# Final project report
# Reporting template

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| Project acronym | | SoilForEUROPE |
| Project title | | Predicting European forest soil biodiversity and its functioning under ongoing climate change |
| Project coordinator | Person (Title, Full Name) | Dr. Stephan Hättenschwiler |
| | Entity (Company/organization) | CNRS |
| Project period (Start date – End date) | | 01/01/2017 – 30/11/2020 (covid-19 extension) |
| Project website, if applicable | | https://websie.cefe.cnrs.fr/soilforeurope/ |

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| Author of this report | |
| Title, first name, surname | Dr. Stephan Hättenschwiler |
| Telephone | +33 4 67 61 33 49 |
| E-mail | Stephan.hattenschwiler@cefe.cnrs.fr |
| Date of writing | 15/11/2020 |

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| Indicate a contact person for the project, if different from the author of the report | |
| Title, first name, surname | |
| Telephone | |
| E-mail | |

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| List of partners involved in the project (company/organization and principal investigator). Please use partner numbers to specify the tasks, work packages and inputs of each partner in sections 4.3, 5 and 6.2 to 6.4. | Partner 1: CEFE/CNRS, Stephan Hättenschwiler<br>Partner 2: Ecotron Montpellier/CNRS, Alexandru Milcu<br>Partner 3: KU Leuven, Liesbet Vranken<br>Partner 4: SLU Umea, Paul Kardol<br>Subcontract Partner 4a: VU Amsterdam, Matty Berg<br>Partner 5: UFZ Halle, iDiv Leipzig, François Buscot<br>Partner 6: U Gent, Kris Verheyen<br>Partner 7: Univ. Freiburg, Michael Scherer-Lorenzen<br>Partner A: INRA Bordeaux, Hervé Jactel<br>(edit as needed) |

### 1. Short description for publicity

Covering about 210 million ha of land area in Europe, forests are a major ecosystem type and play a central role in strategies of climate change mitigation. European forests also harbour a tremendous diversity of organisms, most of them hidden within the soil, which contribute to ecosystem functioning and services to human societies. Knowledge about soil biodiversity, its effects on ecosystem functioning, and its resistance and resilience to climate change, however, lags critically behind and is not explicitly considered in management decisions. The BiodivERsA project SoilForEUROPE aimed at establishing a better knowledge base on soil biodiversity by evaluating how the diversity of different groups of soil organisms varies with canopy tree species richness along a climatic gradient across Europe. We found that some groups of soil organisms like soil fungi or macrofauna members, such as earthworms, spiders or millipedes, are more diverse in forests with tree species mixtures compared to monoculture stands. The activity and abundance of soil organisms also resisted better to summer drought in soils from tree species mixtures than from single species forests. These findings advocating the importance of tree species mixtures for soil biodiversity and the functions they have, may help guide forest management decisions in the context of climate change. Indeed, we observed that a better knowledge about the role of soil biodiversity modifies decision processes in forest management, which could significantly improve the resistance of future forests and the services they provide to future generations.

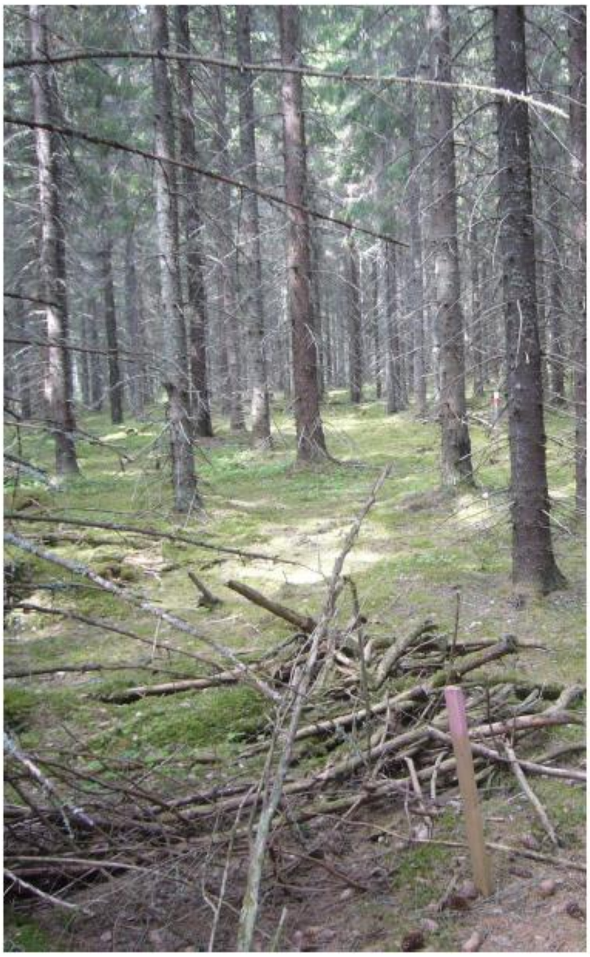

**Photo 1:** Two permanent forest plots at the Finish site used for soil sampling in the SoilForEUROPE project in June 2017. A single tree species stand with *Picea abies* (left) and a mixed stand with the three species *Picea abies, Pinus sylvestris* and *Betula pendula* (right). Photo credit: S.Hättenschwiler.

**Photo 2:** Conjoint sampling of soil microorganisms, nematodes, mesofauna, macrofauna and fine roots by members of the SoilForEUROPE project in a permanent mixed species plot in Italy, March 2017. Photo credit: S.Hättenschwiler.

## 2. Summary

Forests are a major ecosystem type in Europe and participate to fundamental ecosystem processes, for example in the cycling of water, carbon, and nutrients, and as such contribute key ecosystem services to human well-being. Ecosystem services, such as timber production, water purification, or carbon sequestration may increase in importance under ongoing climate change and for potential mitigation strategies. Forest management does not always see the forest for the trees, which harbours a tremendous diversity of organisms beyond just the trees themselves. The largest part of this diversity by far lives belowground in the soil and remains poorly studied and largely ignored. With the BiodivERsA project SoilForEUROPE we aimed to better understand how soil biodiversity is related to tree species richness, which may provide an easily applicable indicator for soil biodiversity and its consideration in decision processes. A second aim was to unravel soil biodiversity contributes to forest ecosystem resistance and resilience in response to climate change. Our results from four typical and distinct European forest ecosystems, ranging from Mediterranean to boreal forests, showed that some key groups of soil organisms like fungi and macrofauna, consisting mainly of earthworms and a wide diversity of arthropods such as insects, are more diverse in forests composed of three tree species than in single tree species forests. Higher tree species richness was also associated with a higher resistance of the activity of microbial communities, to which fungi contribute significantly, to repetitive drought. Likewise, nematodes and mites, two important groups of small soil fauna, maintained higher abundances in forests of higher species richness compared to monocultures under drought. Our research further highlighted that forest managers are not sufficiently aware of the diversity and functional importance of soil organisms and tend to underestimate the belowground world when taking management decisions. We showed that management decisions were influenced after managers watched a short, couple minute-long informational video on the role and importance of soil biodiversity, and thus helped to improve the structure and functions of future forests. This may have significant consequences for how forests will resist to future climate extremes. Collectively, the results of our project underline the undervalued importance of soil biodiversity for the functioning of European forests and their responses to climate change. By linking soil biodiversity to tree species richness, we provide an easy applicable indicator allowing forest managers to foster soil biodiversity and thereby increasing forest resistance to climate change.

## 3. Objectives of the research

The BiodivERsA project SoilForEUROPE had four main objectives.

(1) The characterization of the diversity and abundance of major groups of soil organisms, including microorganisms, micro-, meso-, and macrofauna, as a function of tree species richness in four key European forest ecosystems using a selection of permanent FunDivEUROPE plots and two European TreeDivNet sites. These belowground biodiversity data were then used to evaluate their relationship to ecosystem functions in order to develop a predictive framework for how soil biodiversity affects the functioning of forest ecosystems.

(2) The determination of belowground tree functional traits, such as morphological and chemical fine root characteristics in response to tree species richness, in order to incorporate root traits and the abundance of mycorrhiza in the assessment of tree species richness effects on belowground processes.

(3) The investigation of how the relationships between below- and aboveground diversity affect ecosystem functioning under climate change, using the broad climatic gradient covered by the FunDivEUROPE plots and experimental approaches with rain exclusion in the field (tree diversity experiments) and under controlled conditions, using the CNRS European Ecotron.

(4) The assessment of the knowledge about soil biodiversity and its importance in forest ecosystem functioning by forest managers and how it differs among different regions in Europe. This objective also included the quantification of how explicit information on the role of soil biodiversity may affect decision making processes in forest management.

## 4. Project activities and achievements

The field sampling in the permanent plots at the chosen four FunDivEUROPE sites during spring/summer of the first project year in 2017 was a key component of our project, determining the data basis and providing the material for the two work packages WP2 and WP3. The sampling campaign necessitated a conjoint effort from all Partners with a rigorous application of exactly the same sampling procedures at all sites. With a meticulous planning of the field work during the kick-off meeting in February 2017, we were able to visit all four sites in Italy, Poland, Romania, and Finland during the same phenological stage of forest trees during current-year foliage unfolding in deciduous trees. During about two weeks at each location, four to nine persons of Partners 1, 2, 4, 5, and 7 collected all the soil samples needed for the extraction of tree roots, microorganisms, nematodes, mesofauna (mites and collembolans), and macrofauna (using soil blocks and pitfall traps). Following the sampling, roots were separated from the soil, sorted into species and root traits were determined by Patner 7. Microorganisms were determined at otu level using next generation sequencing by Partner 5, nematodes extracted and sorted into feeding groups by Partner 4, mesofauna extracted and determined at the order level by Partner 4 and 4a, and macrofauna sorted and determined at various taxonomic levels depending on the taxonomic group by Partner 1. Depending on the group of organisms this work of sample preparation, taxa characterization, and identification covered a large part of the project duration and was finished for some groups only in 2020. Constructing a large database including a wide number of different groups of soil organisms from the same soil sampling event across the four forest ecosystem types has been a major achievement of the project consortium. The exciting general synthesis planned in task 4 of WP2 to bring all data sets together and interrelating them with above-ground data from the previous FunDivEUROPE project, therefore, could only be initiated during our last consortium meeting in March 2020 and may be finished after the official end of the project.
A second field campaign at all sites involved the setup of a fine root decomposition experiment using litterbags by Partner 7 during the first half of 2018 and their harvest during fall 2019. The preparation of the needed root material and litterbag construction was laborious and required most of the second half of 2017 and first half of 2018. Partner 6 coordinated the invaluable logistical support by local collaborators and an updated census of all individual trees within all plots at all FunDivEUROPE sites together with Partner 7.
The role of soil biodiversity in ecosystem responses to climate change addressed in WP4 was organized in three complementary approaches. With the first approach, we sought to better understand how tree species richness legacy effects on soil microbial communities may affect microbial responses to repetitive severe drought. With part of the soil samples brought back from all four forest ecosystems during the field sampling in spring/summer 2017, Partner 1 and 2 set up a microcosm experiment where replicates of all soil samples were exposed to repetitive drought and compared to control treatments at the European Ecotron in Montpellier. The drought effects on microbial resistance and resilience were evaluated with repeated measurements of $CO_2$ and $N_2O$ fluxes during the experiment and the analyses of taxonomic (by Partner 5) and functional microbial diversity following the experiment. The large data set was analysed during 2018, a work that was significantly facilitated by the training and decisions taken during a statistical workshop in summer 2018, in which all non-permanent staff of all Partners participated. This workshop laid the ground for common statistical approaches across data sets used by all Partners, which was particularly important for the complex design and multiple factors involved.

A second experiment at a larger spatial scale of complex model ecosystems was planned and set up by Partner 1 and 2 at the European Ecotron in Montpellier using the larger mesocosms at the end of 2017 and most of 2018. The Ecotron mesocosms allowed the construction of a forest understory community with four different tree species growing in a 1m-deep soil of $1m^2$ surface area and to follow $CO_2$ and $H_2O$ exchange under fully controlled conditions. With 16 mesocosm units we manipulated the functional diversity of soil macrofauna communities and summer drought with three repetitive drought events per summer. As a result of a combination of factors, including finalizing the construction of the mesocosm facility and difficulties with the collection of 30 tons of soil and its sterilization, we ran much later with this experiment than initially planned. Summer drought could only be applied in 2019 and given the effort in the setup of the experiment and limited robustness of only one year of data, we decided to continue in the experiment in 2020. Data collection and treatment is still ongoing.

Still at a higher level of complexity and realism, we also included two European tree diversity experiments with planted trees in the field that involved a climate change component with either rain exclusion (FORBIO in Belgium) or watering during summer (ORPHEE in France) in our assessment of interactive effects of tree diversity and climate change on soil biodiversity. Partner 4 and 4a sampled nematodes and mesofauna with the support of Partner 6 (FORBIO) and Partner A (ORPHEE). Soil sampling and fauna extraction was done in 2018 followed by sorting and identification during 2019 and 2020. The data were pre-analysed in 2020 showing clear differences in nematode and mesofauna abundances pointing towards mitigating effects of tree species diversity under drought.

Partner 3, in cooperation with Partner 6, developed a research scheme to (i) evaluate the impact of knowledge of soil biodiversity for choosing amongst different forest management scenarios, (ii) assess how information provision alters preferences and willingness-to-pay (WTP) for conservation of soil biodiversity, and (iii) identify communication strategies and policy instruments to change behaviour of different user groups. Additionally, an initial step was added to gain insights into forest managers' and scientists' mental models concerning soil biodiversity and forest management. Hence, an assessment of the socio-economic value of soil biodiversity was performed through interviews of scientists and forest managers with a specifically created standardized questionnaire. Public preferences were assessed with a large data collection involving 775 citizens from three different European countries. Under the guidance of Partner 3, the whole consortium, including all Partners, developed a series of communication materials based on the collective findings during the three years of data collection, analysis, and interpretation during and following our last meeting in March 2020. These materials are and will be spread to different stakeholder groups and added to the website.

In conclusion, despite some delay in a few activities during the project, the achievements are impressive, including a tremendously rich data set of forest soil biodiversity across major forest ecosystems in Europe, novel experimental insights in the role of soil biodiversity under climate change, and a clearer understanding of how soil biodiversity is perceived by stakeholders and how better information can impact decision making in forest management.

*4.2. Table of deliverables*

<table>
<tr><th colspan="3" rowspan="2">Deliverable and Milestone Name</th><th rowspan="2">Lead partner (country and designation)</th><th colspan="2">Date of delivery (mm/yyyy)</th><th rowspan="2">Comments</th></tr>
<tr><th>Initially planned</th><th>Delivered</th></tr>
<tr><td>Work Package</td><td>Deliverable or Milestone</td><td>Full Name</td><td></td><td></td><td></td><td></td></tr>
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| Deliverable and Milestone Name | | | Lead partner (country and designation) | Date of delivery (mm/yyyy) | | Comments |
|---|---|---|---|---|---|---|
| | | | | Initially planned | Delivered | |
| *WP1* | D1.1 | Detailed field sampling plan and protocol | Partner 1 (France, CEFE) | 03/2017 | 03/2017 | Discussed and developed with feedback from all Partners. Fine-tuned in the field in April 2017. |
| *WP1* | D1.2 | Minutes of annual meeting 2017 | Partner 1 (France, CEFE) and Partner 4a (The Netherlands, VU Amsterdam) | 03/2017 | 03/2017 | Written trace of discussions and all decisions. |
| *WP1* | D1.3 | Minutes of annual meeting 2018 | Partner 1 (France, CEFE) and Partner 2 (France, Ecotron) | 05/2018 | 06/2018 | Discussed and developed with feedback from all Partners. Fine-tuned in the field in April 2017. |
| *WP1* | M1.1 | Statistics Workshop | Partner 4 (Sweden, SLU), Partner 5 (Germany, UFZ/iDiv), and Partner 7 (Germany, U Freiburg) | 07/2018 | 07/2018 | This workshop was planned during the 2nd annual meeting in 2018. It aimed at training the PhDs and postdocs of the project. |
| *WP2* | D2.1 | Soil heterotrophic microorganism and mycorrhizal diversity | Partner 5 (Germany, UFZ/iDiv) | 05/2018 | 09/2018 | Microbial sequencing is done, with a resolution at the OTU level. Analyses of bacterial and fungal communities are performed. |
| *WP2* | D2.2 | Microbial diversity using PLFA | Partner 5 (Germany, UFZ / iDiv) | 12/2018 | 05/2019 | The PLFA analysis for all 64 plots was completed. |
| *WP2* | D2.3 | Taxonomic and functional diversity of soil fauna | Partner 1 (France, CEFE), Partner 4 (Sweden, SLU), and Partner 4a (The Netherlands, VU Amsterdam) | 12/2018 | 12/2019 | The majority of coarse sorting and identification was finished by the end of 2019. |
| *WP2* | D2.4 | Fine root traits and soil occupation analysis | Partner 7 (Germany, U Freiburg) | 12/2018 | 02/2019 | Root sample analysis has been completed. |
| *WP2* | D2.5 | Relationships between above- and belowground diversity and function | Partner 4 (Sweden, SLU) | 12/2019 | 10/2020 | Preliminary analyses are completed. |

| Deliverable and Milestone Name | | | Lead partner (country and designation) | Date of delivery (mm/yyyy) | | Comments |
|---|---|---|---|---|---|---|
| | | | | Initially planned | Delivered | |
| *WP2* | M2.1 | Soil sampling and extraction of all targeted soil organisms | All partners (except Partner 3) | 12/2017 | 12/2017 for FunDivEU exploratories Postponed to 03/2019 for tree diversity experiments | All sampling, extraction and sorting is done. |
| *WP3* | D3.1 | Fine root decomposition | Partner 7 (Germany, U Freiburg) | 12/2018 | 08/2020 | All data are acquired, and preliminary data analysis completed. |
| *WP3* | D3.2 | Soil microbial activity | Partner 1 (France, CEFE) and Partner 5 (Germany, UFZ/iDiv) | 03/2018 | 06/2018 | CLPPs (microresp), SIR, nitrification, denitrification (Partner 1), and activities of hydrolytic enzymes (Partner 5) done for all soil samples from FunDivEU exploratories. Due to the huge workload of these analyses we were forced to abandon these measurements at the TreeDivNet sites ORPHEE and FORBIO. |
| *WP 3* | D3.3 | Litter layer quality | Partner 1 (France, CEFE) | 12/2017 | 10/2019 | The litter layer material of the 320 individual samples from the FunDivEU exploratories was ground and analyzed. |
| *WP3* | M3.1 | Cross linking fine root and leaf litter decomposition | Partner 7 (Germany, U Freiburg) and Partner 1 (France, CEFE) | 06/2019 | NA | Preliminary data analyses of fine root decomposition is done, but crosslinking with leaf litter decomposition is postponed. |
| *WP3* | M3.2 | Cross linking of microbial activity with litter layer characteristics, fine root traits and microbial diversity | Partner 1 (France, CEFE), Partner 5 (Germany, UFZ/iDiv), andPartner 7 (Germany, U Freiburg) | 06/2019 | 03/2020 | Coupling of microbial functional diversity, litter layer and fine root traits is done. |

| Deliverable and Milestone Name | | | Lead partner (country and designation) | Date of delivery (mm/yyyy) | | Comments |
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| | | | | Initially planned | Delivered | |
| *WP4* | D4.1 | Microbial resistance and resilience (microcosm drought experiment) | Partner 1 (France, CEFE), Partner 2 (France, Ecotron) | 11/2017 | 05/2018 | The start of the experiment was delayed because of a pilot experiment and the duration of the experiment was longer than anticipated. |
| *WP4* | D4.2 | Ecosystem resistance and resilience (mesocosm drought experiment) | Partner 2 (France, Ecotron), Partner 1 (France, CEFE) | 02/2019 | 09/2020 | Delayed due to technical issues. This experiment was run in 2019 and prolonged in 2020 in order to acquire more robust results |
| *WP4* | D4.3 | Ecosystem resistance and resilience (mesocosm drought experiment) | Partner 2 (France, Ecotron), Partner 1 (France, CEFE) | New item in collaboration with Partner 5 | 12/2020 | Bacterial and fungal sequencing for soil samples from mesocosm experiment. |
| *WP4* | D4.4 | Climate change x tree species diversity interaction | Partner 6 (Belgium, U Gent), Partner A (France, INRA), and all other partners (except of partner 3) | 12/2018 | 06/2020 | The activities initially planned in the two tree diversity experiments ORPHEE and FORBIO had to be reduced and postponed because of too much work in WP2. Preliminary data analyses completed. |
| *WP4* | M4.1 | Setup and Start of the mesocosm experiment at the Ecotron | Partner 2 (France, Ecotron), Partner 1 (France, CEFE) | 12/2017 | 11/2018 | Delayed due to technical issues (the mesocosms at the Ecotron were not ready). |
| *WP5* | D5.1 | Development of questionnaire and survey | Partner 3 (KU Leuven, Belgium) | 07/2018 | 10/2018 | Some delay because we extended the task of WP5 by including a knowledge mapping through semi-structured interviews to get insights in what forest scientists and managers know about soil biodiversity. |

| Deliverable and Milestone Name | | | Lead partner (country and designation) | Date of delivery (mm/yyyy) | | Comments |
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| | | | | Initially planned | Delivered | |
| *WP5* | D5.2 | Awareness analyses and preparation of knowledge transfer | Partner 3 (Belgium, KU Leuven) and Partner 6 (Belgium U Gent) | 12/2018 | 09/2019 02/2020 | Some delay because of previously mentioned reason (D5.1). Data collection and analysis performed in two steps: detailed analysis on data gathered in Flanders (9/2019) with subsequent data collection and analysis in Finland and Italy (2/2020) |
| *WP5* | D5.3 | Dissemination activities and knowledge transfer | Partner 3 (Belgium, KU Leuven) with the involvement of all partners | 12/2019 | 03/2020 | Some delay as project was extended. Dissemination workshop amongst consortium members organized during the final project meeting near Freiburg |
| *WP5* | M5.1 | Communication materials | Partner 3 (Belgium, KU Leuven) | 12/2019 | 05/2020 | Some delay as project was extended. A set of communication materials was developed throughout the project (see 6.4) |

### *4.3. Scientific outcomes*

**WP2: Soil biodiversity** (WP leader **François Buscot – UFZ Halle / iDiv Leipzig**)

<u>Soil microorganisms (Partner 5 – task leader François Buscot):</u>
With a metabarcoding approach based on Illumina Miseq *amplicon* sequencing of the *bacterial* 16S and *the fungal* ITS2 rDNA, as well as with a more quantitative PLFA approach, we analysed bacterial and fungal communities across all FunDivEUROPE sites. The bacterial diversity data was analysed to explore the links between bacterial community composition, their functionality related to plant growth promotion activities, deduced from their gene profiles by using the Tax4Fun (a software package predicting the functional capabilities of bacterial communities based on 16S rRNA), and root trait dispersion (R-FDis). R-FDis represents a measure of functional similarity of the roots from the dominant tree species in either single species or three species plots. A key result that was quite unexpected was that bacterial functionality linked to plant nutrient requirements declined with increasing R-FDis (Fig 1A). Additionally, bacterial network analyses indicated that forests composed of three dominant tree species have a higher complexity in their bacterial communities compared to forests with only one dominant species, pointing towards a more stable bacterial community with greater functionality in more tree species rich forests (Fig 1B).

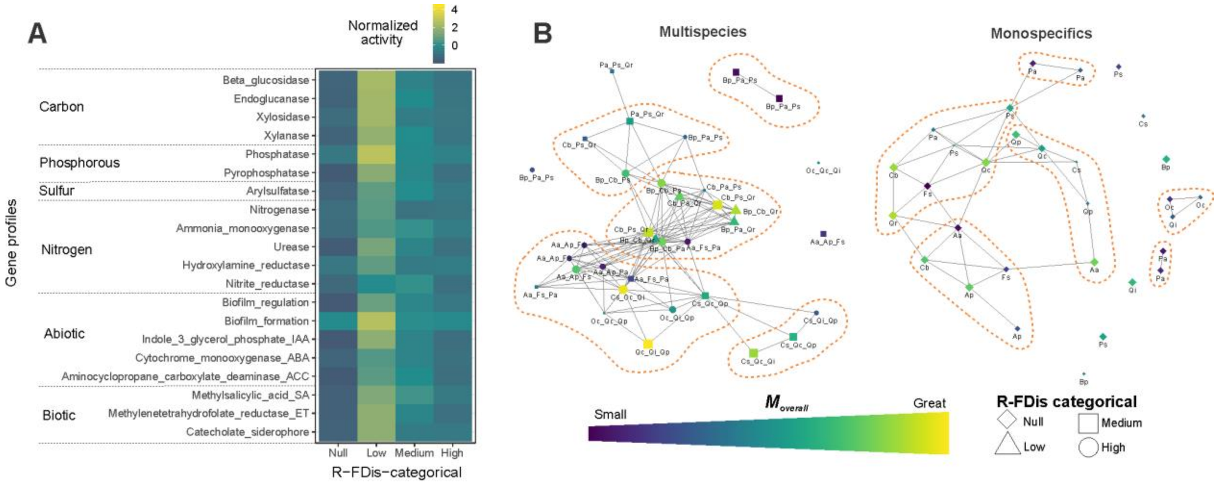


**Fig 1:** A) Heatmap of individual gene abundances of bacterial growth promotion activities tested across the categorical root functional dispersion index (R-FDis categorical). Gene profiles are grouped by nutrients (carbon, phosphorous, sulfur, nitrogen) and activities to tolerate abiotic stress and biotic stress. B) Network of single species and three species forest plots based on bacterial community composition of OTUs with differential abundances; sizes and colors indicate overall multifunctionality (Moverall) and shape root functional dispersion (R-FDis); dashed lines show plot modules; and letters indicate tree species: Aa, *Abies alba*; Ap, *Acer pseudoplatanus*; Bp, *Betula pendula*; Cb, *Carpinus betulus*; Cs, *Castanea sativa*; Fs, *Fagus sylvatica*; Oc, *Ostrya carpinifolia*; Pa, *Picea abies*; Ps, *Pinus sylvestris*; Qc, *Quercus cerris*; Qi, *Quercus ilex*; Qp, *Quercus petraea*; Qr, *Quercus robur*.

For fungal communities, we showed that their diversity depends more on tree community traits than on the number of tree species. Tree traits associated to litter quality and absorptive roots correlated with fungal diversity, especially for the guild of pathogen fungi, and influenced fungal community composition. We could also show that when tree communities were composed of rather rapidly growing trees, microbial communities were associated with an activity of carbon-cycling enzymes. In contrast, when trees were rather slow growing, soil microbial communities showed a higher activity of enzymes involved in nitrogen and phosphorous cycling.
Interesting side products making use of microbial analyses along a soil depth gradient are currently written up to show how soil depth has a stronger structuring effect on soil microbial communities than functional types of trees (deciduous vs. evergreen). Together with Partner 7 we are pushing these analyses further by incorporating absorptive root traits of the trees of different functional types.

Soil fauna diversity (Partners 1, 4, 4a – task leader Paul Kardol):
We quantified soil microfauna, mesofauna, and macrofauna diversity in all SoilForEUROPE plots using group-specific sampling and extraction protocols. Nematodes (microfauna) were identified at the family level, collembola and mites (mesofauna) at the species and the order level, respectively. Tree species mixing had little effect on microfauna and mesofauna diversity, but there were important differences in abundance among forest stands differing in tree species composition. On the other hand tree species richness increased the diversity and evenness of broad taxonomic groups of macrofauna. However, with increasing proportions of evergreen trees in forest stands, macrofauna diversity and evenness were lower. We also highlighted a switch from earthworm-dominated communities in fast acquisitive systems to predator-dominated communities in slow/conservative systems along a gradient of increasing proportion of evergreen trees, as a result of changes in litter quality and forest floor thickness (Fig. 2). Finally, canopy openness was positively related to detritivore abundance and biomass, leading to higher predator species richness and diversity, probably through trophic cascade effects.

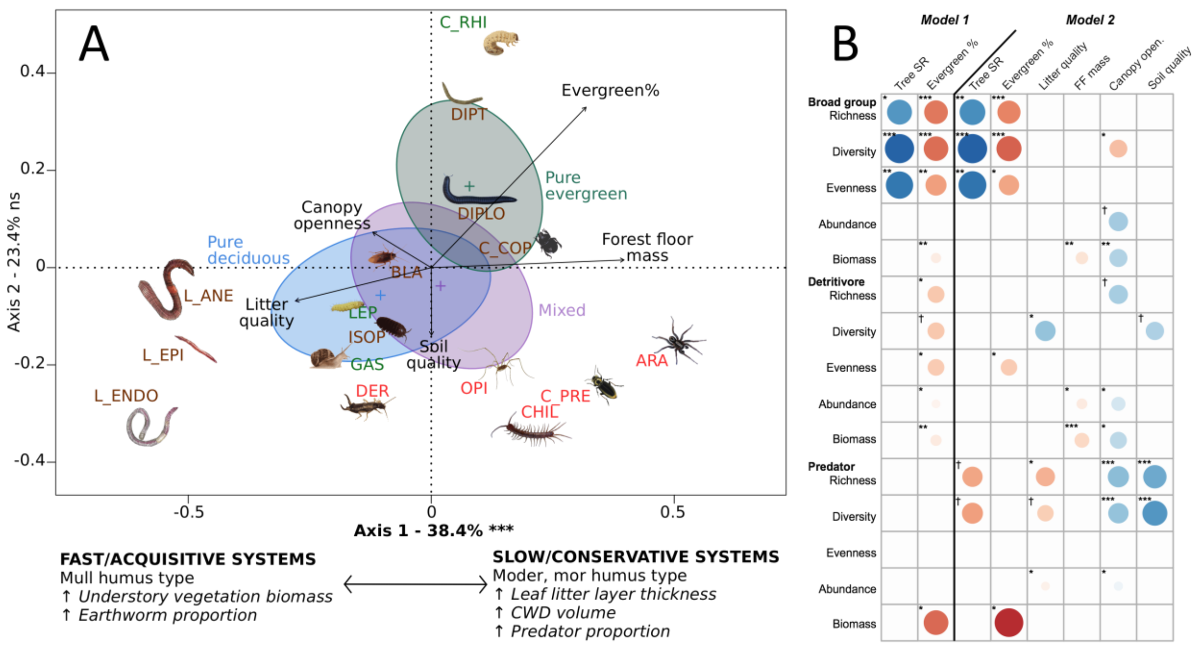


**Fig. 2:** A) dbRDA biplot of macrofauna communities in the SoilForEUROPE sites. Abbreviations: ARA= Araneae, C_PRE= Coleoptera Predaceous, C_RHI= Coleoptera Rhizophagous, GAS= Gasteropoda, CHIL= Chilopoda, L= Lumbricidae, EPI= Epigeic, ANE= Anecic, ENDO= Endogeic, DIPLO= Diplopoda, ISOP= Isopoda, OPI= Opilionidae, DER= Dermaptera, BLA= Blattaria LEP= Lepidotera Larvae, DIPT= Diptera Larvae, CWD= coarse deadwood debris; Text colours: predators in red, saprophagous in brown, herbivores in light green; Solid black arrows represent significant predictor variables; Explained variance (%) and level of significance of each axis are shown in the axis legend; Ellipses correspond to forest systems levels: pure deciduous (light blue), mixed (purple), and pure evergreen (dark green) stands. B) Results from Multimodel Inference analysis of soil macrofauna community descriptors. Model 1 includes only tree species richness (Tree SR) and evergreen % as co-variable, while model 2 includes also microenvironmental variables; Circle size and colour intensity are proportional to the effects strength, red colour for negative effect, blue colour positive effect; Significance levels: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1; Tree SR= tree species richness, FF mass= forest floor mass, Canopy open.= canopy openness (Figures modified from Ganault et al. under revision).

<u>Fine root traits (Partner 7 – task leader Jürgen Bauhus):</u>

We quantified tree fine-root traits related to below-ground spatial niche occupation and indicative of soil exploitation strategies including morphological, chemical, and microbial traits in mixed three-species and single species plots at all four FunDivEUROPE sites. We found that standing fine-root biomass was significantly lower in mixed compared to single species plots, but root length density overall did not change in mixtures and even increased in the most nutrient-rich soil layer. Fine-roots in mixtures were more homogeneously distributed across the three soil depth layers sampled compared to single tree species stands, yet we did not find evidence for vertical root stratification among species.

Moreover, we observed that fine roots in mixtures changed their morphology and chemistry as well as their associations with ectomycorrhizal fungi, i.e. tree fine roots in mixtures were overall longer, thinner, less dense, had higher nitrogen concentrations, and were characterized by higher ectomycorrhizal colonization intensities compared to single species stands (Fig. 3). In addition, the ectomycorrhizal diversity in soil samples was significantly higher in mixed compared to single species stands, further indicating positive biotic feedbacks. Hence, our results indicate that the lower standing fine-root biomass in mixtures may reflect a shift in soil resource acquisition strategies, rather than a lower performance of trees in mixtures.

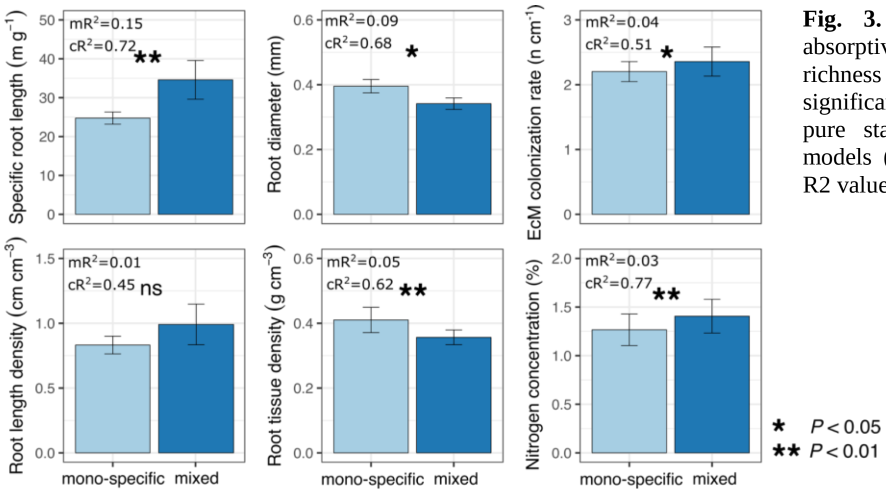


**Fig. 3.** Mean cumulative trait values of absorptive fine roots (±SE) by tree species richness across sites. Asterisks indicate significant differences between mixtures and pure stands tested with linear mixed-effect models (from which marginal and conditional R2 values were derived).

<u>Relationships between above- and belowground diversity (Partners 1, 3, 4, 4a, 5, 7 – task leader Paul Kardol):</u>

In order to better understand how forest plant communities and their functional trait attributes influence soil biodiversity, we used multivariate analysis (redundancy analysis) to explore the effect of tree functional composition and diversity on the abundance of soil organisms classified by trophic groups. While we found weak support for the 'functional diversity' hypothesis, our analysis provides strong evidence in support of the 'functional composition' (or 'mass ratio') hypothesis. Overall, we observed that tree communities dominated by tree species with acquisitive traits support bacterial-dominated soil food webs and high abundances of earthworms, while tree communities dominated by tree species with conservative traits support fungal-dominated soil food web and high abundances of macrodetritivores. Interestingly, we found stronger linkages of soil food web structure with living root traits and leaf litter quality than with green leaf traits. Microhabitat and microclimate related to tree canopy architecture and density were weakly related to soil food web structure. This emphasizes the importance of resources provided by trees in driving soil food web across European forest ecosystems.

**WP3: Soil function** (WP leader **Michael Scherer-Lorenzen – U Freiburg**)

<u>Fine root decomposition (Partner 7 – task leader Michael Scherer-Lorenzen):</u>

We quantified decomposition rates of standard and site-specific fine-root litter in mixed and mono-specific forest stands from the four FunDivEUROPE sites used in SoilForEUROPE. We found that standing tree species richness had an overall positive but weak effect on the decomposition rates of site-specific fine-root litter (Fig. 4). Initial root quality, more specifically nutrient concentrations, were found to drive decomposition rates more than tree diversity. Moreover, regional scale-difference in particular macro-climatic conditions were shown to strongly affect the decomposition rates of standard litter species. Nevertheless, these results suggest that the decomposition rates of the finest tree roots in mixtures cannot be predicted from single-species litter decomposition rates. Hence, tree species mixing may alter biogeochemical cycling in mixed forest stands across Europe.

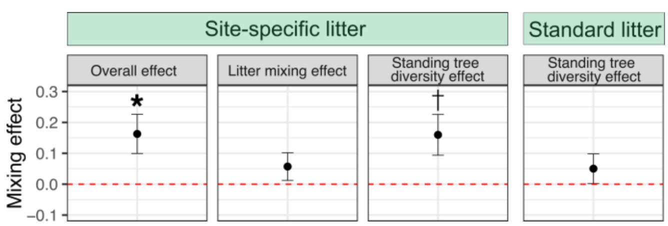


**Fig. 4** Mean mixing effects (±SE) across sites for overall (single-species litter in mono-specific stands vs. mixed-species litter in mixed stands), litter species mixing (single-species litter in mixed stands vs. mixed-species litter in mixed stands) as well as standing tree diversity effects (single-species litter in mono-specific stands vs. single-species litter in mixed stands) for site-specific and standard litter species. Asterisks indicate significant difference from 0 († P <0.1, * P<0.05). (after Wambsganss et al. in prep.).

Microbial activity (Partner 1 – task leader Nathalie Fromin):
With the overall 30 single tree species and 34 mixed tree species forest plots across the four FunDivEUROPE sites, we evaluated how plant litter and absorptive root traits affected broad functions of soil microbial communities, and how this may be influenced by tree species mixing. Our results did not show a direct effect of tree mixing on the soil microbial functions but showed that mixed forests modified soil microbial functioning mainly through absorptive root traits, especially root colonization by ectomycorrhizal fungi. Forest floor litter characteristics had weaker and less consistent effects. This suggests that any change in tree species composition in response to species loss, climate change, or management decisions will affect soil microbial activities and associated ecosystem services through the modification of tree absorptive root traits and their effects on soil microbiota.

**WP4: Climate change** (WP leader **Alex Milcu – Ecotron Montpellier**)

Microbial resistance to drought (Partners 1, 2 – task leader Stephan Hättenschwiler):
With top soil samples from the 64 forest plots across all four FunDivEUROPE sites we designed an experiment at the Ecotron in Montpellier to test the effects of repeated drought events on soil microbial activity (microbial driven $CO_2$ and $N_2O$ fluxes). The results indicate that soils from forest stands composed of three tree species are more resistant to drought events compared to single tree species stands (Fig. 5). In other words, the functioning of the soil microbial community (i.e. the microbial driven C and N processes) were less impaired by the imposed experimental droughts when the soil originated from three tree species forests. Complementary ongoing analyses on acquired data currently focus on identifying the microbial taxonomic and functional groups that are the most sensitive to the drought impact and the role tree species richness can have in alleviating these impacts (publication in preparation).

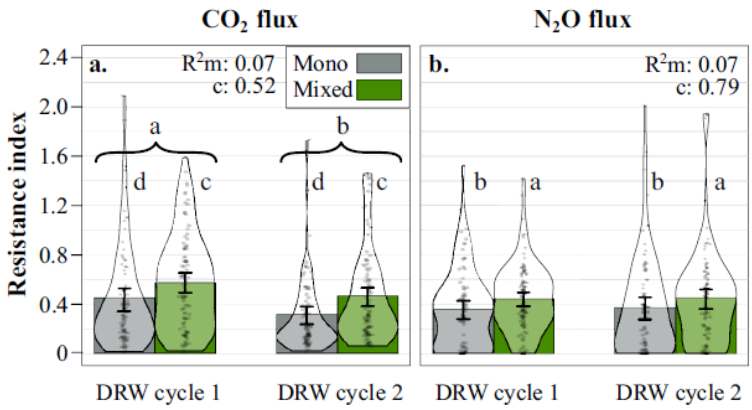


**Fig. 5.** Microbial respiration and denitrification resistance to drought for soils from single tree species stands (Mono, gray, n=90 index values for each gas) or three-species mixed stands (Mixed, green, n=102 index values for each gas for two drying-rewetting (DRW) cycles. The GLMM most parsimonious model results: $R^2$ marginal (m) and conditional (c) and significant differences (lowercase letters). From Gillespie et al. 2020.

Ecosystem resistance to drought (Partners 1, 2 – task leader Alex Milcu):
We constructed model ecosystems using an experimental setup in large mesocosms in the Montpellier European Ecotron allowing to simulate realistic conditions and the measurement of $CO_2$ and water fluxes in relatively large soil monoliths ($1m^2$, 1m depth). By simulating a forest understory of a Mediterranean forest with four tree species, this experiment aimed at assessing another facet of biodiversity, namely the impact of soil biota functional diversity on the resilience and resistance to recurrent severe droughts. We manipulated functional diversity with four groups of soil macrofauna, including endogeic earthworms, anecic earthworms, millipedes, and isopods, all frequent detritivores in the modelled Mediterranean forest. Due to early challenges during the setup of the large experiment as well as the decision to run the experiment a second year (during 2020) in order to increase the confidence in the observed findings, the data are not yet analysed.

Climate change x tree species diversity interactions (Partners 4, 4a, 5, 6, 7, A – task leader Kris Verheyen):

To assess how tree species mixture could modulate drought effects on soil biodiversity, we quantified the abundance of microorganisms (PLFA), nematodes, and microarthropods in two experiments with a crossed manipulation of tree diversity and precipitation (ORPHEE and FORBIO). Our data confirmed that drought greatly reduced the abundance of all major groups of soil organisms, with drought effects being stronger for the fungal energy channel as well as at higher trophic levels. However, our findings provide strong evidence in support to the hypothesis that tree diversity mitigates drought effects on soil biota. In ORPHEE, we found that the drought-induced reduction in the abundance of soil organisms was often stronger in monocultures than in mixed stands (Fig. 6). Fairly similar patterns were also observed in FORBIO, suggesting that this mitigation of drought effects on soil biodiversity by tree diversity could be a general pattern in European forests.

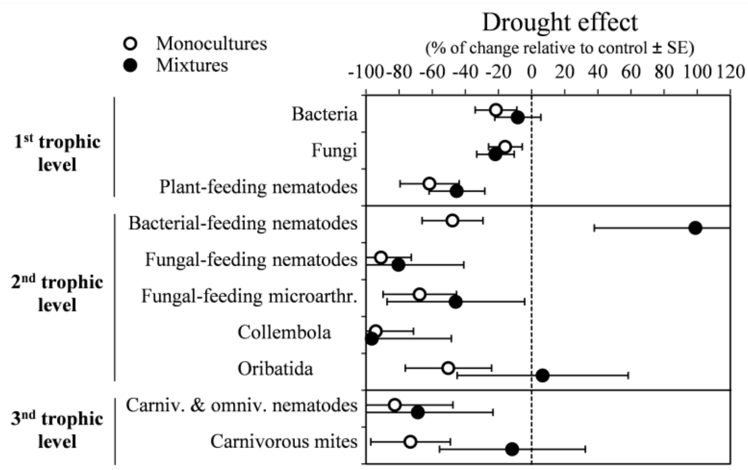


**Fig. 6.** Drought effects on the abundance of different groups of soil organisms in the ORPHEE experiment in tree monocultures and mixtures of tree species. Groups of soil organisms are organized by trophic level.

**WP5 : Socio-economic analysis** (WP leader **Liesbet Vranken – KU Leuven**)

The economic value of soil biodiversity (Partners 3, 6 – task leader Liesbet Vranken):

The assessment of the socio-economic value of soil biodiversity was performed in two steps. Firstly, forest scientists and managers were interviewed in order to study their understanding of the role of soil biodiversity in forest functioning and its link with forest management through a *"Fuzzy Cognitive Mapping"* approach. Secondly, a standardized questionnaire was developed (D5.1) that included a discrete choice experiment to assess citizens' preferences for management choices that impact soil biodiversity. The discrete choice experiment consisted of two rounds with a short informational animated video in between to study the effect of information transfer on preferences and willingness-to-pay (WTP) for forest management scenarios (D5.2). This two-step assessment allowed to gain insights in the hitherto understudied social dimension related to sustainable forest soil management, with a focus on soil biodiversity, and including multiple stakeholder groups. Moreover, a set of policy recommendations were formulated with the ultimate aim to increase consideration of soil biodiversity in forest management decisions and foster adoption of soil biodiversity conservation (D5.2).

The cognitive mapping exercise involved data collection through semi-structured interviews with a limited group of forest managers and scientists in Flanders and Romania. Despite a general awareness of soil biodiversity, differences in understanding of soil biodiversity between scientists and forest managers were found, as well as between Flanders and Romania. Managers seemed to lack in-depth knowledge, indicating the potential of communication strategies to improve forest management via increased managers' capacity. Specifically, our results suggest that these strategies should focus on the intrinsic value of soils, ecosystem functions, and processes. In addition, regional socio-economic and forestry context should be taken into account by focusing on context-specific aspects, especially concerning management and drivers and pressures impacting soil biodiversity. Furthermore, policy design should offer opportunities for knowledge exchange and discussion related to soil biodiversity throughout the forest planning process, by bringing various stakeholder groups together. Our approach that combines a problem structuring framework with *"Fuzzy Cognitive Mapping"* could be used to foster such knowledge exchange and discussion.

The assessment of public preferences for forest management and the effect of information related to soil biodiversity involved data collection amongst 775 citizens including representative samples of 229 citizens in Finland, 299 citizens in Flanders and 247 citizens in Italy. A detailed assessment was performed on heterogeneity in preferences and the effect of the information transfer using data from Flanders. Results showed that the information treatment significantly increased preferences for higher shares of old trees and dead wood, tree species mixing and tree logging through fixed logging roads, which support soil biodiversity. Heterogeneity in preferences was found with decreasing preference heterogeneity after the information treatment. Specifically, 67% of the respondents focused on aesthetics and recreation before the information treatment, while their preferences for biodiversity components, tree logging, and regulating ecosystem services considerably increased after the information treatment. Policy makers can use this information to increase valuation of soil biodiversity by citizens regarding their forest management preferences.

Knowledge transfer to stakeholders (Partners 3, 6 with contributions of all partners – task leader Liesbet Vranken):
The development of communication materials and dissemination of project results to stakeholders are discussed in detail in sections 6.2 and 6.3 (D5.3). As a result, a set of communication materials was developed including a project website, a short informational animated video on soil biodiversity, forest functioning and forest management, stickers with QR code to the website that were spread in forests in the countries involved in this project, a leaflet with the projects' background and main findings, and a PowerPoint presentation with a more detailed outline of findings for scientific use (under development).

### 4.4. *List of project meetings*

| Date | Place | Participating partners | Meeting title and object |
|---|---|---|---|
| 01-02/02/2017 | Bordeaux, France | Several people of all partners (1,2,3,4,5,6,7 and A). | SoilForEUROPE Kick off meeting<br><br>The object was to present all workpackages and different tasks by the WP and task leaders with the aim to specify the details, interfaces among WPs and to organize the work for 2017. A second important objective was to coordinate and plan the fieldwork at the different sites between April and June of 2017. |
| 09-11/04/2018 | Montpellier, France | Several people of all partners (1,2,3,4,5,6,7 and A) | SoilForEUROPE Annual meeting 2018<br><br>The objective was to get an overview of the achieved work in all WPs and tasks and to discuss progress and difficulties. A second important objective was to plan the remaining field work especially in the two TreeDivNet sites ORPHEE and FORBIO. |
| 09-11/07/2018 | Leipzig, Germany | Post-docs and PhD students of the partners 1,2,4,5, and 7 | Statistical workshop<br><br>The objective was to discuss statistical approaches and to develop a common statistical protocol under the guidance of Dr. Fons van der Plas, who was involved in the previous sister project FunDivEUROPE. |
| 15-17/04/2019 | Amsterdam, The Netherlands | Several people of all partners (1,2,3,4,5,6,7 and A) | SoilForEUROPE Annual meeting 2019<br><br>The objective was to summarize the work that was achieved in all WPs and tasks, to discuss progress and difficulties and to plan the remaining work with a particular attention to publication strategies. A second important objective was to prepare and plan the knowledge transfer and outreach activities. |
| 10/03/2020 | Freiburg, Germany | Several people of the partners 1,2,3,4,5,6,7 | SoilForEUROPE Final project meeting 2020<br><br>The objective was to present the latest results from all WPs to the project consortium and to the interested community (open video stream of the meeting). |
| 11-12/03/2020 | Herzogenhorn, Germany | Several people of the partners 1,2,3,4,5,6,7 | Dissemination workshop<br><br>The objective was to reach a final decision on the dissemination strategy for knowledge transfer and outreach. The second, more important objective was to create the communication materials destined for knowledge transfer and outreach. |

### 4.5 *Follow up activities and plans for further exploitation of the results*

We acquired a tremendously rich database across European forests that is presently not fully exploited. A workshop concentrating on crosslinking the different data sets would greatly facilitate the publication of syntheses. Other follow-up activities focussing on further dissemination of the findings both within the scientific community, for example by organizing a symposium, and within different groups of stakeholders and the larger public would increase awareness of the results and their implications.

## 5. Stakeholder engagement in the project

### *5.1 Before the project's start*

Stakeholder engagement was initiated with the project start.

### *5.2 During the project*

Permission to access field sites by stakeholders (Partner 6, 7, A): The maintenance of the field plots in Finland, Romania, Poland, and Italy and access for sampling (WP2, WP4) were only possible by permission of the different landowners and stakeholders.

Involvement of stakeholders as research objects, consultation, and information (Partner 3, 6): Involvement of stakeholders as research objects consisted of semi-structured interviews with 7 Flemish forest scientists, 10 Flemish forest managers, 3 Romanian forest scientists and 6 Romanian forest managers in view of a cognitive mapping exercise on soil biodiversity, forest functioning and forest management. This selection involved scientists of the universities KU Leuven (Flanders), UGent (Flanders), Stefan Cel Mare (Romania) and the research institute INBO (Flanders), as well as public forest managers of the forest administrations 'Agentschap voor Natuur en Bos' (Flanders) and ROMSILVA (Romania). During the interviews in Romania, we were supported by Laura Bouriaud and Cosmin Cosofret of the university of Stefan Cel Mare (Suceava) for the translation of interviews with forest managers. For the selection of private forest managers in Flanders, we consulted Jan Goris from Bosgroep Houtland.

775 citizens were selected anonymously through a market research agency in Finland (229), Flanders (299), and Italy (247) with the aim of obtaining a representative survey sample for each region.

To develop the discrete choice experiment and information transfer, we organized two focus group discussions with each time 8 scientists of the university KU Leuven, as well as one focus group discussion with 10 Flemish citizens.

For translating the survey, discrete choice experiment and information transfer to Finnish and Italian, Timo Domisch (Luke, Finland) and Martina Pollastrini (Università di Firenze, Italy) were involved.

Through the informational video embedded in the survey and discrete choice experiment, 775 citizens were informed about soil biodiversity, forest functioning, and forest management.

The PhD student working on WP 5 recorded a pitch of her research for the SoilForEUROPE project in cooperation with "The Floor is Yours", which is spread through social media and targets the general public. Additionally, she was invited to give a short presentation on forest soil biodiversity at the festival "Pint of Science" which aims to bring science in a comprehensive way to the general public. Unfortunately, this event has been postponed due to the COVID-19 pandemic.

In each country involved in the project (France, Germany, Sweden, Belgium, the Netherlands, Finland, Romania, Italy, and Spain) local forest managers were consulted to spread the stickers with QR code in frequently visited forests by hanging them on information boards near the forest entrances (all Partners involved).

*5.3 Foreseen after the project's end*

The project stimulated the idea of a new project to evaluate the effect of mixed species forests on human health (international project "Dr. Forest" funded under the BiodivERsA programme). Part of the SoilForEUROPE consortium is participating to this new project using the same plots and experimental design.

## 6. Dissemination of results

### *6.1 List of scientific publications*

See dedicated Excel file

### *6.2. Dissemination of results to scientists and scientific organisations*

<u>Oral presentations</u>

Ganault P., Nahmani J., Hättenschwiler S., Gillespie L., David J.-F. Henneron L., Iorio E., Mazzia C., Muys B., Pasquet A., Prada-Salcedo L.D., Wambsganss J. & Decaëns T. 2018. Tree diversity effects on soil macro-invertebrates in European forests. SFE² Conference, Rennes, France (23rd October, 2018).

Gillespie L.M., N. Fromin, A. Milcu, S. Devidal, B. Buatois, & S. Hättenschwiler 2019. European forest soil microorganisms in the face of drought: the influence of tree diversity. 1st Iberian Ecological Society XIV AEET Meeting, Barcelona, Spain (4-7 February 2019).

Gillespie L., Fromin N., Milcu A., Devidal S., Buatois B. & Hättenschwiler S. 2019. How do drying and rewetting stress cycles influence forest soil microbial activity? Stress Survival Thematic Day at CEFE-CNRS. Montpellier, France (9th September, 2019).

Hättenschwiler S., Barantal S., Ganault P., Gillespie L. & Coq S. 2018. Quel enjeux sont associés à la biodiversité des sols? CIAg "De la connaissance de la biologie des sols et de ses fonctions, à son pilotage". Dijon, France (18th October, 2018).

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. Effects of European monocultures and multispecies forests on specific soil fungal communities depends on tree traits and implies changes in soil nutrients functionality. IUFRO World Congress 2019, Curitiba, Brazil. (10th October, 2019).

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. Suelo microorganismos y funciones ecosistémicas. 25 years of Industrial microbiology career in the Pontificia Universidad Javeriana. Bogota, Colombia. (25th September, 2019)

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. Fungal communities and soil functionality respond rather to tree traits than to tree species richness in European forests. 49th Annual Meeting of the Ecological Society of Germany, Austria and Switzerland "Science meets practice". Münster, Germany (12th September, 2019).

Vanermen, I., Muys, B., Verheyen, K., Vanwindekens, F., Bouriaud, L., Kardol, P. & Vranken, L. 2017. What do forest managers and scientists know about forest soil biodiversity? Comparative knowledge mapping in support of soil biodiversity management. FunDivEurope Soil Synthesis Workshop. Leuven, Belgium (10th August, 2017).

Vanermen, I. & Vranken, L. 2019. Designing a Discrete Choice Experiment: A practical guide. Discrete Choice Experiment Workshop LIFT. Leuven, Belgium (27th March, 2019).

Vanermen, I., Muys, B., Verheyen, K., Vanwindekens, F., Bouriaud, L., Kardol, P. & Vranken, L. 2019. What do forest managers and scientists know about forest soil biodiversity? Comparative knowledge mapping in support of soil biodiversity management. Formal BioEconomic Seminar Series. Leuven, Belgium (5th April, 2019).

Vanermen, I., Kessels, R., Verheyen, K., Muys, B. & Vranken, L. 2019. The impact of information-transfer related to soil biodiversity on Flemish citizens' preferences for forest management. 3rd REECAP meeting. Osnabrück, Germany (10th September, 2019).

Vanermen, I., Kessels, R., Verheyen, K., Muys, B. & Vranken, L. 2019. Public preferences for forest management and the effect of information-transfer related to soil biodiversity. Formal BioEconomic Seminar Series. Leuven, Belgium (8th November, 2019).

Vanermen, I., Kessels, R., Verheyen, K., Muys, B. & Vranken, L. 2020. The impact of information-transfer related to soil biodiversity on Flemish citizens' preferences for forest management. 25th National Symposium for Applied Biological Sciences. Gembloux, Belgium (31st January, 2020).

Vanermen, I., Kessels, R., Verheyen, K., Muys, B. & Vranken, L. 2020. The impact of information-transfer related to soil biodiversity on Flemish citizens' preferences for forest management. BVLE PhD symposium. Brussels, Belgium (15th April, 2020). [accepted but cancelled due to COVID-19].

Vanermen, I., Kessels, R., Muys, B., Verheyen, K. & Vranken, L. 2020. Comparing citizens' preferences for forest management scenarios across three European regions: an application of a discrete choice experiment. Formal BioEconomic Seminar Series. Leuven, Belgium (22nd May, 2020).

Wambsganss J., Beyer, F., Freschet G. T., Scherer-Lorenzen M. & Bauhus J. 2019. Fine-root soil exploration and exploitation in mixed and monospecific forest stands across Europe. XXV IUFRO World Congress. Curitiba, Brazil (29 September – 5 October, 2019).

## Poster presentations

Ganault P., Nahmani J., Hättenschwiler S., Gillespie L., David J.-F. Henneron L., Iorio E., Mazzia C., Muys B., Pasquet A., Prada-Salcedo L.D., Wambsganss J. & Decaëns T 2020. Relative importance of tree diversity, identity and microenvironment in shaping soil macroinvertebrate communities in European forests. World Biodiversity Forum, Davos, Switzerland (23 – 28 February, 2020).

Gillespie L., Fromin N., Milcu A., Devidal S., Buatois B. & Hättenschwiler S. 2018. European forest soil microorganisms in the face of drought: the influence of tree species diversity. 13th North American Forest Soils Conference – 9th International Symposium on Forest Soils. Quebec City, Canada (10 – 16 June, 2018).

Gillespie L., Fromin N., Milcu A., Devidal S., Buatois B. & Hättenschwiler S 2019. Tree diversity positively influences soil microbial resistance to drought cycles. Symposium LIFE FORECCAsT. Toulouse, France (19-20 November, 2019).

Kriden I., Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. How do bacterial metabolic traits affect the stability and functionality of European forest ecosystems? 49th Annual Meeting of the Ecological Society of Germany, Austria and Switzerland "Science meets practice", Münster, Germany (12 September, 2019).

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. Influence of tree species richness on fungal communities and their ecosystem functions in different types of European forests. HIGRADE conference – Das Helmholtz-Zentrum für Umweltforschung – UFZ. Leipzig, Germany (May 2019).

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2019. Influence of tree species richness on fungal communities and their ecosystem functions in different types of European forests. Soil Ecology

Prada-Salcedo, L.D., Goldmann, K. & Buscot, F., 2017. Influence of tree species richness on soil microbial communities and their ecosystem functions in different types of European forests. Ecology Across Borders: Joint Annual Meeting 2017. Annual Meeting for 2017 will be joint with the GFÖ, NecoV and EEF. Ghent, Belgium (December 2017).

Vanermen, I., Kessels, R., Verheyen, K., Muys, B. & Vranken, L. 2020. The impact of information-transfer related to soil biodiversity on Flemish citizens' preferences for forest management. XVI EAAE Congress. Prague, Czech Republic (25th – 28th August, 2020). [accepted but postponed until 2021 due to COVID-19].

Wambsganss J., Beyer F., Freschet G.T., Scherer-Lorenzen M. & Bauhus J. 2019. Why fine-root decomposition rates of 13 tree species differ between mixed- and monospecific forest stands: a search for mechanisms across European forests. XXV IUFRO World Congress. Curitiba, Brazil (29 September – 5 October, 2019).

Wambsganss J., Freschet G.T., Scherer-Lorenzen M. & Bauhus J. 2018. Einfluss der Baumartendiv ersität auf funktionelle Eigenschaften von Feinwurzeln und ihre Bodenerschließung. Forstwissenschaftliche Tagung FoWita. Göttingen, Germany (24 - 26 September, 2018).

Wambsganss J., Freschet G.T., Scherer-Lorenzen M. & Bauhus J. 2018. Fine-root responses to changing tree species diversity in mature forest stands across Europe. 13th North American Forest Soils Conference – 9th International Symposium on Forest Soils. Quebec City, Canada (10 – 16 June, 2018).

### *6.3 List of dissemination activities with stakeholders*

The leaflet developed as communication material under WP5 with the contribution of all partners is sent to the forest managers that participated in the semi-structured interviews for the cognitive mapping exercise.

As described under 5.2, a short video was made by the PhD student in which she pitched her research related to the project for the wider public. This video is available on the facebook page of "Science Figured Out".

Additionally, the aim was to give a short presentation related to the project at the "Pint of Science" festival in Leuven (Belgium), but unfortunately this was cancelled due to COVID-19.

We aimed to organize a joint Think Forest discussion forum in Brussels at the end of the project. However, we have not been able to organize this due to the COVID-19 pandemic. Moreover, we contacted EFI Thinkforest, to discuss the organization of such discussion forum but it seemed that our project did not match their priority themes at the moment.

Moreover, we were not able to organize an event for the wider public on disseminations of project results due to the COVID-19 pandemic.
We were contacted by EOS Wetenschap (Belgium) for an interview related to the project which was published in July 2020 (https://www.eoswetenschap.eu/natuur-milieu/het-jammer-dat-bodemecosystemen-niet-de-aandacht-krijgen-die-ze-verdienen).

### *6.4 Dissemination of results to stakeholders (1-page max)*

At the beginning of the project, a logo was developed and a project website was set up in English (https://websie.cefe.cnrs.fr/soilforeurope/). Moreover, we added SoilForEUROPE to the web-based Data Portal of the FunDivEUROPE project to host datasets, presentations, etc. of the SoilForEUROPE project. After a brainstorm session organized at the annual meeting in Amsterdam, we decided to focus on a varied set of interesting achievable communication materials with different target public. The central platform for these communication materials is a dedicated communications page on the project website. Therefore, the project website was translated to the local languages of all countries involved in the project (France, Germany, Sweden, Belgium/the Netherlands, Finland, Poland, Romania, Italy and Spain).
Specifically, we developed a short informational video on the role of soil biodiversity in forest functioning and the influence of forest management. This video corresponds to a shortened version of the video that was used in the standardized questionnaire and discrete choice experiment for Task 5.1 of WP5: https://websie.cefe.cnrs.fr/soilforeurope/communication-en/.

A sticker with a QR code was developed and is attached to existing information boards in specifically selected, highly visited forests in all countries involved in the project (France, Germany, Sweden, Belgium, the Netherlands, Finland, Romania, Italy, and Spain). This sticker encourages forest visitors to scan the QR code and visit the project website (communication materials page) where they can see the informational video, read the leaflet, etc. Furthermore, a leaflet was developed that displays the rationale, methods, and main results of the SoilForEUROPE project. This leaflet consists of one A4 sheet of paper printed on both sides and folded in three and includes a drawing summarizing the main project results for which we cooperated with a professional drawer. This leaflet targets the more interested reader and forest managers. Both the sticker with QR code and the leaflet have been designed by a professional graphical designer. In order to spread these materials in all countries linked to the consortium and study sites of the project, these materials were translated into the local languages of the countries participating in the SoilForEUROPE project (France, Germany, Sweden, Belgium, the Netherlands, Finland, Romania, Italy, and Spain). For Poland, only the website was translated as the local contact person informed us that QR codes wouldn't work in their local context.

A set of PowerPoint slides is currently being developed for use in academic context. These PowerPoint slides go into detail on the rationale and methodology used in the project and include a more detailed exposition of the project results. The aim is to finish these PowerPoint slides as soon as possible and have them added to the website. As the PowerPoint slides are intended for academic use, they will be available in English.

In view of the recent developments due to the COVID-19 pandemic and general tendency towards increasing use of internet and mobile phones in Europe, we decided to focus on the presentation of project results online through the project website and the use of stickers with QR codes that are relatively easy to develop and spread. This seemed the best way to reach a diverse and large public, including citizens, forest managers, policy makers, and scientists. In March 2020, we were happy to have chosen this approach as the organization of face-to-face workshops, meetings, etc. was impossible due to COVID-19. Moreover, over the past couple of months, forest recreation has become increasingly important due to the lockdown in view of COVID-19 and forest visitor numbers have increased considerably (Derks et al., 2020). This strengthens our belief that the approach chosen for dissemination of project results was the most optimal one.

Derks, J., Giessen, L., Winkel, G., 2020. COVID-19-induced visitor boom reveals the importance of forests as critical infrastructure. For. Policy Econ. https://doi.org/10.1016/j.forpol.2020.102253

## 7 Global Impact assessment indicators

### *7.1 Impact statement*

We consider it a bit early to evaluate the impact of our work, because the first publications appeared only a few months ago and presentations of the results at international conferences were largely impossible in the COVID-19 shaken year of 2020. Although the assessment of how information on soil biodiversity affects the perception of its importance and decisions in how forests should be managed, the dissemination of results has only started and it is not yet possible to identify whether and how our work might have an impact in forest management. The potential impact is large, as we showed that knowledge on soil biodiversity is clearly limited and as we also demonstrated that the diversity of some groups of soil organisms depend on tree species richness and have measurable effects on ecosystem functioning especially under climate change.

### *7.2 Synthetic figures for the project publications (including interactions with stakeholders)*

Presently there are 22 project publications, 4 are published, 5 are in revision or submitted, 1 is published in a non-peer reviewed outlet, and 12 are in preparation (listed in the publication list template, but not taken into account in the following table). **1** published paper and **2** papers in revision with impact factor **>5**, including ***Science of the Total Environment*** (1), ***Journal of Ecology*** (1), ***Molecular Ecology*** (1), **2** published papers and **2** papers in revision with impact factor **>4**, including ***Environmental Microbiology*** (1), ***Functional Ecology*** (2), ***Communications Biology*** (1), **1** published paper in ***Forest Policy and Economics*** with impact factor **>3**, and **1** paper in revision at ***Oecologia*** with impact factor **>2.**

Analysis of the *project* publications:

| *Scientific Journal* | *Number* | *Impact Factor (2019)* |
|---|---|---|
| Science of the Total Environment | 1 | 6.551 |
| Journal of Ecology | 1 | 5.762 |
| Molecular Ecology | 1 | 5.163 |
| Environmental Microbiology | 1 | 4.933 |
| Functional Ecology | 2 | 4.434 |
| Communications Biology | 1 | 4.165 |
| Forest Policy and Economics | 1 | 3.139 |
| Oecologia | 1 | 2.654 |
| | | |

International dimension and multi-partnership for publications

| | | Number of publications |
|---|---|---|
| **Multi-partner publications** | **Peer-reviewed journals** | 8 |
| | **Books or chapters in books** | |
| | **Communications (conferences)** | 9 |
| **Single-partner publications** | **Peer-reviewed journals** | 1 |
| | **Books or chapters in books** | |
| | **Communications (conferences)** | 4 |
| **Outreach initiatives including interactions with stakeholders** | **Popularization articles** | 1 |
| | **Popularization conferences** | 2 |
| | **Others** | |

### *7.3. Other scientific outputs*

| | **Number, years and comments (Actual or likely outputs)** |
|---|---|
| **International patents obtained** | |
| **International patents pending** | |
| **National patents obtained** | |
| **National patents pending** | |
| **Operating licences (obtained / transferred)** | |
| **Software and any other prototype** | |
| **Company creations or spin-offs** | |
| **New collaborative projects** | **Dr.Forest**: Diversity of forests affecting human health (Biodiversa). This project also uses sites and plots studied within SoilForEUROPE, FunDivEUROPE and TreeDivNet.<br><br>**MixForChange**: Mixed Forest plantations for climate Change mitigation and adaptation (Biodiversa). This project also uses sites and plots studied within SoilForEUROPE, FunDivEUROPE and TreeDivNet. |
| **Scientific symposiums** | |
| **Others (please specify)** | |

### *7.4. Assessment and follow-up of personnel recruited on fixed-term contracts (excluding interns)*

| Identification | | | Before recruitment for the project | | | Recruitment for the project | | | | After the project | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surname and first name | Sex M/F | E-mail address | Last diploma obtained at time of recruitment | Country of studies | Prior professional experience, including post-docs (years) | Partner who hired the person (Organisation and Country) | Position in the project (1) | Duration of missions (months) (2) | End date of mission on project | Professional future (3) | Type of employer (4) | Type of employment (5) | Promotion of professional experience (6) |
| Barantal Sandra | F | sandra.barantal@gmail.com | PhD | France | 4 | Montpellier European Ecotron | Post-doctoral | 24 | 10/2019 | fixed-term contract | Public research | Researcher | NA |
| Prada-Salcedo Luis Daniel | M | luis.salcedo@ufz.de | MSc. | Colombia | 6 | Helmholtz Centre for Environmental Research - UFZ | Doctoral student | 36 | 04/2020 | fixed-term contract | Public research | Researcher | yes |
| Gillespie Lauren | F | Lgillespie155@gmail.com | MSc. | USA/France | 3 | CEFE-CNRS | Doctoral student | 36 | 05/2020 | fixed-term contract | Public research | Researcher | yes |
| Wambsganss Janna | F | janna.wambsganss@gmail.com | MSc. | Germany | 0 | University of Freiburg, Germany | Doctoral student | 36 | 02/2021 | fixed-term contract | Public research | Researcher | yes |
| Hennerон Ludovic | M | Ludovic.henneron1@univ-rouen.fr | PhD | France | 2 | SLU, Umea, Sweden | Post-doctoral | 18 | 07/2019 | fixed-term contract | University | Associate professor | NA |
| Vanermen Iris | F | iris.vanermen@kuleuven.be | MSc. | Belgium | 0 | KU Leuven, Belgium | Doctoral student | 36 | 05/2020 | fixed-term contract | Public research | Researcher | yes |

### *7.5. Data Management and timeline for open access*

All data arising from SoilForEUROPE were uploaded to the web-based Data Portal of the FunDivEUROPE project, being assigned to a specific data-project within this Portal (https://data.botanik.uni-halle.de/fundiveurope/). Data quality checks were at the responsibility of the Task Leaders, before upload. Data can be search based on a key-word search function, and metadata of each dataset can be downloaded freely. All project members have the rights to download data.

Before using data from other sub-projects, a standardised "paper proposal" had to be sent to all project members, which includes information about the datasets to be used for a publication, details about the data analyses and channel of dissemination. Owners of dataset had two weeks to agree or to reject the use of their data, although rejection never occurred.
The timeline for open access has not yet been determined exactly. It won't be before 2023, the year for which we anticipate all primary research articles from SoilForEUROPE are published.