatic variability by using irrigation and investing in soil biodiversity. The model has therefore been extended to analyse the trade-offs between irrigation and soil biodiversity conservation. The model shows the economic, biological and climatic conditions under which a farmer will prefer to invest in irrigation rather than on soil biodiversity conservation. Results reveal the degree of complementarity between soil biodiversity and irrigation: a farmer willing to use irrigation would have more benefits from it if he has also invested in soil biodiversity since biodiversity enables to transfer water from humid to dry periods and because during dry period water may not be available for irrigation.

Furthermore, when the model allows for drought probabilities, before a certain probability threshold, when drought is more frequent, the model shows that it is rational to invest in soil biodiversity conservation to transfer moisture across agricultural periods. However, beyond a certain level of drought frequency, the model predicts that when droughts are too frequent and disinvestment in soil biodiversity may be an economically optimal decision by farmers.

The bio-economic model has important policy implications as it shows that under climate variability a farmer’s decisions (investment in biodiversity vs. use of irrigation), a policy maker may see that i) water quotas might be preferable to water pricing policies when the farmer’s decisions are not sensitive to prices (cost of irrigation, cost of soil biodiversity loss), and ii) soil biodiversity conservation should be coupled to water resource management policies as soil biodiversity is more difficult to observe and regulate than irrigation.

Third, an empirical production function approach (PFA) has been used to model with data some key aspects stemming from the bio-economic model described above. It highlights trade-offs and synergies between soil biodiversity, ecosystem services and land management practices. We tackled this challenge from a multidisciplinary perspective through a PFA. The PFA covered different complementary approaches: i) an econometric approach that would relate the production of a service to its factors; those resulting from land management practices and those natural derived from the soil characteristics, (ii) a trade-off approach between multiple ecosystems services based on statistical analysis that enables to test whether synergies or trade-offs can be isolated between provisioning, regulating and supporting services and iii) a cost-efficiency analysis of land management measures based on production possibility frontier curves which helps to balance the costs of land management practices with their efficiency. These three approaches were used as we dealt with different spatial scales. At the plot scale, the econometric approach and the statistical trade-off analysis based on data from Lusignan LTO from has helped to understand the relation between soil biodiversity with agricultural practices and to build a function that responses to changes in soil characteristics and to changes in land management practices. At the regional scale, a spatial cost-efficiency analysis has helped to prioritize the nature of conservation policies, for example to act on wetland conservation and/or on land retirement and to prioritize the geographical places to act on.

Using the LTO data from Lusignan, the robustness of the analysis was somewhat limited by the time series data available but we found encouraging results for future research. They suggest a relation between soil biodiversity conservation and yield via the use of pesticides but no clear tradeoffs could be identified with a sufficient degree of confidence due to data limitation. Thus, the generalization of conclusions for the regulation of land management practices based on microlevel (plot) data should be
Conclusions for the regulation of land management practices based on micro-level (plot) data should be taken with due caution as farmers operate beyond the plot level, mainly at the field or regional scale levels. We thus tested these potential trade-offs between multiple services in an experimental site (Scania, Sweden) with better time series data. Here a 100 years’ time series observation enabled us to test trade-offs between multiple ecosystem services: provisioning, supporting and regulating services. We analysed the impact of management practices, on soil ecosystem trade-offs, including reduction of mineral nitrogen fertilization and introducing of grassland in the rotation of a cash crop system. We found a trade-off between soil biodiversity conservation and food provisioning services via land use rotation and fertilization strategies.

In addition, a regional spatial focus was used. A cost-efficiency analysis based on a production possibility frontier approach and a multi-objective programming model showed how different land management practices should be prioritized according to soil characteristics and space. The larger scale analysis was carried out in Denmark (Limfjorden catchment, in Denmark and the Baltic region). Results show that synergies between regulating services (carbon sequestration and nitrogen runoff regulation) are significant and trade-offs exist between regulating and food provisioning services. However, the results also show evidence of trade-offs between the two regulating services, as cost of provision of one service, depends on the level of provision of the other. The policy implication of this result is that significant gains can be achieved from joint implementation of a range of soil ecosystem service policies.

The institutional background of socio-economic valuation of soil ecosystem services

WP5 has performed analysis of current institutions in Europe under which soil services are governed and the diversity of stakeholder values associated with soil services. This has been carried out using a theoretical institutional analytical approach based on a socio-ecological systems approach. This has allowed to address long term sustainability of soil ecosystem services in Europe in particularly when dealing with large scale governance systems and their interconnections within nested multilevel governance structures.

The first analysis (reported in D5.2) focused on the role of key institutional factors affecting soil biodiversity in the EU. In particular, it interrogated how EU institutions of multilevel governance and the role of markets is affecting soil socio-ecological systems (SES) in the EU in respect to the sustainable use of soils. Using SES for soils with a multilevel scale framework applied to the EU, we found that key factors for the sustainable management of soils, in particular concerning resource and governance systems, include cropping patterns, livestock intensity, the share of alternative soil strategies, and also institutional arrangements that lead to behavioral change towards sustainable production in agro-ecosystems. Further, it was identified that major legal instruments to support behavioral change towards protection of soil biodiversity in EU need to be based on comprehensive legal frameworks enhancing agro-environmental cooperation and the coordination of the Common Agricultural Policy and the NATURA 2000 policies together with more clear co-responsibilities and financial measures to support agro-environmentally sustainable practices.

A stakeholder analysis was useful to identify an inadequate division of competencies between the EU and the national administrative levels as a major reason for a misfit of the institutional structure to protect soil biodiversity. This seems to be due to a challenging coordination among national ministries and supranational agencies at the EU level. Additionally, a Soil Framework Directive was considered by...
Supranational agencies at the EU level. Additionally, a Soil Framework Directive was considered by several actors as a key comprehensive framework that would be conducive to the long term protection of soil biodiversity within EU.

Lastly a cross country analysis identified six groups of EU member states differing in the level of sustainability of their agro-ecosystems: i) intense use (Malta, Belgium, Netherlands, Cyprus, Denmark), ii) extensive use (Portugal, Slovenia, Ireland, United Kingdom), iii) diversified use (Italy, Spain Portugal, Greece), iv) high organic farming (Austria, Czech Republic, Estonia and Sweden), v) extensive fodder production (Finland, Bulgaria, Hungary, Poland, Slovakia, Lithuania, Romania, Latvia), vi) moderate intensive use (Germany, France, Luxembourg).

Cost-effectiveness and legitimacy of economic incentive schemes for conservation of soil ecosystem services
There is a relatively long tradition in environmental economics to test the cost-effectiveness of alternative policy options, including the comparability of using market based incentives, such as subsidies and taxes that are applied by means of the commodity markets (e.g. inputs and outputs in the agricultural sector) and more traditional command and control policy options. The Common Agricultural Policy (CAP) of the EU is a mixture of these two routes to change farmers' behavior towards soil management. However there is still not sufficient scientific evidence of the role of more direct and flexible policy tools which includes voluntary schemes such as agri-environmental schemes. WP5 has contributed to the EcoFINDERS objective of i) evaluating alternative (novel) economic incentive schemes to prioritise valuable soil ecosystem services based on the criterion of cost-effectiveness, ii) identifying constraints and barriers to achieving soil conservation targets, and iii) assessing the acceptability of soil conservation policy options. These objectives were tackled by conducting analysis using four national case studies in the EU, including the UK, Denmark in the north of Europe and Slovakia and Slovenia in Eastern Europe.

The more comparable UK and Danish case studies are based on a conjoint modelling approach (choice experiment method) that allows the estimation of the costs of adoption of alternative policy designs and estimation of the extent of policy acceptance. These two studies have focused on agricultural soils in terms of climate regulation potential. They allow the estimation of the economic costs to farmers of achieving carbon sequestration targets by managing soils, vis-a-vis alternative technological measures. The comparable Slovakian and Slovenian studies take a broader perspective and are based on a multicriteria analysis associated with multiple soil ecosystem services and potential soil conservation measures to promote sustainable soils approach under the CAP framework.

The multicriteria mapping has helped to understand different perspectives on agricultural schemes by farmers and the conjoint modelling approach has shown that, not surprisingly, there is potential for introducing novel and flexible policy schemes to enhance cost-effectiveness of soil ecosystem service delivery, compared to traditional command and control approaches based on regulation standards. Such flexible policy schemes are associated with so-called voluntary payments for soil ecosystem services (PES), as part of the broader family of payments for ecosystem services. On the other hand, the results from the multicriteria mapping approach shows that in Eastern Europe farmers still have insufficient appreciation of the concept of soil ecosystem services and soil biodiversity. But all in all, there is some evidence that points at that farm characteristics, farming skills and the wider EU and national policy context are key to potentially design novel economic instruments based on the idea of payments for
Evaluation of cost-effective indicators of soil biodiversity and ecosystem services

WP5 has contributed to the EcoFINDERS objective of identifying cost-effectiveness of bio-indicators of soil quality beyond the narrower notion of costs and benefits from a financial perspective. This has been carried out with soil biodiversity experts and users as this allows to highlight various strategic views represented by different stakeholders. It has been found that there is an important wedge between the prioritised bio-indicators by scientists and other stakeholders such as land users and farmers. This implies that due care should be taken to suggest bio-indicators when land users will also be necessary to collect data to build the indicators as well as when they may also be responsible for monitoring those indicators in the field, e.g. through citizen science approaches.

EcoFINDERS has identified through expert analysis that the three most cost-effective bio-indicators for soil quality are relate to microbial biomass carbon, soil respiration and earthworms. Experts scientists associated with EcoFINDERS placed ‘Microbial Biomass C’ as the most cost-effective bioindicator. Despite the cost of monitoring of this indicator as well as required specialized skills and equipment, this indicator was seen to respond quickly to soil management changes. Second in the ranking was ‘Soil respiration’ that can be measured directly in the field, at a relatively low cost and without specialized skills or equipment. From the point of view of land users, based on criteria i) financial cost, ii) understandability and iii) sensitivity to land use changes the following bio-indicators appeared superior by land users: ‘compaction’ indicator performed best, being one of the simplest and easiest ways to detect soil quality. The pH indicator performed second best. In order to compare the results of cost-effective bio-indicators and indicators beyond cost effectiveness. The selection of bio-indicators beyond-cost effectiveness involves a subjective evaluation from stakeholders combined with scientific expert knowledge. A very important issue is to have referential available for making the interpretation of the values of the bioindicators according to the soil type and land use. EcoFINDERS has pointed towards this approach would requiring broader case study research with a greater volume of land users from around Europe, which would better signify a representative sample of stakeholders.

Potential Impact:

WP1 Biodiversity

Within WP1, we have produced extensive datasets and analyses of soil biodiversity at the continental scale. The project will serve as a landmark study with respect to its ambition in defining and standardising the methodological approaches to study soil biodiversity and functions from such a wide range of soils. It is therefore unique globally in producing such a variety of datasets (from micro to mesofauna, microorganisms, together with other soil chemical and functional properties) from the same soil samples. The methodological approaches, standard operating procedures and the sampling scheme will serve as a useful resource for other similar large scale studies occurring at national, continual and even global scales.

With respect to the data and knowledge produced, as a result of the large scale sampling of soils from across Europe and the enumeration of a variety of soil biotic and abiotic characteristics a much more complete understanding of the extent and variation in belowground biodiversity has been acquired. Without this deeper understanding of soil biodiversity, we are unable to assess its status and whether it is under threat or not. Knowledge of diversity, distribution, functional capability and response is core to
under threat or not. Knowledge of diversity, distribution, functional capability and response is core to
determining if and where tipping points may occur in the ecosystem services provided by soils. As a result
of this project we now possess a better understanding of the main factors likely to impact on soil
taxonomic and functional biodiversity and therefore are in a better position to predict change in the future
be it from altered land usage pressures or climatic change. New models proposed for how plant species
affect the resilience of soil biodiversity and function to future climate change (Task 1.4) will also add to a
body of evidence supporting the wider adoption of efforts to enhance aboveground biodiversity for
enhancing soil functions. Additionally the results obtained as to the characterization of fungal genes
involved in plant biomass degradation also hold promise for the biotechnological exploitation of natural
functional microbial diversity (screening for enzyme variants with novel biochemical properties).

The EcoFINDERS project has particularly identified the benefits to the use of molecular approaches to
widespread soil monitoring. It is noteworthy just how much more rapid these approaches were as
throughout the project it was always the molecular datasets which became available first. The continued
increases in efficiency afforded by sequencing technology improvements will see future benefits in terms of
cost effectiveness, and the further improvements to automated analytical pipelines such as those
developed in WP3 will also facilitate data analyses for non-experts. It is noted that much of the approaches
are currently optimised for microbial taxa, but EcoFINDERS has also made good progress in applying
these technologies to soil fauna (WP3). There still remains challenges for faunal assessment – one can
never get round the fact that larger organisms are more spatially dispersed and so larger sample sizes are
required to obtain a “good catch”, and this is an active area of future research which will build on the
findings from EcoFINDERS. The adoption of such approaches by policymakers will give the necessary
indicators to assess soil health and quality, and underpin methods for soil protection and improvement. It
may also provide insight into optimum procedures for “growing soil” to reverse areas where soils have
been depleted or lost - such factors are essential for food, water and environmental security.

As a result of the EcoFINDERS project, new global initiatives have been established to better understand
soil biodiversity at the global scale, for example the Global Soil Biodiversity Initiative (GSBI,
http://globalsoilbiodiversity.org/). One of the key aims of the GSBI is to synthesise global soil biodiversity
data, to understand drivers of change for both new scientific understanding and also to advise
policymakers of potential soil impacts as a consequence of different land use options. To do this, efforts
are underway to make inventories of global soil datasets. At present, the bespoke EcoFINDERS database
created and predominantly populated through the activities of WP1 and WP4 represents possibly the
largest collection of integrated data on various soil biotic and abiotic properties. This will undoubtedly
serve as a benchmark dataset for future initiatives, and it is noted that the dataset will be hosted and
managed into the future via the JRC’s soils portal (http://eusoils.jrc.ec.europa.eu/).

With respect to dissemination, the results from WP1 have already contributed to several publications in
open source journals. Key examples occurred early in the project with respect to the development and
optimisation of an ISO standard methodology for soil DNA extraction (Plassart et al. 2012. Evaluation of
the ISO standard 11063 DNA extraction procedure for assessing soil microbial abundance and community
structure. PlosOne 7:e44279). Many other publications are either published, submitted, or in preparation –
notably the special issue of Applied Soil Ecology which will be published in 2015. The work conducted in
WP1 has also been reported on in conferences and meetings through the course of the project, including a
special session at the Eurosoil conference in Bari, Italy (2012); presentations at the ISME conference in
Special session at the Eurosoil conference in Bari, Italy (2012); presentations at the ISME conference in Copenhagen; and a large number of presentations at the 1st Global Soil Biodiversity Conference held in Dijon (2014).

WP2 Soil functioning and Ecosystem Services

Soil Biodiversity significantly contributes to the provision of ecosystem services by soils. Land use and soil management may strongly affect soil organisms, and therefore directly and indirectly impact soil functioning and ES provision. While this was known at the time when the EcoFINDERS project was started, in WP2 we focused on further identifying key biota and quantifying functional relationships with soil structure and processes. While comparative field studies across Europe-wide sites representing ranges in intensity of various management scenarios have shown little consistency in forthcoming results, within-sites data are generally consistent and interpretable. It does not seem straightforward, therefore, to generalise our findings across the continental scale, integrating over land uses, soil types or climate. Nonetheless, further synthesis can be made by use of meta-analysis in relation to one-dimensional gradients, as we demonstrated for earthworms and fungi and their contributions to the provision of supporting services in relation to land use intensity transitions.

WP2 has indeed made progress in identification and quantification of functional biodiversity. The consequent linkage to ecosystem service provision has been demonstrated for the Lusignan LTO where positive associations between regulating and supporting services were shown to exist, suggesting a potential synergy between these ecosystem services. At this well-studied site, we have been able - in cooperation with WP5 - to establish the full linkage between soil biodiversity – soil functioning – ecosystem service provision with respect to soil carbon regulation and water regulation. However, these findings cannot be generalised to other sites, as the functional responses in soil biodiversity (particularly earthworms) were not observed in similar detail elsewhere. While detailed studies are needed to fully understand the biodiversity – service provision interconnectivity at any given site (or region), as a result of our research we can nonetheless provide general guidance to promote the provision of ecosystem services and enhance sustainable use of land in the following.

Impact for sustainable land management

Reduced tillage practices are beneficial to enhance water infiltration capacity, improve moisture retention by increased porosity and aggregate formation, and increase drought resistance of soils. Risks for water logging or crop wilting can thus be reduced, though at the likely expense of increased emission of greenhouse gases and – mostly on short-term, and not always – some losses in crop yield.

Reductions in intensity of agricultural management, including reduced fertiliser use, typically lead to an increase in the abundance of fungi relative to bacteria, with benefits for a range of ecosystem services, including microbial retention of nitrogen in soil, soil carbon sequestration, and enhanced stability of soil processes following drought.

The composition of the soil microbial community of grassland soils is in part related to variation in plant traits, in combination with other soil abiotic properties. As a result, our studies demonstrate the potential of management induced changes in plant trait composition to impact the structure of microbial communities, and consequently to influence the processes and ecosystem services that they underpin.

Policy impact

It is recommended that ecosystem services be considered from the perspective of multifunctionality and optimization of service provision, rather than aiming to maximize any single service. This may imply that...
Optimization of service provision, rather than aiming to maximize any single service. This may imply that maximal production of food, feed or biofuel is traded-off with other ecosystem services, such as disease control, prevention of greenhouse gas emission, or prevention of pollution of ground water and aquifers.

The provision of soil ecosystem services may in general be enhanced by reducing intensity of land use and soil management, e.g. in the gradient conventionally tilled arable land < reduced tillage arable land < intensively used grassland < extensively used grassland and forest. Soil biodiversity shifts along with this range, though not just in a quantitative manner but very much in qualitative aspects as well. While direct economical profits may decline along this range, long-term revenues for people and planet tend to be reversed. Despite complexities in functional responses, soil biodiversity can be linked to ecosystem provision, but trade-offs need to be considered. However, soil functioning cannot be linked to soil biodiversity in terms of target values.

Research impact (H2020)
In the past, land use strategies have focused strongly on maximizing single ecosystem services, for example primary production by intensified soil tillage and fertilization. EcoFINDERS research has shown that there are trade-offs among ecosystem services, and that managing multiple ecosystem services may enhance the total delivery of goods and functions from ecosystems. Future research should include trade-off analyses of ecosystem services, in order to find best options for optimizing multifunctionality of ecosystems in terms of sustainable delivery of ecosystem goods and functions.

In EcoFINDERS, we have used a combination of mesocosm and field studies to address objectives of WP2. Whilst laborious, relatively expensive, and complex, this combined approach offers distinct advantages over singular approaches in terms of understanding the mechanisms by which soil biodiversity impacts ecosystem functioning. For example, the field survey on soil biodiversity in the LTO Veluwe chronosequence of time since land abandonment resulted in novel insights how soil biodiversity networks may become tightened during land abandonment, and the mesocosm experiment using labelled nitrogen and carbon has shown that the functional consequence of such tighter networks is that nutrients are captured more efficiently in the tightened soil biodiversity networks.

Soil communities are extremely complex and EcoFINDERS research has shown that it is not only their biodiversity, but also the structure and network configuration of the soil biodiversity that is crucial for soil functioning. Future research initiatives should focus more on network approaches to merge complex biotic interactions that operate in soil into single integrative frameworks for assessing how soil functioning is affected by land use and geographic position. Such frameworks should also take account of the structural and chemical complexity of soil.

Cropping and management regimes have significant impacts on the abundance and species composition of soil biota. Management intensity can alter the diversity and spatial distribution of these biota. It is now apparent that a knowledge of the degree of interaction between co-occurring taxa is critical in understanding the provision of ecosystem services. A deeper knowledge of the spatial and temporal dynamics of taxa within “landscapes” of varying dimensions and the consequences for community assembly at finer spatial scales is required in order to fully appreciate the contributions of biodiversity to ecosystem functioning.

Main dissemination activities
Most activities of dissemination have focused on the scientific community, and were in the form of
Most activities of dissemination have focused on the scientific community, and were in the form of conference presentations (platform or poster, and abstracts) and scientific peer reviewed papers. Most outcome of WP2 in this respect is yet to be submitted for publication. Further we have presented our findings at stakeholder meetings, e.g. field symposia with farmers and agronomy consultants, water board managers, and national and regional policy makers.

WP3 Developing and Standardising Tools and Procedures for Assessment of Soil Biodiversity

As a result of efforts in WP3, cutting-edge methodological protocols are now available for i) the establishment of DNA barcoding reference datasets for soil bacteria, archaea, fungi and fauna, and ii) high-throughput characterization of soil microbial communities by DNA metabarcoding. These are the first standardized procedures that provide an integrated framework for DNA (meta)barcoding of a large variety of soil faunal organisms, which can be expected to highly benefit the efficiency of both applied and academic soil faunal surveys in agricultural landscapes. Detailed SOPs produced by WP3 teams have been published as chapters of an upcoming methodological book in the Springer-series “Methods in Molecular Biology”. Test runs for the developed methodology have identified potential biases that need to be taken into account in interpreting community structures obtained by metabarcoding. A summary of our methodology and test results has been presented during the 1st Global Soil Biodiversity Conference (Dijon, Dec. 2014) and is currently being drafted into a scientific publication due in early 2015. For a number of European soil ecosystems (i.e. semi-natural grasslands and agricultural soils), reference datasets are now in place. DNA barcode sequences for >300 species of mainly microarthropods and enchytraeids (formerly being the most underrepresented groups) have been generated within EcoFINDERS and will soon be freely available in online barcode databases (e.g. BOLD, GenBank). This is an important step forward, as trusted reference data are a prerequisite for molecular diversity screening. Various spin-off publications on the taxonomic interpretation of the gained barcode data (e.g. species delineations and spatial variation) are to be expected in the near future.

WP4 Evaluating and Developing Indicators for Biodiversity

The recommended indicators have been validated at the LTO’s for: robustness, sensitivity, cost, throughput, regional and land-use applicability. This represents a suite of indicators that can be applied across Europe for policy related monitoring schemes. The maps produced addresses threats to soil biodiversity and will be particularly relevant to planning and policy making at the European scale.

WP5 Valuation of Soil Ecosystem Services

EcoFINDERS has developed a conceptual framework that helps better understand the economic value of soil biodiversity and ecosystem services. The framework shows that a scientific basis is need to map soil functions, services before economic values can be estimated, which for the most part are part of so-called “indirect use value”, generally associated with regulating ecosystem services, and the “natural insurance value”. EcoFINDERS has offered a way to start thinking about soil ecosystem services from an economic perspective, one that stresses the idea of the value of reducing the variability of the supply of provisioning services, e.g. in agricultural soils. Such value is linked to the natural insurance value of biodiversity.

Given the natural insurance value of soil biodiversity, EcoFINDERS has modelled the economic value of soil biodiversity for optimising water regulation services that are beneficial for the provision of food. In situations where irrigation technologies are non-available, we have shown that farmers may optimally
situations where irrigation technologies are non-available, we have shown that farmers may optimally choose to insure themselves against climatic variability by investing in soil biodiversity. Further our model offers a powerful hypothesis for further work: there is a degree of complementarity between soil biodiversity and irrigation technologies; that is, farmers may be more willing to use irrigation too enhance agricultural productivity when they have also invested in soil biodiversity since the latter can be seen as a key input that enables to transfer water from humid to dry periods and because during dry period water may not be available through irrigation or may be too costly. Further the theoretical models developed by EcoFINDERS show that under climate variability, when the likelihood for more frequent droughts increases, it is also rational to invest in soil biodiversity conservation to transfer moisture across agricultural periods. These results point towards the need to see soil biodiversity conservation policies complementary with water resource management policies.

From an empirical perspective, EcoFINDERS has also shown that at the plot-level and regional level scales, it is hard to identify win-win situations in terms of achieving different key soil ecosystem services (e.g. food provision and regulation services). We have seen that in reality this is not a general outcome. The policy implication of this result is that significant gains can be achieved from careful implementation of a range of ecosystem service policies that account for ecosystem services tradeoffs.

This also helps design of economic incentives for soil ecosystem services. One such economic instrument that has been the focus of EcoFINDERS is the PES. We have seen that based on farmers’ intrinsic and instrumental motivations for soil conservation, conservation schemes seem not to be prohibitively expensive, potentially because farmers recognise that PES schemes could have significant private benefits, beside the societal ones. In addition we warn that in order to succeed in the design and implementation of cost-effective PES incentive schemes, social equity also needs to be accounted for. Lastly, given the need for bioindicators and for monitoring the effectiveness of soil conservation instruments, EcoFINDERS has found out that there is often a difference in the way stakeholders, such as land users (e.g. farmers), prioritizes them. This implies that due care should be taken to suggest bioindicators when land users will also be necessary to collect data to build the indicators as well as when they may also be responsible for monitoring those indicators in the field, for example through citizen science initiatives.

WP6 Dissemination, Technology Transfer and Training

Dissemination activities to the general public have focused on public events at the LTOs during sampling of soil for further testing and analysis by the EcoFINDERS partners. The largest public event at an LTO was organized in August 2011 at Berchidda, Sardinia, Italy as an event combining the soil sampling with a jazz festival, activities for children and speeches. In addition, events have been organized at Lusignan, France during sampling. At Lamborn forest LTO, SLU, Sweden, a stakeholder symposium for foresters was held. JRC organized an open day in 2013 and a ‘Researcher’s night’ also in 2013, both disseminating EcoFINDERS subjects of soil biodiversity and function. By these dissemination, activities attention has attracted to the EcoFINDERS project and the important topics of soil biodiversity and ecosystem functioning.

Training activities in EcoFINDERS grew from the single planned PhD course to i) a PhD training course combined with a one day symposium at WUR & NIOO, Wageningen, NL, ii) a workshop on soil biological indicators for postdocs and PhD students at Teagasc, Wexford, Ireland, and iii) a Soil Biodiversity Data...
indicators for postdocs and PhD students at Teagasc, Wexford, Ireland, and iii) a Soil Biodiversity Data Synthesis training course at INRA, Dijon, France. In addition to these courses, additional workshops were organized in order to disseminate activities and results between partners and targeting external scientists as well. By these training activities, both basic training in soil ecology, biodiversity and soil biological indicators were achieved, but also advanced training among scientists about current issues as development in the newest molecular techniques, e.g. in barcoding of soil fauna, and planning of soil monitoring programmes has been achieved. Finally, teaching activities targeting school children on subjects of soil biodiversity, function and quality have been developed in Obidos, Portugal. In Wuppertal and Cologne, Germany, in 2013 soil biodiversity and function were demonstrated for the general public at two events by instructions during observations of soil organisms in microscope. By these activities EcoFINDERS has made significant contributions in educating and training young as well as experienced scientists in addition to school children in the current state of knowledge on the main topics of EcoFINDERS: soil biodiversity and function, ecosystem services and soil biological indicators. The education of especially children can have societal impact on the general understanding and appreciation of the living soil and the important soil functions for human kind.

EcoFINDERS has made major impact on transfer of technology to the wider scientific community and consultants by significant contributions to ISO standards through the work in ISO Technical Committee 190 on soil quality. The design and development of ISO standards is a lengthy process and difficult to address to a single project. However, inputs have been made and will in the future be made to coming ISO standards and standards have been published during the course of EcoFINDERS. In this way EcoFINDERS has made significant contributions, especially, in the area of sampling of soil fauna, extraction of microbial DNA from soil, determination of soil biological activity and bar coding of soil fauna.

For all scientists engaged in research dissemination to the scientific community is of outmost importance, and EcoFINDERS has been able to contribute extensively to scientific dissemination. Most significant is the organization of the first and very successful Global Soil Biodiversity Conference, held in Dijon, France as a closing symposium of EcoFINDERS. This was organized by EcoFINDERS partners in close collaboration with the Global Soil Biodiversity Initiative. The number of participants and presentations were overwhelming: > 700 participants and more than 500 oral and poster presentations. With the conference being held at the very end of the EcoFINDERS project meant that many results from the project were presented and discussed at this conference. The conference was finalized by a public event during the world soil day with a series of interactive stands including some organized by secondary schools, research, stakeholder organization, JRC, with activities for children; this event was inaugurated by the French Ministry of Agriculture, in the presence of the Director of Natural Capital DG ENV and the Chief Executive Officer of INRA; 400 attendants have visited that event. In addition to this conference, EcoFINDERS chaired a session EUROSOIL in Bari, Italy in 2012, co-organized XVI International Colloquium of Soil Zoology, Coimbra, Portugal in 2013, and 6th International Oligochaete Taxonomy Meeting, Palmeira do Faro, Portugal, in 2013, and several sessions at SETAC Europe and World meetings during the project period. Many scientific publications in peer-reviewed journals have been published and many more are in preparation, among those some have been published in Nature journals and one will shortly be submitted for publication in Science.

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Related documents

[final1-ecofinders-final-report-figures-vf.pdf]

Last update: 28 July 2015
Record number: 168040