JULY 20, 2020

FINAL PROJECT REPORT

SoilForEUROPE project

PROF. LIESBET VRANKEN

KU LEUVEN
DIVISION OF BIO-ECONOMICS

Final project report

1. COORDINATES

1.1 PROMOTOR

Name: Prof. Liesbet Vranken
Function: 100 % ZAP docent – work package leader
Address: Department of Earth and Environmental Sciences, Division of Bio-Economics, KU Leuven, Celestijnenlaan 200E – Box 2411; B-3001 Leuven (Heverlee)

Phone: +32.16.32.23.95
E-mail: liesbet.vranken@kuleuven.be

1.2 STAFF AT THE EXPENSE OF THE PROJECT

Name: Prof. Bart Muys
Function: 100 % ZAP docent
Address: Department of Earth and Environmental Sciences, Division of Forest, Nature and Landscape, KU Leuven, Celestijnenlaan 200E – Box 2411; B-3001 Leuven (Heverlee)

Phone: +32.16.32.97.26
E-mail: bart.muys@kuleuven.be

Name: Iris Vanermen
Function: BAP – Doctoral grant
Address: Department of Earth and Environmental Sciences, Division of Bio-Economics, KU Leuven, Celestijnenlaan 200E – Box 2411; B-3001 Leuven (Heverlee)

Phone: +32.16.37.37.16
E-mail: iris.vanermen@kuleuven.be

Function: BAP – Research Assistant
Address: Department of Earth and Environmental Sciences, Division of Bio-Economics, KU Leuven Celestijnenlaan 200E – Box 2411; B-3001 Leuven (Heverlee)

Phone: +32.16.37.37.16
E-mail: margot.vancauter@kuleuven

Name: Kewan Mertens
Function: BAP – Post-Doctoral Researcher
Address: Department of Earth and Environmental Sciences, Division of Bio-Economics, KU Leuven Celestijnenlaan 200E – Box 2411; B-3001 Leuven (Heverlee)

Phone: +32.16.37.37.16
E-mail : kewan.mertens@kuleuven.be

1.3 CONTACT PERSONS OF THE ADMINISTRATION AND FINANCIAL SUPPORT SERVICE

Name: Iesel Van der Plancken
Function: AP – International Funds
Address: Schapenstraat 34 – Box 5100; B-3000 Leuven

Phone: +32.16.32.04.46
E-mail: iesel.vanderplancken@kuleuven.be

Name: Ronja Jurien
Function: AP – Administration
Address: Department of Earth and Environmental Sciences, KU Leuven
Celestijnenlaan 200E; B-3001 Leuven (Heverlee)

Phone: +32 16 321812
E-mail: ronja.jurien@kuleuven.be

2. PROJECT STATE

2.1 ANNUAL PROJECT MEETINGS

2.1.1 KICK OFF MEETING SoilForEUROPE, BORDEAUX

On the 1st and 2nd of February 2017 a SoilForEUROPE kick off meeting was held in Bordeaux, France. All members of the project were invited to participate. The aim of the meeting was to present the different work packages of the project to the project members and to have a discussion on the best way to approach the different tasks in the project. An agenda of the meeting and the meeting minutes are included in Appendix A. The meeting minutes contain a list of the project members that attended the meeting, an overview of the information given in the different presentations of the work packages and an overview of the discussion and some important decisions. Our work consists of a socio-economic analysis of forest soil biodiversity and is represented in work package 5. The promotor and leader of work package 5, Prof. Liesbet Vranken, gave a presentation on the aim of this work package and the methods to perform the socio-economic analysis.

2.1.2 KICK OFF MEETING BiodivERsA, BRUSSELS

On the 4th of April 2017 a BiodivERsA kick off meeting was organized in Brussels, Belgium. The aim of the meeting was twofold:

(1) Present the 26 projects funded through the BiodivERsA 2015-2016 call, of which SoilForEUROPE is part of
(2) Present administrative and reporting modalities during the projects' lifetimes.

The SoilForEUROPE project coordinator, Dr. Stephan Hättenschwiler, attended this meeting and presented a poster on the SoilForEUROPE project. A draft of the meeting agenda and a copy of the poster can be found in Appendix B.

2.1.3 ANNUAL MEETING SoilForEUROPE, MONTPELLIER

The first annual project meeting was held from the 9th of April, 2018 until the 11th of April, 2018 in Montpellier, France. During this meeting, progress in the different work packages was discussed. An agenda of the meeting and the meeting minutes are added in Appendix C, similar to the reporting on the kick-off meeting. Prof. Bart Muys represented our work package at the meeting. However, Prof. Liesbet Vranken and Iris Vanermen were not able to join this annual meeting in Montpellier. Nevertheless, they participated through a skype connection and presented the progress achieved in work package 5.

2.1.4 ANNUAL MEETING SoilForEUROPE, AMSTERDAM

The second annual project meeting took place from April 15th to 17th in Amsterdam, the Netherlands. For each work package the progress was discussed and a planning for the remaining work was proposed. An agenda of the meeting and the meeting minutes are added in Appendix D. Our work package (WP5) was represented by Bart Muys and Iris Vanermen. Liesbet Vranken was unfortunately not able to join, but was briefed in detail after the meeting. During the meeting, Iris Vanermen gave two presentations on her work for the project, specifically task 1 of WP5. Moreover, task 2 was discussed in a separate session guided by Bart Muys, which was organized as a brainstorm session with the entire group to come up with ideas for the dissemination and development of communication materials for the project output. Afterwards, all members of WP5 further elaborated on this discussion to select which materials to develop to communicate the project results.

2.1.5 FINAL PROJECT MEETING SoilForEUROPE, FREIBURG

The final project meeting was held from March 9th until March 12th in Freiburg, Germany. All members of WP5 attended the meeting, including Liesbet Vranken, Bart Muys and Iris Vanermen. During the first day of the meeting, the project results were presented for each work package. Iris Vanermen presented the main findings of her work in two presentations related to task 1. Moreover, we organized an internal dissemination workshop, as part of task 2, to extract the key messages linked to the results for each work package in the project. The output of this workshop was then used for the development of the communication materials (see section 2.3.) The agenda of the meeting and the meeting minutes are added in Appendix E.

2.2 WP5 TASK 1: SOCIO-ECONOMIC ANALYSIS OF FOREST SOIL BIODIVERSITY

The first task of work package 5 aimed to assess the socio-economic value of forest soil biodiversity. A first step was taken by drafting a protocol that can be found in appendix F. This protocol describes the aims of the work package, the methods that were intended to be used and a call for support from the project members. Specifically, the analysis was done in two steps. Firstly, forest scientists and managers were interviewed in order to assess their understanding of the role of soil biodiversity in forest functioning through a fuzzy cognitive mapping approach and its link with forest management decisions. Secondly, a standardized questionnaire was developed that included a discrete choice experiment which aimed to assess citizens' preferences for management choices that impact soil biodiversity. The discrete choice experiment consisted of two rounds with a short informational video in between to study the effect of information transfer on preferences. Both steps of the analysis are explained in more detail in following sections (2.2.1 and 2.2.2), as well as the output of each step regarding (upcoming) publications.

2.2.1 COMPARING SOIL BIODIVERSITY UNDERSTANDING OF FOREST SCIENTISTS AND MANAGERS

For this first step, face-to-face semi-structured interviews were organized with forest scientists and managers in Belgium and Romania about their perspective on the role of forest soil biodiversity. Specifically, 7 Flemish scientists, 10 Flemish forest managers, 3 Romanian scientists and 6 Romanian forest managers were interviewed. A field trip to Romania of about one week was organized to gather the Romanian data. Based on the fully transcribed interviews, understanding was compared between forest scientists and managers, and Flemish and Romanian respondents, using a fuzzy cognitive mapping approach based on the R package cogmapr. This R package was developed by Frédéric Vanwindekens, who assisted us in the analysis and became a co-author of the scientific paper. Through this method, interview transcripts were coded in relationships between concepts and individual cognitive maps were constructed based on these codings. Afterwards, a social cognitive map was constructed for each stakeholder group by arithmetic addition of the individual cognitive maps of all members within a stakeholder group. The analysis involved a discussion of structural characteristics of the social cognitive maps, a comparison of centrality values of the concepts between stakeholder groups, a comparison of relationship weights between stakeholder groups, a discussion of detailed understanding of three clusters of relationships and an assessment of heterogeneity within stakeholder groups. A scientific paper on this knowledge mapping has been written and has been accepted for publication by the Journal of Forest Policy and Economics. The scientific paper is titled *"What do scientists and managers know about soil biodiversity? Comparative knowledge mapping for sustainable forest management."* and is included in Appendix G, together with the confirmation of acceptance for publication.

2.2.2 CITIZENS' PREFERENCES FOR FOREST MANAGEMENT RELATED TO SOIL BIODIVERSITY AND THE EFFECT OF INFORMATION-TRANSFER

The second step involved the development of an online standardized questionnaire that included a discrete choice experiment and a short informational video. The aim of this standardized questionnaire was to assess the wider public's preferences for forest management related to soil biodiversity and the effect of an information transfer about soil biodiversity and forest management on these preferences. The online standardized questionnaire was spread in three European regions, following a North-South gradient which represents different forest types: Finland, Flanders and Italy. For the selection of attributes, or management characteristics, for the choice experiment, a scoring exercise was developed that was spread online within the institutions linked to the project consortium and used during three focus group discussions in Flanders. Specifically, two focus groups were organized with experts (division of bio-economics and division of forest, nature and landscape) and one focus group was organized with general citizens (friends and family). Each focus group discussion counted around 8 participants and lasted 1h to 1h30. Moreover, a cooperation with Prof. Roselinde Kessels of the University of Antwerp was set up, who is an expert in discrete choice experiment design using Jmp. The information transfer was constructed through a short video, in cooperation with KU Leuven's media service Limel. In the three regions, the data were collected through a market research agency (iVOX) which allowed to apply a quota sampling approach resulting in representative samples based on a number of socio-demographic characteristics (age, gender, education level). The questionnaire was first launched in Flanders in February 2019, resulting in data collected of 300 respondents. Then the standardized questionnaire was translated to Finnish and Italian with the help of project partners in each country and was launched in September 2019. In each of these countries (Finland and Italy) data was collected from a sample of 250 citizens.

Based on this data collection, two to three scientific papers are or will be written. Specifically, a first paper has been drafted which used the data collected in Flanders to perform a detailed analysis of the effect of information transfer related to soil biodiversity on public preferences for forest management. This analysis included a detailed assessment of preference heterogeneity and heterogeneity in the way that citizens reacted on the information transfer. A draft version of this scientific paper has been added in Appendix H. A second paper is currently in the phase of finalizing the analysis and starting to write the manuscript. This paper focuses on the comparison of public preferences for forest management across the three regions (Finland, Flanders and Italy) and includes a comparison of the effect of the information transfer across these three regions. The aim is to have a first draft of this paper finished in September 2020. A last step in the analysis would focus on the technical aspect of including an opt-out option in the choice experiment and the effect that his might have on the preference structure and the effect of the information transfer. As it would probably be too much to include this in the paper on the comparison of preferences across the three regions, there might be an opportunity to include it in a separate scientific paper, depending on the timing. Alternatively, this last step in the analysis could be included in the doctoral thesis of Iris Vanermen as a smaller separate chapter.

The scientific work that has been performed in view of task 1 of WP5 (see sections 2.2.1 and 2.2.2) has been presented at national (e.g. the National Symposium of Applied Biological Sciences on January 31st 2020 in Gembloux) and international scientific conferences (e.g. 3rd meeting of REECAP network on September 9th – 10th 2019 in Osnabrück), as well as during (internal) seminars.

2.2.3 WP5 TASK 2: COMMUNICATION AND DISSEMINATION OF THE PROJECT RESULTS

The second task of our work package involved the dissemination of project results and specifically the development of communication materials. While we were responsible for this task, it involved a cooperation with the entire project consortium and in particular with the colleagues that participated in the dissemination workshop which was organized during the final project meeting (see 2.1.5). 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/). After a brainstorm session organized at the annual meeting in Amsterdam (see 2.1.4), we decided to focus on a varied set of interesting achievable communication materials. The central platform to which this set of communication materials is attached, is the project website. Specifically, the aim was to develop a sticker with QR code that will be attached to existing information boards in specifically selected forests that are highly visited by citizens. The QR code leads to a communication materials tab on the project website that collects a digital version of all communication materials. The Dutch version of the sticker is added in Appendix I. Firstly, a short informational video was developed 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 (see section 2.2.2). You can access this video on the website through this link: https://websie.cefe.cnrs.fr/soilforeurope/communication-en/. Secondly, a leaflet has been developed that displays the rationale, methods and main results of the SoilForEUROPE project. This leaflet consists of one A4 printed on both sides and folded in three, and includes an overview drawing of the main project results for which we cooperated with a professional drawer. We are currently finalizing the leaflet of which the current last draft version has been added in Appendix J. 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 and the project website were translated into the local languages of following countries participating in the SoilForEUROPE project: Finland, Sweden, Belgium/The Netherlands, Germany, France, Romania, Spain and Italy. For Poland, only the website was translated as the local contact person informed us that QR codes wouldn’t work in their local context. Lastly, a set of powerpoint slides is currently being developed for use in academic context. These powerpoint slides go in deeper detail into 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 by September/October 2020. Once finalized, the powerpoint slides will be added to the communication materials tab on the website. These slides will be provided in English.

2.3 PLANNING

Hence, the aim is to publish three to four scientific papers based on the analysis performed for task 1 of work package 5 for which we are responsible. So far, one paper has been accepted for publication by the Journal of Forest Policy and Economics (see section 2.2.1) and a draft version of the second paper is available, with the aim to submit it to a scientific journal by the end of August 2020. The plan is to finish a first draft of the third paper by September 2020 and assess at the moment the possibility for a fourth paper. Concerning task 2, the development and translation of the project website, sticker with QR and informational videos have been finalized. The development and translation of the leaflet are in the final steps and should be finished within one to two weeks. The development of the powerpoint slides is aimed to be finished around September/October 2020.

3. AGREEMENT, CONTRACT & PATENT

None of the involved partners have specific requirements on the protection of existing datasets. Guidelines and agreements on scientific integrity will be followed as drafted by the research institution. Research results produced in the framework of previous PhDs or research projects will be used and shared by SoilForEUROPE participants when appropriate, after achieving consent of the original author and with properly acknowledging the source and author of the data. The SoilForEUROPE partners decided that no convention was required to define the collaboration and data exchange between partners. Plans of publications and conference presentations will be communicated at each project meeting.

4. APPENDICES

APPENDIX A: AGENDA AND MEETING MINUTES KICK OF MEETING BORDEAUX 1-2 FEBRUARY 2017

SoilForEUROPE kick off meeting 1/2 February 2017 Bordeaux

Meeting draft agenda

Wednesday, 1 February

14:00	Arrival and Introduction round	
14:20	General proposal overview of SoilForEUROPE	S. Hättenschwiler
14:40	FunDivEUROPE sites and major results	M. Scherer-Lorenzen
15:00	TreeDivNet site FORBIO	K. Verheyen
15:15	TreeDivNet site ORPHEE	H. Jactel
15:30	WP2: Assessing soil biodiversity - WP leader F. Buscot)	
	Task 1 – Soil microorganisms	T. Wubet
16:00	BREAK	
16:20	Task 2 – Soil fauna Discussion about which fauna groups are feasible depending on expertise and time	P. Kardol
17:00	Task 3 – Fine roots	J. Bauhus, **M. Scherer-Lorenzen**
17:30	WP3: Soil processes - WP leader M. Scherer-Lorenzen)	
	Task 1 – Fine root decomposition Discussion on how to link to available leaf decomposition data	M. Scherer-Lorenzen
18:00	Task 2 – Microbial activity	N. Fromin
20:00	Diner in town	

Thursday, 2 February

09:00	<u>WP4: Climate change - WP leader A. Milcu)</u>	
	Task 1 – Microbial resistance/resilience	S. Hättenschwiler
09:30	Task 2 – Ecosystem resistance/resilience	A. Milcu
10:00	Discussion round on organizational aspects of soil sampling	ALL
11:00	BREAK	
11:30	<u>WP5: Socio-economic analysis - WP leader L. Vranken)</u>	
	Task 1 – The economic value of forest soil biodiversity	**L. Vranken**, B. Muys
12:00	Task 2 – Knowledge transfer to stakeholders	**L. Vranken**, B. Muys
12:30	Planning of the field season 2017	ALL
13:00	Lunch	
14:00	Planning of the field season 2017	ALL
15:00	General discussion	ALL
16:00	Administrational aspects	S. Hättenschwiler
16:15	Meeting closure	

MEETING MINUTES (by Matty Berg & Stephan Hättenschwiler)

Participants:

Stephan Hättenschwiler, Hervé Jactel, Andreas NAME (representing Fernando Valladares), Nathalie Fromin, Silvain Coq, Johanne Nahmani, Alexandru Milcu, Olivier Bouriaud, Paul Kardol, Kris Verheyen, Michael Scherer-Lorenzen, Janna Wambsganss, Filippo Bussotti, Liesbet Vranken, Iris van Elm

Excused:

David Wardle (moving), François Buscot (sick), Jürgen Bauhus (teaching), Bart Muys (teaching), Thibaud Decaëns (moving)

1. *General overview (Stephan)*

- Proposal overview

There are two projects that are thematically close to SoilForEUROPE in the BiodivERsA call (SOILMAN, focussing on ecosystem services driven by soil biota, SOILCLIM, focussing on climate change effects on soil organism composition in agroecosystems). Possibility to meet with these consortia at the BiodivERsA kick off meeting in Brussels the 4,5 April 2017.

- Administrational points and funding

Funding: Money for 3 years. End of project max 3 months after end project (end 2019). Almost all groups received the money they requested. Matty is funded via subcontracting (money has been arrived in Sweden). Six site managers (F.Valladares Spain, F. Bussotti Italy, H. Bruelheide Germany, O. Bouriaud Romania, B. Jaroszewicz Poland, L. Finer Finland) associated with the project (money will be allocated via the budget from Gent (Kris) – needs at the respective sites need to be evaluated befor transfer).

Reporting : After 18 months interim report, after 36 months final report. Additional national request?

Database: should be made available at the end of the project. There is an action going on at the moment to join soil fauna databases across Europe. EU seems to be interested to contribute to this activity financially. This could also be part of the communication strategy. There might be a possibilities to associate SoilForEUROPE data bases to those established during FunDivEUROPE at iDiv Leipzig (see with C.Wirth, S. Ratcliffe?).

Project website: Where? and who will be responsible? Attach to FunDivEurope website, if we can allocate a little bit of money? CEFE is another option, but other options might be possible.

2. *FunDivEUROPE (Michael)*

- Overview of what was done

7th framework, running for 4 years, 24 institutions, 6 countries (NS and EW gradient): exploratory platform: 209 plots to set up gradients of tree species richness in six different forest types. Approaches: observation, experimentation, modelling, i.e. experimental platforms (TreeDivNet), country-specific forest inventories, exploratory platforms (the six sites). Focus on multi-functionality (bats, birds, vegetation, pests, herbivores, ecosystem processes) with the concept of all measurements done in all plots.

All data are in the database, have been quality checked, when using data original data providers should be contacted and agreements concerning publications should be made. Database is not public. There is a website address to check what is there but data cannot be downloaded without a password.

Experimental platforms: plantations of trees varying in species diversity and exceptionally also with additional climate change treatments (ORPHEE, FORBIO – the two experiments included in SoilForEUROPE).

Exploratory network: Replicated gradient of tree diversity with a homogenous environment to reduce covariation. Allow to distinguish between species diversity and species identity effects at high, but not perfect evenness. Plots are 30x30m plus buffer zone, nine 5x5m subplots. Positions of all individual trees are mapped and their size and growth was/is documented. Trees are individually labelled (in most sites, if lost can be restored). Lots of logistic information available (and accommodation present). All the specific measurements/sampling done within plots have been carefully mapped (e.g. three locations within three subplots where understorey vegetation has been measured in detail). Also no-go zones are present. There is a plot and methods paper (Baeten et al. 2013). At all sites there was stakeholder involvement (led by Austria team who has the details), and there exist **local stakeholder boards**.

About 40 papers have been published, still ongoing. Main results: Prevailing species identity effects, no single species fulfills all functions. Mixtures do not perform worse than monocultures. There are species diversity and functional diversity effects. Tree diversity enhances multifunctionality when moderate levels of functions are desired (van der Plas et al. 2016).

Question: Are there enough monoculture plots? Across species there are sufficient numbers, but for some species and some locations there is only one plot. Also, understorey vegetation can differ between monoculture plots.

3. TreeDivNet site FORBIO (Kris)

There are actually three sites in Belgium. Site Zedegem: 1-4 species diversity, from a pool of 5 species, with at total of 90.000 trees. 42 plots, 42x42 meters each (800 trees). Trees planted in 2010 on former potato field. Trees are now 7-8 m high. Sandy soil with 8-10% silt content. Deep soil, dry to moist, no water stress (initial soil cores are sampled and stored). Variables on tree growth, element cycling, biodiversity dynamics. Additional treatments with rainfall shelters (5x5 meters, -50% exclusion, but same spatiotemporal pattern; together with Monique Carnol) from monoculture to 4-species with beech and oak as target species. Measurements in this additional treatment are tree growth, litter decomposition (tea bag) soil nutrient availability, soil microbial biomass.

4. TreeDivNet site ORPHEE (Hervé)

Location is near Bordeaux. Monocultures to 5 species mixtures, in 31 combinations. 100 trees per plot. Distance between trees 2 x2 m and trees have always the same neighbour species. 36 inner trees are measured. 8 blocks and 32 plots. Irrigation (vs non-irrigated control plots) since 3 years using sprinklers operating at night from March to October (3mm of rain per night) to alleviate summer drought (June to September).

Start in 2007 on previous pine plantation. Stump removal, fencing, planting tree seedlings from nurseries on fertilized soil (PK). Replanting in 2008-2009. Mowing plots in 2008-2009 (to remove understorey plants.

Collected data: dendrometry (survival, height, DHB), herbivory (insects), biodiversity (understorey vegetation, Carabidae (**pitfall traps, also this year- potentially interesting to combine with macrofauna data**), birds), processes (litter decomposition (tea bag), soil biological activity, microclimate). There is a soil archive (9 soil cores per plot).

5. WP2

Task 2: Soil fauna (Paul)

Aims: 1. Link tree diversity to soil fauna diversity 2. Link tree diversity to functional diversity of soil organisms
Needed data: numbers and names of species and trait values (challenging)
To get these data there is a general trade-off between number of plots, number of groups of organisms and depth of taxonomic precision.

Question: which groups/species should we include, and what taxonomic resolution should we aim for?

Decision:

1. nematodes: determination to feeding group level combined with life history traits and body sizes
2. mesofauna: collembola, taxonomic level? mites will be collected, but who may identify them?
3. macroarthropods: as many groups as possible, taxonomic level?

Question: how many samples and when to sample?

Decision:

1. Sampling should include as many groups as possible. We will see afterwards to what level of taxonomic resolution we can go.
2. The FunDivEUROPE sites should be sampled in spring/early summer 2017 for all groups of organisms. We may later see whether it is possible/needed to sample in fall for certain groups. TreeDivNet sites ORPHEE and FORBIO not yet clear (spring 2018?)

Question: What traits and how to get them, both response and effect traits?

Decision:

1. First take traits from trait data bases, and traits that are not available should be measured. Go for life history groups? Needs more discussion amongst specialists.
2. Nematodes: Functional groups, i.e. life history traits (colonizer vs persister, cp-values) + indices (maturity index, structure index, enrichment index), body size spectra, mouth parts (feeding group).

Question: Who will do what?

Decision:

1. nematodes: Umea
2. mesofauna: extraction in Amsterdam, determination of collembolans? mites?
3. macroarthropods: collections centralized in Montpellier, determination?

Question: Which soil layer?

Decision:
We will respect common protocols for the different groups of organisms, i.e. top 10 cm of soil for fine roots and microorganisms (fine roots additionnally at 10-20 cm and 20-30 cm soil depth), 5-6 cm for mesofauna, 15 cm for macroarthropods.

Question: What sites and what plots?

Decision:
FunDivEU sites: Because of heavy work load for counting/identifying soil organisms Spain (shallow soils that are very difficult to sample) and Germany (species overlap with Poland and Romania and bark beetle induced losses of trees) will be sampled less. For the spring 2017 sampling campaign focus on Italy, Poland, Romania, and Finland. Monoculture and 3-species plots will be sampled, which means about 59 plots (45 more plots if 2-species plots were to be included).
ORPHEE: 42 plots (n=3)
FORBIO: 36 plots

Task 3: Tree fine roots (Michael)
1. Spatial occupation (quantify fine root spatial arrangement –how?)
2. Root traits: biomass, specific root length, live to dead mass ratio, branching patterns, chemical composition (C, N, P, Ca), mycorrhizal colonization for each tree species. Separation and identification of tree fine roots may be difficult in FORBIO and ORPHEE due to dense understorey vegetation.

Questions:

- What other root traits? It would be good to have some kind of thoughness traits (relevant for consumers): maybe lignin concentration or some kind of physical resistance? Secondary metabolites? Tannins could be done in Montpellier, total phenolics protocol in Montpellier requires 0.5 g of material.

- Possibility of combining mycorrhizal determination with molecular approaches (Halle/Leipzig)?

- What kind of sampling design?

Decision:
Sampling spots within plots defined based on equal distances among tree individuals rather than random (see sampling protocol we discussed).

6. WP3

Task 1: Fine root decomposition (Michael)
The fine root decomposition study will be set up in a second time after the fine root sampling for trait determination in spring 2017. Perhaps in fall 2017?

Question: What root material to be used for decomposition?

- The increasingly acknowledged large differences among different root orders will be difficult to respect in this large scale study (too laborious for separationg different root orders). Rather the traditional approach of fixed diameter cut off (at < 2mm)? Perhaps better to respect at least the same root orders across species (e.g. the first two or three orders will be taken rather than a fixed diameter cut off)?
- Standard root material or plot-specific root material?

Decision:
Plot-specific root material will be difficult to get in sufficient quantity. Roots from each species may be collected at a common site (e.g. arboretum or plantations), and this same root pool may then be used to construct litterbags for all sites/plots the particular species occurs. Add a common garden experiment to tease apart root mixture effects from plot diversity effects?

Question: What mesh size for litterbags?

Decision:
Small enough to avoid roots growing into mesh bags: 50 m? This allows mycorrhizal hyphae to pass but not roots. This mesh size also then means that there is no point to extract fauna from bags, but nematodes?

Task 2: Microbial activity (Nathalie)

Introduction of the concepts, hypotheses, and questions (see presentation). Litter chemistry affects soil microbial structure and respiration. Litter mixtures affect soil microbes, higher biomass and activity (but high variability in the data) due to increasing catabolic diversity. What about roots? Root traits respond to global change. Root traits also impact ecosystem processes. Root traits seem good predictors of soil microbial community (especially root N concentration).

Different proxies: microbial respiration (SIR), nitrification enzyme activity (NEA), fungal biomass, PFLA, enzymatic activity, genetic diversity (sequencing)
Microbial life strategy framework (high vs low nutrient content; copiotroph vs oligotroph; high vs low growth rate).

Question: What samples to be measured?

Decision:
We should make the measurements on the **same samples like for WP2/1 (microbial diversity), WP2/2 (fauna) nematodes, WP2/3 (roots)**.

Question: Do we include the litter layer? We could do the basic measurements on litter in spring as there will be litter around. Maybe we can use a litter decomposition model, using the output variables as a proxy for what enters the root zone. By only using the root traits we might miss something for the microbial community structure/activity. Maybe we can use a crude NIRS analysis for the litter at the time of sampling (56 samples).

Decision:
The litter layer will also be sampled and air-dried at each spot of sampling (see sampling protocol discussion).

Question: Can we use proxies that can serve as response and effect traits so we can use the same scheme for all biotic groups? Obviously the underlying traits are difficult to measure but we could measure the response and effect and use these measures as the trait.

7. WP4

Task 1: Microbial resistance/resilience (Stephan)

As we were running late and Nathalie already exposed the general issues about microbial response variables, Stephan did not present this task in detail. However, a number of questions were touched on during general discussions.

Question: What is the soil material to be taken to the Ecotron and how much of it?

Decision:
The remaining soil from the same 0-10 cm top soil samples taken for extracting roots and for microbial diversity, activity and nematode measurements should be used. Is the amount sufficient? The Ecotron protocol needs to be determined to know the amount of soil required. If soil from the 5 sampling spots will be bulked, the quantity should be sufficient.

Question: Timing of the experiment?

Decision:
In the meantime there was a meeting with the Ecotron staff to discuss some details further (3 March 2017). The incubators to be used for the experiment are available from September 2017. The soils need to be stored between sampling (April for Italy) and the start of the experiment (September/October). Air dried soil seems to be most appropriate. Isn't this already representing a drought event?

Task 2: Ecosystem resistance/resilience (Alex)

Presentation of the aims and the design of the proposed experiment using the Ecotron mesocosms. A challenge will be the collection of sufficient individuals of fauna to compose the 4 different fauna communities each for 2 different functional diversities (using response traits to drought based on Matty's data set of temperate species) – the design is 2 fauna diversity levels x 2 watering treatments x 4 replicates (i.e. 4 different fauna communities that can be different based on species composition and relative abundance but with the same level of FD). Trace gas fluxes will be measured (CO_2, CH_4, N_2O) with the aim to calculate the global warming potential).

Question: What type of soil to be used, where to be harvested? How many soil layers?

Decision:
One mesocosms has 1 m^2 soil surface and is 1 m deep, so we will need around 25 tons of soil. As fauna will represent temperate forests in the Netherlands, soil could be taken from there as well. Logistically feasible? Or from Belgium (Kris may have a contact)? From the Cevennes (beech forests at about 1000 m altitude) in the north of Montpellier would geographically be the closest. A relatively fertile soil would allow for higher diversity and abundance of fauna.

Question: How to treat the soil before using it in the experiment to remove fauna?

Decision:

Could be done with steam (CEFE is equipped), but is it efficiently excluding all fauna? Gamma radiation would be another possibility, but this may affect microbial communities as well, which we do not whish to manipulate. Perhaps a specific dose allows to kill fauna selectively without affecting microorganisms too much?

Question: How and where to collect soil fauna? Large amounts of individuals will be needed, is it possible to get all of them from The Netherlands?

Question: What type of beech seedlings, size, provenance, etc.?

Decision:
During the general discussion the idea came up that it would be great to use isotopically labelled litter to cover the soil surface (we would need 200 g m^{-2}). This would allow to follow the label in the soil food web (^{15}N and strontium as a Ca marker?). How to produce this litter? Kris mentioned the possibility of using some individuals of trees to be planted in two weeks in Belgium as part of a large project Kris is involved. Exellent idea, and Kris arranged things that 35 individuals (1.5 m tall) of each of the three species *Fagus sylvatica, Acer pseudo-platanus*, and *Prunus avium*) are planted in pots for an easier labelling. Individuals of this size will produce approximately 30 g of litter. These same 3 species should then also be used in the ecotron experiment (probably 2 individuals per species = 6 trees in each mesocosm). How big/old should they be? The same provenances as in Kris' experiment? What about mycorrhiza?

Question: What kind of climatic conditions will be used? Do we mimic a particular site, for instance the conditions of the site where we select the soil from?

Question: How do we control soil humidity in a finite lysimeter?

Decision:
A reference tensiometer and using suction tubes to regulate soil water at the bottom of the lysimeters seems to be important, especially in the context of drought effects. Lysimeters will have to be ordered quickly. We would need some field reference for soil water potential.

Question: Time schedule?

Decision:
The mesocosms will be used for another experiment in 2019, so our experiment should start in fall 2017!

Question: What response variables in addition to gas flux measurements? Decomposition of leaf litter (important also to interpret stable isotopes), root decomposition? root growth? Introduce a ^{13}C label? Pore size distribution using NMR?

8. WP5

Task 1: Economic value of soil biodiversity (Liesbet)

Presentation of the context towards ensuring proper management decisions. Requires awareness about the importance of soil diversity for soil processes and associated ecosystem services. Managers need to be convinced that they can act and do something to enhance ecosystem resilience. And it is important that actions are community supported rather than pure top-down decisions. This can be explained by the benefit some actions has for certain services. The knowledge and literature is there, but the public has to be made aware.

Task 1 is time consuming as it requires knowledge mapping of scientist and managers to see where the gaps are and what can be done to close these gaps (based on surveys). Choice experiments is the approach to assess preferences by managers and users (presenting different forest management scenarios along with their consequences in terms of costs and gains)

Question: What type of management scenarios should be included in the choice experiment? Which attributes should be added to the charts?

Decision:
Potential attributes: tree species, timber extraction, tree density, number of thinnings, open/closed landscapes, labour input, costs. How much attributes do we add?

Question: What are the target groups for the choice experiment?

Decision:
Forest managers already participated in many surveys in Belgium. They may be saturated? Could it be adapted to other countries? By whom? Language issues... It would be very interesting to broaden the cultural differences for example with a comparison in Romania. This may require different attributes in different countries with different cultural backgrounds.

Question: Which information should be provided in the choice experiment? How can soil biodiversity be included more specifically?

Decision:
Perhaps with mushrooms and berries? Dead wood?

Task 2: Knowledge transfer (Liesbet)

In the proposal policy briefs were suggested as a mean of transferring knowledge. We discussed the pertinence of these and whether they are really read and if yes how much they can influence behavior. Perhaps personal presentations adapted to the target group would be more efficient. EU officials? Forest house in Brussels?

Local stakeholder and user groups should be reached, but for this the whole consortium is required to participate, not just Liesbet's group. There was recently a brochure by the GIP Ecofor on soil biodiversity with contributions by Thibaud. An important event for communication will be the IUFRO conference in Brazil in 2019. Other pre- or post-conference meetings? However, stakeholders are not on these meetings. Technical meetings for managers? Presentations for national agencies? A final conference?

Question: What is the best communication strategy (what and how) and which policy instrument to increase awareness for soil biodiversity?

9. Discussion on the organisation of sampling and planning of the field season 2017

There were different discussion blocks at different times during the meeting. Several decisions could be reached, which are integrated in the circulating sampling protocol.

Main decisions:

- In 2017 we concentrate on sampling in the FunDivEUROPE sites. We focus on the 4 sites in Italy, Romania, Poland, and Finland to keep sampling and identification efforts feasible. Sampling in FORBIO and ORPHEE sites in 2018.
- At all sites (FunDIV, FORBIO, ORPHEE) we consider monocultures and 3-species mixtures only. There was also a discussion whether we should also include the 2-species mixtures. In the end we voted against it because for a regression approach to species richness it is not sufficient anyway and will be too much work.
- Sampling at the plot level in FunDIV: five subsamples per plot are taken based on tree neighbourhoods (for meaningfull fine root sampling) trying to include: 1/ the three "understorey plots" of the nine official subplots, 2/ the two additional subplots along the "X", 3/ if there are no convient tree neighbourhoods within these subplots, subsamples may be taken in the remaining four subplots or even from the buffer zone outside the plots.
- At these 5 sampling spots, soil cores will be taken for 1/ fine root traits, 2/ microbial diversity (molecular analyses), 3/ nematodes, 4/ microbial activity, 5/ soil to be used in the Ecotron microcosm experiments (WP4, task 1).
- Microarthropod samples (3 samples per plot in the "understorey subplots") will be taken in immediate vicinity of three of the five sampling spots for roots (with special equipment provided by Matty).
- Macroarthropod samples (3 samples per plot in the "understorey subplots") consist of soil blocks (25 x 25 x 25 cm) taken for hand sorting of soil fauna.
- Timing of sampling: After the KOM we decided to do the macrofauna sampling also in spring 2017, wich means that we will do a coordinated sampling for all groups of organisms and all measurements planned in spring 2017.
- Pitfall traps are being planned at CEFE to put out during sampling campaigns in spring 2017.
- It is important that a team representing the consortium leaves together for the different field campaigns in the different countries. A minimum of 4 persons should participate each time, but 5 persons would be better. We expect that the three PhD students from Freiburg (Janna), Montpellier (NN) and Halle (NN) are participating in all of these campaigns. Alternatively these three groups designate another person (researcher or technicien) to participate. It would be good if as many people as possible could participate at the first field sampling in Italy in order to modify and adjust sampling procedures if needed.

Actions required:

- Draft of sampling protocol (Stephan)
- Agenda for field campaigns in spring 2017 (Janna, Michael)
- List of equipment needed in the field (Janna, Michael, all)
- Contact site managers if assistance is possible to empty pitfall traps (Stephan)

10. General discussion

Meetings

We agreed on one meeting per year for the whole consortium, and maybe additional meetings of subgroups depending on the topic and work package / task specific discussions. Next annual consortium meeting is planned for late January / beginning February 2018 in Montpellier. Let's try to decide quickly on a date.

Budget

Kris needs a clear vision of what support is required at the different sites to construct a budget plan and transfer funds to site managers. Amount could be depending on the maintenance activities and working day costs. Field assistant costs (via contract and hiring a specific person). If specific activity are needed for a specific contributor then that person should be pay for the additional costs from the partner-specific budget.

FunDIV sites

- See with site managers for potential problems in the specific plots (logging, fire, disease, ...).
- Even if activities will be reduced at the sites in Spain and Germany, we should at least make sure that tree growth will be measured again during SoilForEUROPE everywhere.

Stakeholder survey

The consortium commits to think about possibilities to involve local stakeholders and/or user groups for WP 5.

Information

Bart informs the consortium that he is hosting Dr. Juan Zou as a post-doc with one objectif to run common analyses on already existing soil data from the FunDivEUROPE project. Could provide interesting interactions.

APPENDIX B: AGENDA KICK OF MEETING BIODIVERSA & COPY OF POSTER

Draft agenda:

CALL 2015-16: PROJECTS' KICK OFF

BiodivERsA COFUND Call on « understanding and managing biodiversity dynamics to improve ecosystem functioning and delivery of ecosystem services in a global change context: the cases of soils and sediments, and land- river and sea-scapes (habitat connectivity, green and blue infrastructures, and naturing cities) »

Concept

The aims of the Projects' kick-off meeting are twofold:

(i) Present the 26 projects funded through the BiodivERsA 2015-2016 call;

(ii) Present administrative and reporting modalities during the projects' lifetimes.

Participants

Kick off meeting

- All BiodivERsA partners willing to attend, especially the partners who contributed to fund research projects within the 2015-2016 COFUND Call
- Representatives from the projects funded (preferably the principal investigators)
- The Chair and Vice-Chair of the Evaluation Committee
- Members of the Evaluation committee

Dates

- April 4th (PM) 2017

Location

BelSPO offices
231 avenue Louise
1050 Brussels
Belgium

Draft agenda

PROJECTS' JOINT KICK OFF (2-6 PM – April 4th)

Closed session

- Introduction by the Call Secretariat, presentation of key call figures, and of BiodivERsA requirements in terms of reporting, acknowledgement of funding, etc. by the BiodivERsA Secretariat (20 min)
- Presentation of additional opportunities available to BiodivERsA funded projects by the SSI/SPI officer (20 min)
- Presentation of the Access and Benefit Sharing legislation and what it may imply for funded research projects, by an ABS expert (20 min)

Opening of the public kick-off (coffee break)

- Introduction by the BiodivERsA coordinator (5 min)
- Keynote by the Chair and vice-Chair of the Evaluation Panel (30min)
- Keynote on Nature-Based Solutions by an EC representative (15 min)
- Flash presentations of the 26 funded projects (60 min)
- Funded projects' forum (50 min)

Poster:

SoilForEUROPE

biodiversa
2015-2016 COFUND Joint Call

Predicting European forest soil biodiversity and its functioning under climate change

S. Hättenschwiler[1], F. Buscot[2], P. Kardol[3], J. Roy[4] , M. Scherer-Lorenzen[5], K. Verheyen[6], L. Vranken[7], and the SoilForEUROPE consortium* [1]CEFE Montpellier, [2]UFZ Halle/iDiv Leipzig, [3]SLU Umeå, [4]ECOTRON Montpellier, [5]U Freiburg, [6]U Gent, [7]KU Leuven

CONTEXT

- Despite being the largest ecosystem in Europe (210 million ha), forests remained fairly marginal in past research on how soil biodiversity affects ecosystem functioning.
- This lack of understanding hinders the assessment of potential impacts of forest biodiversity loss on soil processes and their resistance and resilience to climate change.
- Moreover, the historical, educational and economical values of soil biodiversity are likely misjudged by forest managers and the larger public, probably because of a general ignorance about soil biodiversity.
- Links between tree diversity and soil biodiversity remain elusive, but their existence would greatly facilitate predictions of soil biodiversity and ecosystem functioning under climate change and its consideration in decision making.

➔ **SoilForEUROPE** aims at (1) linking soil biodiversity with tree species richness across European forests, (2) determining the role of biodiversity in ecosystem resistance and resilience to drought, and (3) assessing the socio-economic value of soil biodiversity and its impact on decision making.

Figure 1. Heterotrophic microorganisms, such as fungi (here in a boreal forest (left)), and soil macro-fauna, such as millipedes (here *Cylindroiulus caeruleocinctus* in a Mediterranean forests (right)) are two key groups of soil organisms determining carbon storage and nutrient turnover in forest ecosystems to a great extent. Photos by S. Hättenschwiler.

MAIN HYPOTHESES

- Forest tree diversity and associated leaf and root traits control the abundance, diversity, functional traits, and community composition of soil organisms.
- Higher soil biodiversity increases the resistance and resilience of tree growth and soil processes in response to extreme drought.
- Limited knowledge by the broader public on the role of soil biodiversity in providing forest ecosystem services leads to inappropriate management decisions.

STUDY SITES

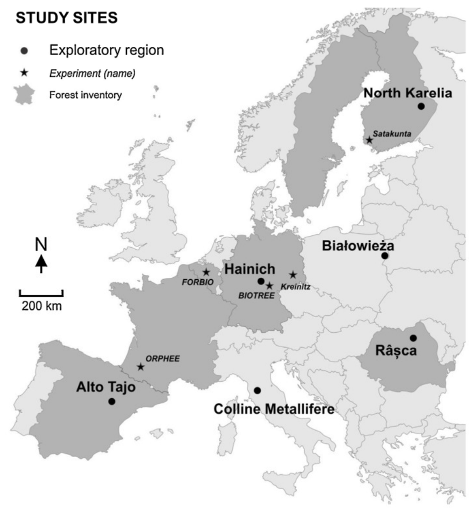


Figure 1. The locations of the six forest types (exploratory region – filled circles) where the tree diversity gradients were set up in a previous project (FunDivEUROPE). Soil biodiversity and soil processes are assessed in these sites and data will be combined with already available data for above-ground biodiversity and ecosystem processes to evaluate relationships among above- and below-ground biodiversity and process rates. At the two experimental platforms (stars) ORPHEE and FORBIO the impact of changes in precipitation on soil biodiversity and soil functioning is assessed in the field (Figure from Baeten et al. (2013)).

APPROACHES

1) Using organism group-specific methodology, the diversity of soil microorganisms, nematodes, micro-arthropods, macro-fauna, and fine root traits are assessed along tree species diversity gradients in six typical and climatically different European forest types (Fig. 1). Relationships among below- and above-ground diversity measures and ecosystem processes are evaluated with multivariate analyses and structural equation modelling.
2) The role of biodiversity in the resistance and resilience of ecosystem processes in response to drought is assessed in tree diversity experiments that manipulate precipitation (ORPHEE and FORBIO), and with experiments at the European Ecotron in Montpellier. In the Ecotron, trace gas emissions (CO_2, N_2O, CH_4) are measured in response to drought and to changes in biodiversity.
3) The perception of soil biodiversity and its contribution to ecosystem services by forest managers and the broader public is assessed with specifically designed surveys. Choice experiments for specific target groups (forest users and managers) allow to evaluate how soil biodiversity criteria influence decision making processes.

* **Further participants to the SoilForEUROPE consortium**: E. Ampoorter (U Gent), L. Baeten (U Gent), J. Bauhus (U Freiburg), F. Beyer (U Freiburg), M.P. Berg (VU Amsterdam), S. Coq (CEFE), T. Decaëns (CEFE), S. Devidal (ECOTRON), N. Fromin (CEFE), L. Gillespie (CEFE), H. Jactel (INRA Bordeaux), A. Milcu (CEFE), B. Muys (KU Leuven), J. Nahmani (CEFE), C. Piel (ECOTRON), O. Ravel (ECOTRON), L. Salcedo (UFZ Halle), I. Vanermen (KU Leuven), L. Vranken (KU Leuven), J. Wambsganss (U Freiburg), D.A. Wardle (NTU Singapore), T. Wubet (UFZ Halle)

APPENDIX C: AGENDA AND MEETING MINUTES SOILFOREUROPE ANNUAL MEETING 9/11 APRIL 2018, MAS DES VIOLETTES, MONTPELLIER.

SoilForEUROPE annual meeting 9-11 April 2018, Mas des Violettes, Montpellier

Meeting agenda

Monday, April 9th

13h to 15h	Arrival at the Mas des Violettes (see practical information)	
15h00	Beginning of the meeting with introduction of participants	
15h15	General overview and administrational issues S. Hättenschwiler	
15h30	**WP2: Assessing soil biodiversity** (WP leader F. Buscot)	
	Task 1 – Soil microorganisms (task leader F. Buscot) Microorganisms Current status and perspectives	L. Prada Salcedo / K. Goldmann / F. Buscot
15h50	Discussion	
16h10	**Task 2 – Soil fauna** (task leader P. Kardol) Macrofauna Current status and perspectives	P. Ganault / JF. David / J. Nahmani / S. Coq / T. Decaëns
16h30	Discussion	
16h50	BREAK	
17h10	Mesofauna and nematodes Current status and perspectives Discussion about pooling samples	L. Henneron / P. Kardol M. Berg / D. Wardle
17h30	Discussion	
17h50	**Task 3 – Fine root traits** (task leader J. Bauhus) Fine roots Current status and perspectives	J.Wambsganss/M. Scherer- Lorenzen / J. Bauhus
18h10	Discussion	

18h30	**Tree growth at FunDivEU sites**	M. Scherer-Lorenzen K. Verheyen / O. Bouriaud
19h00	**Microclimate at FunDivEU sites**	R. Matulo
20h00	DINNER	

Tuesday, April 10th

09h00	**Continuation of WP2: Assessing soil biodiversity**	
	Task 4 – Diversity relationships (task leader D. Wardle) General ideas and outlook	L. Henneron / P. Kardol / D. Wardle
09h20	Discussion	
09h40	**FunDivEU soil data synthesis initiative**	J. Zuo / B. Muys et al.
10h00	Discussion	
10h20	General wrap-up Discussion "Soil Biodiversity"	
11h00	BREAK	
11h20	**WP5: Socio-economic analysis** (WP leader L. Vranken)	
	Task 1 – Economic value of biodiversity (task leader L. Vranken) Current status and perspectives	I. Vanermen / B. Muys K. Verheyen / L. Vranken
11h35	Discussion	
11h50	**Task 2 – Knowledge transfer** (task leader L. Vranken) Current status and perspectives	I. Vanermen / B. Muys K. Verheyen / L. Vranken
12h05	Discussion	
12h30	LUNCH	
14h00	**WP4: Climate change** (WP leader A. Milcu)	
	Task 3 – TreeDivNet sites (task leader K. Verheyen)	
	Ground beetles at ORPHEE	H. Jactel
14h15	Discussion and planning of sampling activities at ORPHEE and FORBIO sites	
15h00	**Task 2 – Ecosystem resistance/resilience** (task leader A. Milcu)	

	Ecotron mesocosm experiment Status, problems, perspectives	S. Barantal / A. Milcu / Ecotron staff et al.
15h20	Discussion	
15h45	BREAK	
16h00	Visit Ecotron	
19h30	DINNER	

Wednesday, April 11th

09h00	**Continuation of WP4: Assessing soil biodiversity**	
	Task 1 – Microbial resistance/resilience (task leader S.Hättenschwiler)	
	Microcosm drought experiment	L. Gillespie / N. Fromin / A.
	Current status and perspectives	Milcu / S. Hättenschwiler
09h20	Discussion	
09h40	**WP3: Soil processes** (WP leader M. Scherer-Lorenzen)	
	Task 1 – Fine root decomposition (task leader M. Scherer-Lorenzen)	
	Fine root decomposition experiment	J.Wambsganss / J. Bauhus
	Current status and perspectives	M. Scherer-Lorenzen
10h00	Discussion	
10h20	**Task 2** – Microbial activity (task leader N. Fromin)	
	Microbial activity at the FunDivEU sites Current status and perspectives	L. Gillespie / S. Hätten- schwiler / N. Fromin
10h40	Discussion	
11h00	BREAK	
11h20	**General Discussion** (including sampling, data integration, publication policy, meetings,…)	
13h00	LUNCH	
14h00	End of meeting	

MEETING MINUTES (by Sandra Barantal & Stephan Hättenschwiler)

Participants:

Sandra Barantal, Jürgen Bauhus, Jean-François David, Nathalie Fromin, Pierre Ganault, Lauren Gillespie, Kezia Goldmann, Stephan Hättenschwiler, Ludovic Henneron, Hervé Jactel, Paul Kardol, Alexandru Milcu, Bart Muys, Johanne Nahmani, Luis Daniel Prada Salcedo, Michael Scherer-Lorenzen, Kris Verheyen, Janna Wambsganss, Yong Zheng.

Partial participation via skype:

Liesbet Vranken, Iris van Elm

Invited participants:

Radim Matulo (Mendel Univ Brno, Czech Republic – microclimatic measurements at FunDivEU sites), Juan Zuo (KU Leuven, Belgium – FunDivEU soil data synthesis)

Excused:

Matty Berg (teaching), François Buscot (Lab evaluation), Sylvain Coq (sabbatical leave), Thibaud Decaëns (travelling), David Wardle (teaching)

11. Overview and administrational issues (Stephan) – 9/4/18

Funding period until end of December 2019 with maximal possible extension of 3 months (March 2020).

Interim report is due in June 2018. Stephan will contact PIs and WP leaders for writing this report in the coming 2months. A final report is due in December 2019.

Main achievement during first year is the coordinated and very successful sampling campaign at the four FunDivEUROPE sites. A special thank to the excellent team of PhD students Janna, Lauren and Luis, who participated in the sampling at all four sites between mid-April and end of June 2017 and assured the same sampling protocol everywhere.

Project website: There is still no SoilForEUROPE webpage. Who would be willing to take responsibility and where should it be hosted? It might be a page attached to the FunDivEUROPE website or to the CEFE website, but other options might be possible. A SoilForEUROPE project description might also be implemented on Research Gate, but not all of the participants like that idea.

Project Logo: Lauren drew a draft of a SoilForEUROPE logo based on the same European map frame used for the FunDivEUROPE logo. The majority liked Lauren's proposal with some discussion whether a dung beetle is an appropriate representative for macrofauna. Lauren owns the photo that was used for the beetle drawing, which is an advantage. Perhaps a millipede or isopod would be better, but dung beetles have been collected with pitfall traps as well.

Question: May we use the same frame as was used for the FunDivEUROPE logo?

Decisions:

1. Lauren offers to take care of the website (she will contact people at CEFE for hosting at CEFE). It will be important to link it clearly with the FunDiv website (Michael and Lauren will discuss about that).
2. Michael will contact the Romanian team who drew the FunDiv logo to ask about using the same frame for the SoilFor logo.

12. WP2: Assessing soil biodiversity

Task 1 – Soil microorganisms (talk by Luis)

Data acquired for the top 10 cm layer so far. The sampling included three different depth (0-10 / 10-20 and 20-30cm), and it remains to be decided what to do with the deeper layers. Microbial community structure determined with NGS. Data are so far analysed at the order level: with regard to the relative abundance of the different fungal orders, there are clear differences among countries and very interesting, there is a higher fungal diversity (but not bacterial diversity) in mixtures compared to single-species stands.

Next steps: analysis with a higher taxonomic resolution (genus level) and focus on some particular functional groups.

Discussion

- Organic layer has been excluded from the microbial sampling whereas it might be very rich in microorganisms. This could lead to a bias in microbial diversity, but the sampling protocol has been decided based on the amount of work and comparability among sites. However, dried and ground material from the organic layer is available at CEFE (Lauren).
- Impossible to separate the latitudinal gradient from the site effect but more climatic data will be used as covariables.
- Can mycorrhizae be distinguished in the data? If data will be analysed at the genus level it might be possible to have a better idea about mycorrhizal community structure.
- The relative proportion of bacteria to fungal biomass would be an interesting and important information (see functional group approach by Ludovic), but due to the different primers used for bacterial and fungal sequencing, this cannot really be calculated from the molecular data. Additional PLFA analyses are considered important (see below).

Task 2 – Soil macrofauna (talk by Pierre)

All detritivorous species (millipedes and isopods) have been identified. The identification of other groups is ongoing (ground beetles, spiders,..). There might be help for centipedes and ants, but this would require some budget. Staphylinidae are highly abundant in certain sites, but identification is difficult; could be done with the help of specialists. A millipede species new to science has been discovered in Italy!

Next steps: complete the identification and use functional trait from BETSI database to characterize functional diversity.

Discussion

- Earthworm data must be interpreted cautiously as the sampling was not adapted for that group. Earthworm data from FunDiv are available but it was not the best sampling conditions because of very dry years.
- It would be interesting to use an indicator species approach such as IMDVAL (Dufrêne and Legendre 1997, Ecological Monograph: Species assemblages and indicator species : the need for a flexible asymmetrical approach).
- Use tree functional groups based on litter quality in addition of using coniferous species proportion.
- Would it possible to use a neighbourhood approach? The sampling design already account for a neighbourhood approach as sampling has been done at equal distance of three different individual trees (either from the same species or from three different species). Data of tree diameter and distance from sampling location will be very important (data with Janna).
- It will be very relevant to communicate the discovering of a new millipede species.
- Some discussion about statistical models emerged. We clearly need to avoid the use of different statistical models among the different groups.

We should use a coherent and common statistical approach within the consortium. A statistical workshop should be organized as soon as possible, preferably before the end of the summer.

→ invite former FundivEurope postdocs (Eric, Sophia, Fons, Lander?)

→ the best time for PhD students would be next summer (July)

Decisions:

1. Organization of statistical workshop. Michael proposes to contact former FunDiv postdocs to kick start the organization of the workshop. Where? For example in Frankfurt (Senckenberg Museum) where Fons and Eric are working.

Task 2 – Mesofauna and nematodes (talks by Ludovic and Paul)

Nematodes: Nematodes from all samples have been extracted.

Identification at the species level probably not very relevant and too time consuming but the feeding groups will be identified. A functional approach based on feeding groups, body size, life history traits will be used. The colonizer vs. persister (C-P value) might be interesting.

Mesofauna/collembola: All extracted but only sites from Finland are completely identified. Functional group approach (hemiedaphic/euedaphic/epiedaphic) does not allow to clearly separating functionally different species. Functional trait approach will be used based on different databases.

Next steps: Both, data on nematodes and mesofauna functional diversity should be available in fall 2018 the latest.

Discussion

- The question about how and when to sample in the experimental platforms FORBIO and ORPHEE was raised (see discussion below).
- The issue of level of replication (5 subplots that allow to couple across different data sets at a relevant local scale but are strictly speaking pseudo-replications in the assessment of differences between

monospecific and mixture plots vs. bulked samples, i.e. one true replicate per plot) was brought up. Nematode counting (all individuals from a sample) and feeding group determination (from a smaller subsample) is extremely time consuming and not possible to do at the subplot level (5 x 64 plots)! Anyway, for some data sets only bulked data will be available (molecular determination of microbial diversity and macrofauna).

- As regard with functional trait based approach: the use of different databases may result in some bias (Pierre knows an *in prep* paper emphasizing that bias).

Decisions:

1. Determining nematode and mesofauna diversity from plot-level bulked samples. For nematodes: do bulking from a subsample and keep the remaining material for each sup-plot separately in case one wants to come back to this later.

Task 3 – Fine root traits (talk by Janna)

The initial protocol was to sieve roots out of three individual cores taken per sub-plot (i.e. tree triplet) directly in the field and to use the soil for all other analyses. This would have been the best solution for direct comparison among the different data, but comparisons of total fine root length from these samples and that of an intact core (taken in all subplots as a security) from which roots were sorted with the traditional method (water soaking), showed large differences and no clear correlation between the two methods. Architectural traits would not be reliable anymore based on the field-sorted material. Only roots from intact cores and washed in the lab will be considered.

All root morphological traits based on the functional classification (absorptive vs. transport fine roots) have been measured at the subplot level.

Next steps: Analysis of nutrient and secondary metabolite content of roots will be done but maybe not enough material to do this at the subplot level (bulking?).

Discussion

- It is easier to identify roots from different species based on morphological traits rather than based on chemical signature (NIRS).
- Mycorrhizal tips were counted so it will be possible to estimate mycorrhizal abundance.
- How to proceed with deeper soil layers (10-20 cm and 20-30 cm)? Probably bulking across the 5 subplots to keep workload reasonable.

13. <u>Microclimate measurements at FunDiv sites (talk by Radim)</u>

There is clearly a lack in information and detail on microclimatic conditions and how they are affected by plant cover. Presentation of a new sensor designed and developed by a Czech start up that measures soil humidity, soil temperature and air temperature continuously. Data show that there are strong differences at very small spatial scales, which are never captured with the traditional approach of using data from meteorological stations at low spatial resolution.

The same company also developed dendrometers that are robust, accurate and relatively cheap.

Discussion

- Radim's team installed microclimate sensors in all FunDiv sites. These data could be interesting to combine with SoilFor data.

14. *New tree growth inventory at FunDiv sites (talk by Kris)*

We agreed during the Kick off meeting in Bordeaux last year that Olivier and his team will re-measure all trees at all FunDiv sites with SoilFor funding provided to the Gent team. Olivier could not participate at the meeting in Montpellier, and Kris presented the data.

All diameter and height measurements have been done with the exception of the Polish site. This will soon be completed. These data will allow to calculate productivity for the period from 2012 to 2016.

Stem cores have also been take for tree ring width measurements. The whole data base will soon be available.

15. *Continuation of WP2: Assessing soil biodiversity – 10/4/18*

Task 4 – Diversity relationships (talk by Ludovic)

Link tree diversity with soil diversity and soil food web complexity by using functional approaches of tree and soil organisms diversity. Compare the relative importance of leaf *vs* root functional traits in the explanation of soil diversity. Use of conceptual frameworks based on site fertility and the predominance of the bacterial vs. fungal channel (evokes again the importance of reliable bacteria to fungi biomass data).

Discussion

- Analysis with linear mixed effect models with site as a random factor. The advantage is that noise related to site effects are absorbed, but some statisticians warn that only four levels are insufficient for this approach. They recommend including at least 15 levels for using the random factor structure. There seems to be no consensus about that aspect, and it would be good to come back to this point during the statistical workshop.
- Besides exploring relationships between plant and soil organisms diversity, there are different options for syntheses across the entire FunDiv and SoilFor data sets. Another focus for example could be on how soil diversity and ecosystem processes are related. Such syntheses would depend on the timing of data availability.

Availability of data for Ludovic's synthesis and wrap-up discussion on soil biodiversity:

Microorganisms

- Consider functional groups: databases linking taxonomy and function especially for fungi.

- It would be important to get the fungal/bacteria ratio: this might be done if enough soil is left. PLFA analysis would be better than qPCR.

Mesofauna

- Collembola, Nematode abundance/functional diversity will be available in fall 2018.
- Mites have been extracted: Oribatidae and Uropodidae are separated but not identified at the species level.

Macrofauna

- 2 approaches TSBF (extraction from a soil/litter block) *vs* pitfall traps: how to merge the two data sets (TSBF accounts for less mobile species and those living within the soil matrix while pitfall traps account for highly mobile species moving on the soil surface). Trophic group abundance is already available while finer taxonomic resolution takes more time or won't be achieved for all groups. Abundance and trophic group data are already available for all sites.

Fine roots

- Most of the data will be available in May 2018. This includes relative root biomass of each species at the subplot level and root traits (at plot level?) for the top soil (0-10 cm).
- While root traits and calculated CWM traits reflect well the sampling position within the triangle of three individual trees, it is questionable whether this can be up-scaled to the plot level (different relative abundances of the trees). With the basal are of each tree species at the plot level and that at the triplet level, estimates should be ok.

Soil characteristics

- Soil texture from FunDiv samples were analysed at KU Leuven. This will be important data for SoilFor.
- Soil chemistry data are incomplete from FunDiv and differ in spatial scale and sampling scheme (total C and N content, pH, and humus form at the plot level are available). However, we did not initially plan to do these analyses. Should we do some more analyses? For further analysis, leftover of soil samples pooled at the plot level (64 samples) might be analysed (ideally 100g/sample). Kris could take care of those.
- Litter data: leaf litter fall (quantity and quality) available from FunDiv. In SoilFor we additionally sampled the litter plus organic layer of each subplot. C and N analyses will be done at CEFE (Lauren). Other data needed from this? Perhaps just from pooled samples (64 plots)?

Understorey vegetation

- Available from FunDiv data, but not at the same loction like the subplot tree triangles.

Decisions:

1. PLFA analyses need to be done at the plot level (64 samples). Lauren and Luis will check what frozen samples could be used for this (either "enzyme samples" at CEFE or the samples left for molecular analyses at UFZ). Where to analyse (prizes differ strongly among labs)? ffers to take care of the website (she will contact people at CEFE for hosting at CEFE). It will be important to link it clearly with the FunDiv website (Michael and Lauren will discuss about that).

2. Additional soil chemistry analyses are needed. Lauren will check how much soil material is left after all experiments and measurements are finished (probably only possible towards the end of 2018). Perhaps the soils from the pilot microcosm experiment could be used?

16. *FunDiv soil data initiative (talk by Juan)*

Presentation of the current initiative to synthesize soil data from the former FunDiv project. There are currently two papers planned, one evaluating non-additive effects on soil processes and characteristics, and a second using the SEM approach to evaluate the relative importance of soil parameters for ecosystem functioning.

Discussion

- For the non-additivity approach it will be important to control the variance for comparisons with the same monocultures.
- SEM model :
  - The interpretation of drought effects are delicate because it is based on allocation to roots within the top 10 cm of soil. Resistance to drought will be more likely determined at lower soil depths with deeper growing roots.
  - Might be interesting to run analysis for each country separately, but not enough data to run within country models.
  - Might be interesting to include herbivory measured across all FunDiv sites.
- The FunDiv synthesis effort is sufficiently different from what is planned in SoilFor with more and different data on soil organisms.

17. <u>WP5: Socio-economic analysis (talks by Iris and Liesbet)</u>

Presentation of the DPSIR framework as an interview guide and explanation of the knowledge mapping. The knowledge mapping is targeting two distinct groups: forest managers and forest scientists. So far, this was done in Belgium and Romania with a distinct outcome. The choice mapping is planned also for Belgium and Romania. The knowledge transfer activity will be later in the project. A priori it will include the steps: 1) assessing the current knowledge, 2) asking about the importance of soil biodiversity, 3) informing, 4) assessing the newly acquired knowledge.

Discussion

- A relatively low number of persons are interviewed for the knowledge mapping. It seems to be important to broaden up within the two countries, but also to include Finland and Italy as additional countries. Leena Finer and Filippo Bussotti could be the contact persons for the establishment of the two target groups and for helping with translation.
- The identification of a knowledge gap seems to be difficult. What kind of knowledge is considered as adequate or inadequate ?
- There was quite some discussion about the questionnaire, which some of the meeting participants filled out or tried to fill out. It aims at defining the selection of the characteristics describing different forest management scenarios tacking into account two different objectives, conservation of soil biodiversity and multiple ecosystem functioning. Would two different scoring tables not facilitate the activity, because “biodiversity” and “management” could be scored independently. It is difficult to synthesize across the two with only one table. Two tables would also allow to better identify trade offs (for example one attribute might be very important for ecosystem multifunctionality but not for soil biodiversity). They would also see the deviation between different objectives rather than the average, which is difficult to interpret. Another discussion point referred to the qualification of “important” in the questionnaire. What does it mean exactly? Important in the positive or negative sense, or does this not matter? The considered scale seems also important. Some decisions are taken at the stand

level and others at the landscape level, which might be contrasting. It is difficult to make choice when different scales are confounding.

Decisions:

1. Rethink the questionnaire and maybe include two separate scoring tables and clarify the meaning of “important”.
2. Enlarge the number of interviews and try to extend to Finland and Italy for a broader comparison with the help of the respective site managers.

18. *WP4: Climate change*

Task 3 – TreeDivNet sites (talks by Hervé and Kris)

Hervé and Kris describe the ORPHEE and FORBIO sites briefly and Hervé shows some interesting data on ground beetle abundance and diversity (using pitfall traps) that appears to be positively affected by tree diversity and negatively by drought.

Discussion

The discussion then unfolds on what kind of additional measurements are feasible at the two sites with the restricted time and budget. Initially, we anticipated to redo the same sampling as was done at the FunDiv sites in the second year of the project. In view of the amount of work related to the samples from 2017, this seems not realistic.

- The sampling scheme could be limited to monocultures and three-species mixtures like in FunDiv. The fact that FORBIO includes rather a dilution design focussing on the two target species (beech and oak), however, means that the designs are somewhat different at the two sites.
- Sampling effort and following analyses could be simplified. Anyway, molecular analyses for microbial communities will be too expensive. Could PLFA be done instead? How many samples exactly? For the mesofauna lamina baits could be installed, which give an idea of mesofauna activity (who would do it?). Extraction of mesofauna using the equipment from Amsterdam and a coarse assessment of collembolan and mites (by Ludovic?) might be feasible as well. Since pitfall traps have already been used at ORPHEE, macrofauna assessment could be limited to pitfall traps. A rough determination of broad functional groups (e.g. detritivores vs. predators) could be done in Montpellier. The 2x2 m rain exclusion plots seem too small for pitfall traps, but screens to concentrate trapping could be used. Would the catch be representative for the relatively small surface area of rain exclusion? Roots: fine root biomass estimates might be done by the consortium (group effort). Some root survey has already been initiated at ORPHEE (project DiPTiCC). Perhaps this will suffice (Hervé is checking back with the colleagues doing this work at ORPHEE).
- Timing of sampling in fall 2018 after the summer with rain treatment (exclusion in FORBIO and irrigation in ORPHEE).

Decisions:

1. Aiming for the same sampling protocol as used in the FunDiv sites. Extraction and preparation of samples will be possible and level of identification can be seen later. The local teams at ORPHEE and FORBIO could assist or do these samplings. This needs to be clarified.
2. Sampling in the monocultures and three-species mixtures exclusively. This yields 48 plots (24 control and 24 irrigated) in ORPHEE and 36 plots (18 control and 18 rain exclusion) in FORBIO.

3. Sampling in fall and coordinated by local staff.

Task 2 – Mesocosm experiment (talk by Sandra)

Outline of the experiment with a special focus on the concept how to determine macrofauna functional diversity as an additional treatment together with drought. The setup of the experiment has been very difficult, because of several logistic problems like finding an appropriate soil or the defaunation of the soil. Also, it is the very first experiment using the mesocosms and their installation and quality check still need to be finalized.

Discussion

- Experimental design: in the case it is impossible to find three snail species (in the ideal case snails, earthworms, millipedes and isopods, each with three species, are the four low functional diversity treatments), the highest functional diversity treatment should also include an extreme scenario of high functional richness by including all species. This would allow a better balance compared to the "no fauna" replicate, which could be an alternative to the "snail" treatment. Another possibility could be to split the earthworm treatment in two by considering endogeic and anecic earthworms as two distinct groups.
- The inoculation of the gamma-radiated soil with microorganisms was relatively straightforward (but should be repeated a second time using a coarser mesh to better include nematodes and protists). However, establishing a natural mesofauna community is more difficult. Different approaches are considered.
- The shift to a "Mediterranean" rather than a "temperate" system also meant that plant species had to be replaced compared to the initial plan. The labelled (Sr and ^{15}N) leaf litter material (from *Prunus, Acer* and *Fagus*) produced by Kris' team could still be interesting.
- Use the ^{13}C signature to estimate the turnover of rhizodeposit carbon (choose between short term pulse labelling vs long term labelling).
- During the visit of the Ecotron and the lysimeters for the SoilFor mesocosm experiment, ants have been discussed as a potential invader problem.

19. <u>Continuation of WP4: Climate Change – 11/4/18</u>

Task 1 – Microbial resistance/resilience (talk by Lauren)

Presentation of the experiment, its design and choices (intensity of drought and differences among countries). The exposure in the Ecotron just ended the week before and with the tremendous sampling effort, the data are not yet analysed.

Discussion

- Resilience *vs* recovery: There is quite some confusion in the current literature, but it seems what is measured here is rather recovery and not resilience (Michael knows of a recent review paper on the terminology of disturbance processes, reference?). It would be important to standardize definitions within the consortium based on recent agreements.
- It will be difficult to relate these measurements under highly controlled conditions to the situation in the field.
- The problem of soil storage: Because it was not possible to work with fresh soils (sampling covered the long period between April and June), they had to be air-dried. This means that all soils experienced a storage related drought of 7 months from sampling to the start of the experiment. This may impact the results of drought effects.

20. WP3: Soil processes – 11/4/18

Task 1 – Fine root decomposition (talk by Janna)

This is an experiment to be installed in the FunDiv sites during the coming weeks. It aims addressing the mixture, environmental (excellent that the microclimatic sensors from the Czech group are installed – see above), and litter quality effects on root decomposition. Together with the plot-specific root material (sampled at a common site not being part of the FunDiv sites), there are also common substrates (*Pinus sylvestris* and *Carpinus betulus* roots, and wood sticks). Single species root bags are also exposed in the mixtures for the assessment of interaction effects. Five replicates per plot (same locations like during sampling) yield a total of 1330 litter bags! The functional classification (see above) was chosen to take absorptive roots only for the decomposition experiment and a mesh size of 100 μm was chosen.

Discussion

- Home field advantage issue: The species used for standard root material are present in some countries/sites. There are still the wood sticks!
- Duration of decomposition experiment: Should harvest dates account for anticipated differences in decomposition rates? The problem with less than 12 months exposure is that not all the different seasons (climatic conditions and variation) will be covered. It is better to standardize and harvest after one year. Roots are anyway not decomposed so rapidly and there should be sufficient amounts of material left.
- If there is too much soil contamination within root litterbags, it might be controlled by measuring the ash content instead of washing the samples (which might be too time consuming and risks to alter microbial composition). Another possibility would be to analyse C and N and to express decomposition as C and N loss (see Handa et al. 2014).
- It might be interesting to save subsamples for further analysis (e.g. microbial or microfauna community composition). Storage?

Decisions:

1. A 12-month exposure duration everywhere.

Task 2 – Microbial activity (talk by Nathalie)

Overview of all the analyses that have been made on the air-dried soils from all sites. These analyses were made at the subplot level (5 x 64). There were country-specific effects on all measured parameters and there were also a few mixture effects. Counter-intuitively, there appeared to be lower catabolic diversity in mixtures compared to mono-specific stands.

Discussion

- Another way to compare monocultures vs mixtures: use the transgressive overyielding approach by comparing the best monoculture to mixtures. This approach is important for foresters because they do not want “inferior” mixtures compared to their best monocultures.
- Enzymatic analysis? The samples were taken and are frozen. However, it is a large amount of work, which needs to be justified by a clear and interesting hypothesis. Depending on the amount of material left, choices have to be made. PLFA seems to be more important than enzymatic activity for the moment.

21. General Discussion

- **Next Meeting?** It would be good to have an additional two general meetings before the end of the project. The next one should then be in spring 2019 and it seems that two first weeks of April (1 to 15, Easter Monday will be the 22 April) are the most suitable. Amsterdam might be a central location (Matty?). The final project meeting would then be during the first three months of 2020.

- Any need for further sampling at the FunDiv sites? It doesn't seem necessary.

- Organization for OPRHEE and FORBIO sampling: it is difficult to organize it now because it will depend how and when from the local people could assist. Anyway, the sampling should be done after the drought period at the end of summer/beginning of fall (September?).

FORBIO: choose beech and oak monocultures and the 3-species mixture including oak and beech.

It would be great to be able to use the same corers used for mesofauna field sampling in FunDiv sites (Matty's – could they be sent to Kris and Hervé, respectively during September 2019?).

Pitfall traps are not perfectly adapted for the relatively small surface at the FORBIO site: fence around plots might set up and then do an exhaustive sampling. Still not ideal for carabids and araneida but it might be worth trying. However, this will be a lot of work.

Root-related work will not be possible for the Freiburg group (too much work). However, there is a root initiative going on in ORPHEE in the DiPTiCC project. Hervé will make the link between the root group working at ORPHEE and Freiburg.

Dried soil samples (before the plantation) are available for ORPHEE.

- **Data sharing**

The key interest of the SoilFor project is to interlink the different data and to foster common publications across teams. How to handle the database? For FunDiv there is a central database (in Christian Wirth's lab in Leipzig) handled by a database manager (Sophia Ratcliff). The procedure was to go through the database manager to be able to use data from others. The advantage is that there is only one data set of a given parameter with some quality check, which we would need for SoilFor as well. Ludovic agrees to take over the responsibility to manage the database, Michael will check with Sophia/Christian whether this is possible based on the existing FunDiv protocol and server or whether it is better to do it separately and elsewhere for SoilFor.
Michael will ask FunDiv PIs whether it is ok for the SoilFor consortium to use FunDiv data without compulsory co-authoring of former FunDiv people, the data will be public anyway.

- **Publication policy / Paper writing**

Michael exposes how this was dealt with during FunDiv. Including data from others in a paper meant 1) accepting the priority of group-specific publications without necessarily the need to wait until group-specific papers are published when the presentation of data and the main story are different between the two. 2) Co-authorship of data owners.
To facilitate involvement and discussion at a very early stage, lead authors were asked to send a paper proposal (a one page "ideas-page" not an entire draft!) to the whole consortium before writing actually starts. This has the advantage that everybody is informed at a very early stage of the paper project and allows involvement from the beginning.
Site managers were always invited to participate in FunDiv papers but this practice may not apply systematically any longer for SoilFor papers. Stephan will take contact with site managers to discuss this issue.
Final drafts of papers should be shared with everybody from the consortium. This helps to keep everybody informed about the latest insights and avoids subtle contradictions among papers.
Towards the end of SoilFor, there will likely be more opportunities to write "multifunctional papers" including FunDiv data.

Decisions:

1. Ludovic will take the responsibility to collect and manage the different data in a common SoilForEUROPE data base. It remains to be discussed whether it is possible/beneficial to connect to the FunDiv data base.
2. We adopt the publication policy from FunDiv, with the modification regarding the involvement of site managers.
3. As a consortium effort, we should be happy with multi-author papers. PhD students and postdocs should be supported as first authors.
4. To facilitate planning of papers and exchange on interesting papers, the PhD students and postdocs should develop their ideas for papers (thesis chapters) in the coming months. These ideas should be shared among all members of the consortium towards fall 2018 / end of year 2018 the latest. This will also help in taking decision what additional parameters should be measured and to plan for general papers and how data are combined most efficiently. It would be great to organize writing workshops in a later stage. We could also use some tools such as basecamp (a kind of forum) to work together on general papers.
5. Publications of consortium papers using multiple data sets should not be delayed because a more specific study has not been published as long as there is not critical overlap in how the data are analysed and presented and in the conclusions.
6. Any paper draft will be sent to everybody before submission to make sure there are no conflicting conclusions among the different papers.
7. The FunDiv papers referred to the same design paper, which should also serve as a reference for SoilFor papers:

   Baeten, L. et al (2013) *A novel comparative research platform designed to determine the functional significance of tree species diversity in European forests*. Perspectives in Plant Ecology, Evolution 15, 281-291. doi: 10.1016/j.ppees.2013.07.002.

APPENDIX D: AGENDA AND MEETING MINUTES SOILFOREUROPE ANNUAL MEETING 15-17 APRIL 2019, AMSTERDAM.

SoilForEUROPE annual meeting 15-17 April 2019
VU Amsterdam

MEETING AGENDA

Monday, April 15th

Arrival during late afternoon in Amsterdam

19h00 Dinner in town (could also be later depending on arrival times)

Tuesday, April 16th

09h00	Welcome address	M. Berg
09h05	General remarks	S. Hättenschwiler
	Microorganisms / Fine roots – FunDivEU sites	
09h20	Microbial diversity	L. Prada Salcedo
09h40	Microbial activity	L. Gillespie
09h50	Fine root traits, mycorrhizae	J. Wambsganss
10h10	Fine root decomposition	J. Wambsganss
10h20	Discussion (e.g. links, missing data, difficulties, next steps, data analysis, publication strategies, …)	
11h00	BREAK	
	Nematodes / Mesofauna – FunDivEU sites	
11h20	Nematodes and Mesofauna	L. Henneron
11h40	Discussion (e.g. current status, next steps, data analysis, publication strategies,…)	

Macrofauna – FunDivEU sites

12h00 Macroarthropods, earthworms, others P. Ganault

12h20 Discussion (e.g. remaining groups to identify,
data analysis, publication strategies,…)

12h30 LUNCH

13h30 **Macrofauna** – FunDivEU sites: continuation of the discussion

Diversity relationships – FunDivEU sites

13h50 Data syntheses L. Henneron

14h10 FunDivEU soil data synthesis initiative B. Muys

14h30 Discussion (e.g. putting data together – how,
which?, FunDivEU data?, publication strategies,…)

15h00 **Wrap-up and general discussion soil biodiversity FunDivEU sites**

Need of additional data, remaining identification work, functional diversity approach, publication units, timeline of publications,…

16h30 BREAK

Work at ORPHEE and FORBIO

16h50 ORPHEE/FORBIO: sampling, available data,… L. Henneron

17h10 Discussion (more data needed?, next steps, publication strategies,…)

Resistance / resilience to drought

17h30 Microcosm experiment: soil microbial responses L. Gillespie

17h50 Discussion (remaining work, publication strategies,
including diversity data from F. Buscot group?,…)

19h30 DINNER

Wednesday, April 17th

	<u>Resistance / resilience to drought</u>	
09h00	Ecotron mesocosm experiment: ecosystem responses	A. Milcu
09h20	Discussion (difficulties, current status, planned measurements, larger collaboration within the consortium,…)	
	<u>Socio-economic analysis</u>	
09h50	Cognitive mapping of soil biodiversity	I. Vanermen
10h15	Public's preferences for forest management	I. Vanermen
10h40	Group discussion on knowledge transfer	I. Vanermen
11h00	BREAK	
11h20	Socio-economic analysis: general discussion (remaining work, next steps, publication strategies,…)	
11h40	**<u>General Discussion</u>**	
	Planning of the final year, needs of the PhD students, publication policy, knowledge transfer activity, meetings, future of SoilForEU,…	
13h00	LUNCH and End of meeting	

SoilForEUROPE annual meeting 15-17 April 2019
VU Amsterdam

MEETING MINUTES (by Paul Kardol & Stephan Hättenschwiler)

Participants:

Matty Berg, François Buscot, Sylvain Coq, Pallieter De Smedt, Pierre Ganault, Lauren Gillespie, Kezia Goldmann, Stephan Hättenschwiler, Ludovic Henneron, Hervé Jactel, Séverin Jouveau, Paul Kardol, Alexandru Milcu, Bart Muys, Luis Daniel Prada Salcedo, Michael Scherer-Lorenzen, Iris Vanermen, Janna Wambsganss.

Partial participation via skype:

Johanne Nahmani, Nathalie Fromin (didn't work well…)

Excused:

Sandra Barantal, Jürgen Bauhus, Kris Verheyen, Liesbet Vranken, David Wardle

1. Overview, general issues (Stephan)

Project website: Thanks to Lauren for putting up the website. It is still a bit empty though. Materials (photos, publications, news,…) should regularly be sent to Lauren who will keep the website updated.

Reminder for Acknowledgements: Use the 'official' sentence for the acknowledgements in all SoilForEUROPE publications: « **This research was funded through the 2015-2016 BiodivERsA COFUND call for research proposals, with the national funders Agence Nationale de la Recherche (ANR, France), Belgian Science Policy Office (BELSPO, Belgium), Deutsche Forschungsgemeinschaft (DFG, Germany), Research Foundation Flanders (FWO, Belgium), and The Swedish Research Council (FORMAS, Sweden)**. » In addition, in any power point presentation or poster, use the BiodivERsA logo, as well as the funders' logo. As pan-European project, we have to acknowledge all the funders of our research project and not only the funder of the team who is leading the publication!

Funding period until end of December 2019 with maximal possible extension of 3 months (March 2020).

A final report is due in December 2019.

Final conference: There will be a BiodivERsA final conference and workshop in Brussels, Nov 12-14. All projects should be represented with a presentation. The participation at the workshop is optional. It is about the future orientation and activity of BiodivERsA. Stephan is ok to attend, but it could also be someone else representing the consortium or multiple participation is also possible.

2. Microorganisms , fine roots

Luis: Microbial diversity

Work on fungi is well advanced with interesting data (39% of fungal genera are shared among countries, particularly strong mixture effect in Romania). Most of the lab work has been completed and data analysis makes good progress. Bacteria are also of interest, but data not yet analysed, perhaps something for a student project? Tree diversity was treated at the order level (mostly Pinales and Fagales with one species in the Sapindales). Enzyme activity seems higher with richer tree communities, and there are some preliminary PLFA data.

Discussion

- Important discussion on the different approaches of how to represent tree diversity. Plant orders with only three orders seems limited and not well distributed among the four sites. Effects of mycorrhizal types?

Litter quality (trait diversity)? More refined phylogenetic diversity (seems limited with only 13 species in total)? Selection vs. complementarity effects: can we test for this?

- Tree species identity effects could be evaluated; mixture effects remains clearly the key aspect of the study and the experimental design (i.e. 1 vs. 3 species).

Next steps: It will be important to define a common approach how to test for tree mixture effects. We should avoid that one team uses plant orders, another team evergreen vs. deciduous, or anything else.

Lauren: Microbial activity

Some preliminary data on SIR, MicroResp, catabolic activity, denitrification, but not yet any thorough statistical analyses. So far, there are no strong patterns emerging. The evergreen-deciduous species dichotomy provides little further insight, and experimental design is not really chosen to test this properly. The idea is to use SEM to explain the data by including also soil data and fine root data (see with Freiburg team).

Discussion

- Logistical constraints required soils to be air-dried upon sampling. They stayed dry for up to 5 months with unknown consequences for microbial communities.

Next steps: Finalize statistical analyses, which requires first a decision how to model tree diversity (see below).

Janna: Fine root traits / decomposition

Paper proposal 1 on spatial distribution of fine root biomass

First data show that total fine root biomass is higher in mixtures in Finland, but lower in Poland compared to monocultures. Distinction between absorptive and transport roots was critical! Absorptive roots show higher biomass in monocultures than in mixtures (Poland, Romania, Italy) and distribution is more homogeneous in monocultures. Overall weak neighbourhood effects (DBH + distance).

Paper proposal 2 on fine root traits

A lot of traits have been measured (including different nutrients). SRL often higher in mixtures than monoculture and mycorrhizal colonization is also higher in mixtures. Very interesting data in combination with the biomass of absorptive roots!

Root decomposition (use of 100 µm mesh):

Still ongoing with two more field campaigns (Finland and Romania), but litterbags in Italy (417 out of 420) and Poland (347 out of 355) were retrieved.

Discussion

- For the interpretation of root data it would be great to have some nutrient availability and soil water data. Perhaps understory vegetation as a surrogate for fertility? Radim's data for soil humidity?

Next steps: Complete root decomposition data collection and also the need for a finalized statistical protocol.

General Discussion on microbes and roots

- What about authorship related to previously collected data during FunDiv? Michael did check this with FunDiv consortium a year ago and common agreement was that no official request is needed anymore. However, depending on the weight of the FunDiv data in a specific paper, it would be nice to ask whether initial data owner would like to contribute. In any case, former data owners need at least to be acknowledged in any paper using the data.
- Further discussion on how to use tree species mixtures other than for the number of species. The distinction between evergreen and deciduous species not necessarily appropriate (unbalanced design) and the phylogenetic approach (or separating by plant orders) suffers from very low numbers of species and orders. The trait dissimilarity approach seems to be a must do, but we need to agree on what traits to consider and how to use them in a statistical model: scores from PCA? An interesting concept paper could be about the question of how "close" a trait needs to be to the process studied. A good approach here seems to focus on 1) litter traits and 2) root traits as those influence soil organisms more directly.

Next steps: It will be very important to further discuss the common statistical model, especially the aspect of tree diversity (what else beyond species numbers?) and the co-variables to be included (soil, climate,…).

Decision: Further discussion of the issue and agreement on a common statistical model required (see latest discussions with a note from the Montpellier group (email by Pierre 18th May 2019).

Ludovic: nematodes and mesofauna

A food web approach is chosen for interpreting the nematode data. So far about 60'000 individuals are counted (with 10'000 identified). Grouping into feeding guilds and c-p (r-K) strategies.

No mixture effects on total nematode abundance, with the exception of a rather negative effect (in mixtures compared to monocultures) in Italy. Country effects are clear. There is an apparent composition effect though, which is not significant. Points to the direction that individual tree species may have an effect.

Preliminary data on collembola do not show any clear patterns, but only Finland and Poland have been identified so far (Italy and Romania remain to be done). There are 39 species in Finland – relatively rich but abundances are comparatively low. A trait based approach will be chosen to characterize communities (380 species in trait data base).

Discussion

- Should country-specific climate data be used in the analyses? The same approach like in the Ratcliff et al. 2017 paper or in the Joly et al. 2017 paper could be used (both FunDiv papers). Perhaps the random variable of "country" already accounts for climate differences sufficiently well? In any case we should use the same co-variables in the different papers and avoid constructing different climatic indices for the different papers.

Next steps: Again, a clarification of the statistical approach is needed, especially in how to deal with climate.

Pierre: macrofauna

Paper proposal 1: macrofauna community composition

Based on hand-sorted soil block samples (3 per plot) and pitfall traps (4 per plot). A general linear model approach with a series of explanatory variables collected during FunDiv and SoilFor (including Lauren's ground litter layer data).

PCA approach for soil variables looks very nice and promising. PCA for litter layer data show a bit surprising results – perhaps because humus types are very different?

No clear patterns for total abundance data in mono vs. mixtures. Biomass seems to be lowest in plots with a lot of evergreen species.

Diversity profiles (Hill's number) looks very interesting and may show a slightly higher diversity in mixed plots.

Paper proposal 2: body size

Focussing on responses to resource quality and habitat complexity/heterogeneity. Using the BETSI trait data base.

Discussion

- Should we use the % evergreen abundance as explanatory variable? This is not how the experiment was designed. Above all compare mono vs. mixture and then perhaps use a functional diversity approach in addition (see discussion elsewhere).

Next steps: Complement identification of fauna (still a lot of work) and figure out the common statistical model to be used.

Ludovic: diversity relationships/data synthesis

Conceptual framework based on leaf economics spectrum with unproductive vs. productive type of ecosystem. Plant traits that determine resource quality and soil food web structure. Tree mixing effects can be framed by mass ratio vs. functional diversity hypotheses. Potential analyses include 1) effects of tree identity on soil biodiversity, 2) effects of tree functional diversity on soil biodiversity, and 3) effects of soil functional biodiversity on its responses to tree functional diversity.

Discussion

- What kind of traits to be included in the assessments? Relative importance of leaf vs. root traits?
- Should tree identity (based only on monocultures) and tree diversity effects be presented in two different papers or one bigger paper?
- The "nested" meta-model: What variables to be included? Maybe even include the landscape level? Probably matters less for soil biota.
- What kind of SEM to be used? Including latent variables? Partial Least Square (PLS) analyses? They would not be influenced by co-linearity.
- Potential overlap with soil organism group-specific projects of papers? How to deal with unpublished data? Not an easy question and potential overlap among different groups of organisms need to be discussed. In general, priority for the specific PhD papers before synthesis work, but they should proceed definitely at the same time in parallel.

Next steps: Complementing the acquisition of the different data sets and testing different SEM options.

Bart: FunDivEU soil data synthesis

Exposure of the different paper projects based on previous FunDivEU data:

Paper 1: Tree litter effects on earthworm-soil interactions in European forests (De Wandeler et al. in prep). Includes leaf litter trait ordination and humus characteristics ordination. SEM approach taking into account in particular the pH tresholds at <5 because of nonlinear pH-earthworm relationships. Towards a positive feedback loop driven by earthworms. Alternative stable states in soils?!

Paper 2: Disentangling pathways of biodiversity effects on ecosystem functioning (Van Meerbeek et al., in prep.). SEM on soil processes and their impacts on 1) forest productivity, and 2) temporal stability of tree growth. New is the use of Ellenberg values as indices for soil moisture, fertility, etc.!

Paper 3: Non-additive effects of tree species mixtures on soil related ecosystem functions (Zuo et al., in prep.). A traditional and straightforward analysis based on mixture effects with a large overview on all soil related functions. Juan is back in China on a permanent position and paper writing got some delay.

Discussion

- Very nice work on humus traits! Should they be used/included as well in SoilForEU? In what way? Instead of Lauren's litter layer characteristics or in addition?
- The Ellenberg "Zeiger-values" are a very interesting approach to complement the data set with missing data (especially an integrated view on soil humidity is difficult to get otherwise). May be interesting to include in SoilForEU data analyses as well!

Wrap-up discussion on FunDivEU sites:

- <u>Missing data / additional data to be considered:</u>

Climate variables may be a weak part and could/should be complemented. Especially soil humidity is a critical aspect for some of the response variables. Possibilities include:

Radim's microclimate data (sensors installed at about the same time as SoilForEU sampling took place. It includes continuous measurements of soil humidity (TDR) and temperature (10 cm depth?) as well as ground layer temperature (15 cm above the soils surface). Who gets in contact with him (Michael, Janna, Stephan?)

Bart: NDVI data available for all plots. Surface temperatures from Landsat maybe another possibility. Scale? 70 x 70 m resolution may not be adequate for our plot size?

The Ellenberg humidity and temperature indicators (as discussed above) could be a nice and quite accurate alternative for the characterization of microclimate integrated over time!

Humus type separation to be included? It is possible to combine the different discrete characteristics into a continuous variable (Bart).

pH might be particularly important for some groups of organisms (earthworms, fungi vs. bacteria).

- <u>Remaining identification work and measurements:</u>

Ludovic, Matty, and Paul have a plan for mesofauna and nematodes!

Macrofauna: Still requires contacting some specialists for certain groups.

Microorganisms: Only fungi or will prokaryotes also be included? Probably a student thesis on prokaryotes to include them as well.

Root traits: Tannin analyses would be nice, but probably there is not enough material left. Janna will check and if there is enough analyses could be done in Montpellier.

Root decomposition: Two sites to be sampled (Romania and Finland).

- **Database:**

Ludovic continues to centralize the data. The plan is that the SoilForEU data will be integrated into the FunDivEU database at some point. Ludovic will try to get into contact with Sophia. NOTE: Make sure that all data are properly coded, so that the origin of the data (SoilFor or FunDiv) is absolutely clear! Also make sure that data for all countries are organized in one Excel sheet. There will be a few issues with plots that were allocated to different species combinations in SoilFor compared to FunDiv (due to decreasing/increasing abundances of some species that changed the species combinations).

- **Common statistical model:**

Ludovic et al. continue the discussion on the functional trait approaches to determine stratification of different groups of traits and which traits to be included. More generally, it will be important to agree on a common statistical model to avoid that each group comes up with a different solution. Discussions are important to be continued right after the meeting! (see latest discussions with a note from the Montpellier group (email by Pierre 18th May 2019).

- **Publication policy:**

There seems to be no conflicts and communication is transparent. We just need to be careful with the different multivariate approaches that are planned to avoid redundancy and to respect priority of the papers focusing on one group of soil organisms but which data are also used for the general bigger picture.

Ludovic: Work at ORPHEE and FORBIO

Current status of analyses: Ludovic works currently on the nematode samples and preliminary data show some tree diversity effects on nematode abundance. The mesofauna samples still need to be done (planned for end of summer). Root biomass samples are almost done and PLFA analyses will be done at SLU, but it is unclear when exactly the data will be available (before summer?).

Additional data are available, especially for ORPHE (a lot of ground beetle data).

Discussion

- In ORPHEE (and maybe also in FORBIO) some of the effects may be driven or at least co-determined by the understory vegetation that varies a lot among tree diversity treatments.
- Ground beetle data to be included in the same paper or separate story?
- Should the data from the two sites be published together or not? The problem is the very different experimental design (fully factorial in ORPHEE and dilution gradient for oak and beech in FORBIO) and the different “drought” treatment (rain exclusion in FORBIO and watering during summer in ORPHEE). There is also a pseudoreplication issue. It will depend on what the results look like, but

for now the consensus is that it will be best to keep the two experiments separately for their publication.

Lauren: resistance/resilience to drought in microcosms

Paper 2: Effects of drying/rewetting cycles on soil microbial activity (CO_2 and N_2O fluxes).

Strong effects of drying-rewetting but no tree mixture effects. However, there seem to be some interesting interactions, especially for the cumulative measurements.

Paper 3: Effects of drying/rewetting cycles on functional diversity (the idea is to combine with Luis' molecular data).

Not too many effects so far.

Discussion

- The biggest issue is that for transport, storage and experimental preparation the soils collected in the field had to be stored air-dried. The soils stayed dry for 3 to 5 months before the start of the experiment. This could have strongly affected microbial communities (the molecular data indeed show that the communities were quite different compared to those collected in the field and immediately analysed.
- The final statistical analysis depends on the determination of the common statistical protocol, because site-specific characteristics and the coding of tree diversity should be the same as for the field data (see above).

Alex: resistance/resilience to drought in mesocosms

The experiment is based on 16 lysimeter units with 2 levels of functional diversity of soil macrofauna (including isopods, millipedes, and earthworms) crossed with 2 levels of precipitation (control vs drought).

The setup of the experiment has been very difficult due to a number of technical (construction of the lysimeters and fully operational mesocosms) and methodological (appropriate soil and its sterilization) issues. This caused a delay of a year.

Measurements include: continuous measurements of CO_2 and H_2O fluxes at the ecosystem scale, responses of soil communities and plants (a total of four tree species).

Due to the delay with the experiment, a second different experiment on transgenerational effects in drought adaptation in Quercus ilex was combined with the SoilForEU experiment. Practically this just means that Q. ilex seedlings that were planned anyway are now from a known seed source and that some of the seedlings will be harvested during the experiment.

Discussion

- Full fauna inventory before the start of the drought treatment? Yes, if technically possible. It would be good to have an idea about the presence/abundance of the added soil fauna.
- What should be measured and when? Still under discussion are plant measurements and how to track recovery after drought exposure.
- How long is it possible to run the experiment? A full growing season will be included for sure (end of 2019). After this the SoilForEU project will end, but the setup of the whole experiment was a massive amount of work and it would be a pity not to add at least a second year for which the

effects are expected to be more marked. Processes like tree growth and decomposition also are slow to respond.

- Funding of personnel is very limited. It would be good to find a possibility to hire another postdoc for 2020. Possibilities might include a NOW-Rubicon proposal led by Matty.

Next steps: Planning the pre-treatment fauna inventory. Discussing and decision on how to implement the drought treatment (not trivial…). Matty will look into the possibility of a NOW-Rubicon grant for postdoc funding.

Iris: socio-economic analysis – cognitive mapping

The aim is to assess and compare stakeholders' understanding of 1) the relationship between soil biodiversity and ecosystem services, and 2) the impact of forest management on soil biodiversity using fuzzy cognitive mapping as approach. The data are based on semi-structured interviews.

The comparison between forest managers from Belgium and Romania (both from the public and private forest management) showed differences in the understanding of the importance of soil biodiversity.

The comparison between scientists and forest managers also showed differences in the level of detail of understanding, but in general forest managers are aware of soil biodiversity and generally acknowledge its importance. It is, however, a rather diffuse knowledge.

Discussion

- Very interesting approach, but sample sizes appear relatively small. Iris explains that the interviews and their analyses is time consuming and that the sample size is representative of other work in this field using the same or similar approaches.

Next steps: Finalize the analyses, but overall the work is quite advanced.

Iris: socio-economic analysis – preferences for forest management

A discrete choice experiment based on random utility theory is proposed via a specialized company who takes care of contacting people and collecting the answers.

With the use of an information video (made by Iris), the effect of information transfer is tested (choices before and after the detailed information.

Use of choice card with different attributes and different scenarios for the attributes that refer to multiple ecosystem services that can be influenced by forest management and soil biodiversity.

The experiment is done with a panel of 300 citizens per country from ITA, BEL, and FIN.

Next steps: Data analysis is ongoing and more specifically there are some alternative methods to be tested.

Bart: knowledge transfer/outreach

Bart reminds the consortium that we planned and proposed a workshop to extract key messages from the results of the project and to discuss and plan outreach activities. We need to do this during a next meeting (combining with final project meeting? – see discussion below).

For the outreach products we need to make choices, we cannot do a little bit of everything.

Possibilities:

- Stakeholders' workshop as a side event at EFI (European Forest Institute). Bart is in contact with responsible people and they are interested in such a side event. Next possibility at their meeting in Aberdeen 2019 seems too close. Perhaps plan a ThinkForest event for 2021? EFI is particularly interested in our project as France left the multidonor trust fund (MDTF) of EFI, but is an important player in the ERANET BiodivERsA.

- A modified, advanced version of Iris' video, which could be translated in different languages. An animated ppt as an additional possibility? Can we meet the standards of such material that are quite high today with our own capacities or would we need to hire a professional company for it? There are already some nice and illustrative short videos on YouTube made by Gerlinde De Deyn, Ingrid Lubbers and others from WUR (Michael sent the links).

- QR codes: This could work out very well, is known by most people and would not require a huge investment from our side.

- Comics: Pierre was referring to a one page comic drawn and written by his sister about his PhD work. This could be a more personal way of communicating to a somewhat different audience. Popularity of comics is very different among countries (France has a rich tradition).

Discussion

- The planning of a workshop amongst consortium member will be very important.
- QR code: what should it refer to? What kind of information? Just a video or a webpage with more in-depth info. Just a little hint to trigger people's curiosity? Could work well…
- A version of the video for teachers?
- Ludovic mentions GSBI (https://www.globalsoilbiodiversity.org/), which seems to be a good idea to link our project to because they have a large network. Who can make the contact?
- Matty: Some more personal videos about ourselves, who we are and what we do as researchers.

Next steps:

Bart is taking contact with EFI to see whether a ThinkForest event is possible for 2021.

Organization of a workshop as a promised project deliverable is important.

General Discussion

The general discussion was short since we discussed the important scientific issues well during the meeting. It was focusing mainly on when and where to plan the next and final project meeting. We all agreed that the **mandatory workshop** on outreach materials should be combined with the final project meeting rather than planning it as an event on its own.

We discussed that it would be nice to also combine the final meeting with some (optional) social activity, for example a hike, excursion, or winter activity if it is planned during winter somewhere in the mountains.

Possibilities for a **meeting location**: Black Forest near Freiburg (Michael knows a winter sport training center where we could meet). Some ONF (French forestry agency) housing that is typically remote somewhere in a forest (different locations throughout France (Sylvain was mentioning this and could look into this in more detail). Some adventurous option in nature would be great, but we need to make sure that the accessibility in winter is not a problem and that travelling to get there from the different parts of Europe will not take too long.

Dates? March 2020 seems as a good option, which then would point towards some winter activity for the social part. It seems ok from the 8th onwards. The only difficulty is that some of the national funding ends at the end of 2019, which could make funding of the meeting attendance difficult for some colleagues. Also, some of the PhD and postdoc contracts end before that date and we need to make sure that it does not compromise the participation of PhDs/postdocs.

We agreed on a meeting with 3 nights at least, including 1 day to present the principal findings and discuss publications, 1 day of workshop on outreach materials, and 1 day of some social activity.

Next steps:

Find an appropriate meeting location (Michael, Sylvain, Stephan).

Define the exact meeting dates.

THANK YOU MATTY FOR ORGANIZING THE LOGISTICS OF THE MEETING (IT WAS GREAT IN AMSTERDAM!)

THANK YOU ALL FOR THE PRODUCTIVE MEETING AND EXCELLENT COLLABORATION!

APPENDIX E: AGENDA AND MEETING MINUTES SOILFOREUROPE FINAL MEETING 9-12 MARCH 2020, FREIBURG.

SoilForEUROPE annual meeting 9-12 March 2020 Freiburg

biodiversa

MEETING AGENDA

Program for Tuesday, March 10th

09h00 Welcome address M. Scherer-Lorenzen

09h05 Project overview S. Hättenschwiler

Soil biodiversity in tree species mixtures

09h20 Abundance, functional traits and decomposition of tree roots J. Wambsganss et al.

09h40 Functional responses of soil microbial communities L. Gillespie et al.

10h00 Bacterial and fungal diversity L. Prada Salcedo et al.

10h20 BREAK

10h40 Abundance and trophic group composition of nematodes L. Henneron et al.

11h00 Soil macrofauna abundance and diversity P. Ganault et al.

Interactions with climate change

11h20 Soil fauna responses to altered precipitation in planted tree species mixtures L. Henneron et al.

11h40 Resistance and resilience of microbial activity to drought L. Gillespie et al.

12h00 Interactive effects of drought and functional diversity of macrofauna on ecosystem functioning N.N.

12h20 LUNCH

Socio-economic analysis of soil biodiversity

14h00	What do people know about soil biodiversity?	I. Vanermen et al.
14h20	Preferences for forest management	I. Vanermen et al.

General Discussion

14h40	Integrative data syntheses	L. Henneron et al.
15h00	The near future of SoilForEUROPE and the field sites	
15h20	BREAK	
16h00	Departure for Feldberg	

Program for Wednesday March 11

Agenda Workshop: Developing communication materials

09h00	Introduction: - Communication strategy SoilForEUROPE - Plan for today	I. Vanermen / L. Vranken / B. Muys / K. Verheyen
09h20	Extracting key messages of the project - Based on the inputs delivered by the partners in advance, 1 or 2 key messages per WP will be extracted.	- Participants will be divided in 4 groups, 1 per WP. - Each group should contain at least 1 person from the WP and 1 person from another WP
10h30	Presentation of key messages per WP + discussion (5 to 10 min. per WP) - Each group presents the 1 or 2 key messages that they extracted.	- Entire group together
11h00	BREAK	
11h15	Developing content of Introduction and Methods - Based on the input on breakthroughs delivered in advance, the most important elements for introduction are selected. - Another group writes out the crucial steps of the methods that were applied in the	- Participants will be divided in 2 groups, 1 will focus on introduction and the other on methods. - Ideally, one person per WP in each group.

	SoilForEUROPE project, based on the information extracted from the website and protocol.	
12h10	Presentation of Introduction and Methods + discussion (10 min. each)	- Entire group together
12h30	LUNCH	
13h30	Development of communication materials - Leaflet (A4, two-sided) - (Animated) powerpoint slides - Policy brief	- Participants will be divided in 3 groups, one per communication material. - If possible, at least one person of each WP per group
15h30	Presentation of what was created so far and discussion (10 min. each)	- Entire group together
16h00	BREAK	
16h15	Final discussion on communication tools and future planning - Distribution of stickers with QR code? - Joint ThinkForest discussion forum? - …	- Entire group together
16h45	Closing of the day	I. Vanermen / L. Vranken / B. Muys / K. Verheyen

SoilForEUROPE annual meeting 9 – 12 March 2020 Freiburg

MEETING MINUTES (by Stephan Hättenschwiler)

Participants:

Pierre Ganault, Lauren Gillespie, Kezia Goldmann, Stephan Hättenschwiler, Ludovic Henneron, Paul Kardol, Bart Muys, Luis Daniel Prada Salcedo, Michael Scherer-Lorenzen, Iris Vanermen, Kris Verheyen, Liesbet Vranken, Janna Wambsganss.

Excused:

Sandra Barantal, Jürgen Bauhus, Matty Berg, François Buscot, Sylvain Coq, Thibaud Decaëns, Nathalie Fromin, Alex Milcu, Johanne Nahmani, David Wardle.

1. Presentation of results

The major results of all work packages and tasks are presented in a "symposium-style" event at the University of Freiburg (see meeting program) with a live stream for colleagues who could not attend and all other potentially interested people.

The progress in data analyses and evaluation in general, and since last year's meeting in particular, is impressive.

Discussion

- The microclimatic data measured by the Czech group (Radim Matulo, Mendel Univ Brno) at all FunDivEUROPE sites and all plots is available, and will be uploaded (by Michael) to the data portal soon.
- There is still the open question how microclimatic variables may be integrated in the models evaluating mixing effects among sites and plots. The Czech measurements covered the time period after our sampling and are maybe not enough integrative over longer time periods. Bart mentioned the very good experience they made by using indicator values (Ellenberg and maybe others outside of Middle Europe) for understory vegetation. This could be a powerful way of including microclimatic conditions.
- Kris reminded that some soil parameters are also affected by tree (plant) communities and that the SEM run for example by Lauren should probably include an additional connection from tree mixtures to soil parameters (integrated as PCA axes).
- Stephan noted that the interesting approach of redundancy analysis used by Ludovic to assess soil micro food webs places fungi and bacteria differently compared to the respective trophic groups of nematodes, which is a bit surprising. Paul notes that a difficulty might be the combination of different types of data (e.g. biomass vs abundance) and that the units need to be checked.
- The terminology used is still too heterogeneous. We need to be careful that the definitions and terms used are the same across the different papers (to be clarified by Lauren, Pierre, Luis and Ludovic over their Slack channel?).

2. General Discussion

The general discussion was shifted to the evening after getting to the Feldberg.

- Stephan informs about the final report expected by BiodivERsA for the end of May 2020. Stephan will prepare the document by mid-April the latest and send it around to all PIs for specific contributions to the different items. In addition, all PIs should check the guidelines and deadlines for reporting back to their *national* funding agencies.
- Are SEMs the most pertinent way of analysing all data in an integrated way? Most importantly, we need to determine clear hypotheses that are possible to test with SEMs. An alternative is variance partitioning which may provide clearer and more easily understandable data (see example Ratcliff FunDivEU paper – Ecology Letters 2019)
- There is also all the FunDivEU data available for potential inclusion in data syntheses that could be useful for specific hypotheses to test.

- It is challenging to bring together all the different data sets. One way could be PCAs across all groups of organisms, but the question how to deal with different units will be important.
- A potential question for an integrative paper could be how soil diversity across different groups of organisms affect ecosystem processes with an approach that also includes FunDivEU data.
- Paper writing and authorship: Kris reminded that we should not forget to keep the site managers in the loop and informing them systematically about the manuscripts we are working on. This means also to include them in the mailing list when a manuscript is being sent around for comments/contributions. Owners of specific FunDivEU data sets should also be informed when these data constitute a component to the specific paper.
- Michael: all data sets produced during SoilForEU should eventually be uploaded on the FunDivEU data portal (https://fundiv.befdata.biow.uni-leipzig.de/). The responsibility for this upload is with the person/group that produced the data. There is a new person responsible for managing the FunDivEU data base: claas-thido.pfaff@uni-leipzig.de
- Lauren: The SoilForEU webpage should be kept up to date, please don't forget to send the reference of poster presentations, oral presentations and papers to Lauren and later to Stephan (who will take over the management of the web page when Lauren left CEFE).
- Lauren: What soil samples are available from the field sampling in 2017? Frozen, air-dried soil samples?

Decisions:

1. Uploading of SoilForEU data in the FunDivEU database by each data owner/producer. The deadline for doing so is when the paper using the respective database is accepted for publication. Michael is creating several new "projects" within the SoilForEUROPE "phase" in the data portal. These projects correspond to the different Tasks within SoilForEUROPE. **All data sets should have the suffix "SoilForEU_example" and must be linked to these projects.** The PhD students agreed to develop a checklist for data quality and metadata, that should be completed before data upload.

2. Establish a list of remaining soil samples (frozen and air-dried) and where and under what conditions these are stored. **Janna, Lauren, Luis, Ludovic please check if and what kind and what quantity of soil samples remain and provide the info to Stephan.** These samples are eventually available to others, but the consortium should be informed before giving away any samples.

3. Dissemination workshop (11,12/03/2020)

The Belgian team (Iris, Liesbet, Bart, Kris) organized the workshop to discuss and prepare dissemination items (see specific workshop program).

The following products are suggested:

- The existing **SoilForEU webpage** translated into different languages including those spoken in the countries of the consortium members and the field sites.

- The **information video** Iris made and which is already available on the project webpage should also be translated into these languages. Beyond being accessible on the webpage, the video should also be distributed more widely at different fitting occasions.

- **QR code stickers** with a small introductory text in the country-specific language with the QR code linking to the language-specific webpage.

- **Leaflet** with complete, but easily understandable information about the project.

- **Animated slides:** A series of slides that encapsulate all the important information, results and take-home messages in a synthetic way. The idea is to have a slide show at hand to share amongst the members of the consortium allowing presentations on the whole project for different occasions (conferences, teaching, information for an informed public,…). The slides will also include an oral presentation by a spoken voice allowing self-explanation of the slides.

- (**Policy brief** in the BiodivERsA format.)

During two sessions of work in three subgroups we prepared the basic elements for the dissemination products. During the first session, we were focussing on key messages about the three groups of organisms, namely tree roots, microorganisms, and soil invertebrates. In the second session, we dealt with messages for climate change impacts, consequences/recommendations for forest management, and methodological aspects. After each work session, the materials were presented to the whole group and discussed.

In two groups we then worked on the specific content of the two items “leaflet” and “animated slide” during the evening of 11/03 and the morning of 12/03.

Discussion

- **Translation of web page**: The web page will be maintained at CEFE beyond the funding period. For the translation the idea is to work with a plug-in allowing to share all graphical material except text among the different language-specific web pages. Lauren has currently no time to take care of this, but will plan to see into this together with Stephan and the responsible technical person at CEFE after the end of the month. The aim is to have the url-link of the language-specific webpages as soon as possible to be able to create the QR codes rapidly even if it takes a bit more time to create the contents (translations).
- **Information video**: There are already a few colleagues who agreed to translate the spoken text for the video. Iris will put together the text in a Word file as support for the translators.
- **QR code sticker**: The proposition made by Lauren and Iris looks very good and we all agreed to proceed with this version. The very few words of text also need a country-specific translation (same people who translate webpage text and video?).
- **Animated slides**: Iris, Ludovic, Michael, Lauren and Stephan worked on the content of the slides on 11,12/03. The targeted public is the group of people with basic knowledge and general interest in the topic (bachelor and master level). The slide show should tell the whole story of SoilForEUROPE with an introduction, the general context, purpose and aim, major results from the project and some wider conclusions. The major part of the discussion was focussing on the results from SoilForEUROPE. The challenge is to present the results in a balanced way, also mentioning that some responses were not significant, but still telling a compelling and clear story without entering in too much detail.
- **Leaflet**: Janna, Pierre, Luis and Paul worked on the content of the leaflet on 11,12/03. The targeted public is the group of people involved in forest management aiming to

distribute the leaflet in forest management offices, meetings, etc. The leaflet should transmit the essential message from SoilForEUROPE, with also providing some very basic background information and the usual references to partners of the project and funders. Much of the discussion was about the focus of the results, whether it should be more on tree species mixing or on the influence of evergreen (coniferous) species. Forest managers may be more readily connecting to the evergreen influence, but we decided that we should stay in line with the core question of the project and focus on mixture effects.

- Policy brief: We did not discuss the policy brief in detail. This should be done in tight collaboration with the BiodivERsA office anyway, if they support the initiative. We should focus first on the other items, with a potential policy brief to be considered only later.

Decisions:

1. Iris will put together a Word file with the text of the SoilForEU webpage and send it to the country-specific translators. Targeted date: First half of April.

2. Iris will put together a Word file with the text of the information video and will send it out to the country-specific translators. Targeted date: Together with the webpage text in the first half of April.

3. Lauren and Stephan will work out the URLs for the webpage in the different languages to enable the creation of the QR codes. Targeted date: First week of April (Covid-19 related confinement in France renders the delivery date unsure, but first week of April will not be possible).

4. Ordering of QR code stickers by Iris. Targeted date: mid-April (see difficulty with planning ahead in previous point).

5. Animated slides: Stephan will send the unfinished template produced during the workshop to Liesbet, Bart and Kris for further planning of the work. Targeted date: second half of March. We decided to keep the main focus on tree species mixing, but also to include the importance of functional group composition (i.e. the importance of evergreen species).

6. Leaflet: Most of the discussion during the morning of 12/03 was about what and how to present the SoilForEU results in the leaflet. We decided to produce a drawn figure showing the main results in the form of a drawing with only little text. This will be the core of the leaflet. Because of the importance of the quality of the figure, we decided to involve a professional drawer. Janna and Pierre will contact two different persons who might be interested in this work. Targeted date for drawer engagement: End of of March. As a team we worked on the content of this figure and Pierre established a list of the important messages that should be captured with this figure. In addition to this main figure, Paul will add the results of ORPHEE and FORBIO. These results will be included through bullet points (the use of a graph was discussed but this was expected to overload the leaflet in combination with the main figure on mixture effects).

We split the further work on particular parts of the leaflet amongst us (Stephan: title part with propositions of a photo, Michael & Ludovic: general context part, Ludovic & Paul: take home message, Lauren: contact info, Paul: climate change effects, Pierre, Janna: results figure). A more advanced version of the leaflet based on this further work will then be sent to Liesbet, Bart and Kris for further planning. Ludovic agreed to collect the different parts of the leaflet to put it together before sending it to Liesbet, Kris & Bart). **Targeted date for the more advanced version: End of March**.

APPENDIX F: PROTOCOL WORK PACKAGE 5 – SOCIO-ECONOMIC ANALYSIS

SoilForEUROPE: WP5 Socio-economic impact: Protocol

1. Purpose

1.1 Scientific context and relevance

The soil is one of the most vital natural resources on earth but currently, the pressure on soils increases. An important soil component is the soil biodiversity. Soils comprise about ¼ of the global biodiversity and hence are an important sink for life sustaining the delivery of multiple ecosystem services. Nevertheless, soils, and specifically soil biodiversity, are often overlooked and undervalued.

In forests, soil fauna are essential to create a healthy soil that is able to sustain a productive multifunctional forest. Forest management can impact tree and soil biodiversity directly or indirectly since both are linked through plant-soil feedbacks. Hence, management could influence the delivery of ecosystem services.

This research wants to focus on the socioeconomic value of forest soil biodiversity. Forests can fulfill multiple functions but mostly not at the same time. Preferences for functions and their adapted management scenarios differ between forest stakeholder groups. Although management influences soil biodiversity, it is often not taken into account when decisions are made. Provision of information may contribute to an increased understanding and changing preferences towards a more sustainable forest management, taking soil biodiversity into account.

Evaluating what forest users, including managers and the wider public, really know about and how they value soil biodiversity and its relation to ecosystem services, is of high priority for the development of information strategies and decision making.

1.2 Objectives and hypothesis

This research wants to assess the current knowledge on the role of soil biodiversity, held by forest scientists, forest managers and the wider public. By comparing the knowledge possessed between these groups, the flow of knowledge will be assessed. Moreover the effect of tradition, culture and local context will be investigated by collecting data in multiple countries, following a gradient from North to South Europe. We will test following hypothesis using face-to-face interviews and standardized questionnaires:

Hypothesis 1: *Despite the available scientific literature on the role of soil biodiversity in providing forest ecosystem services, this knowledge is limited among forest users and managers and could lead to inappropriate management decisions.*

Additionally, we will look at preferences for management scenarios of the forest managers and general public and how these preferences change when information on soil biodiversity is provided. Again, the effect of tradition, culture and local context will be assessed by comparing data from multiple countries. We will test following hypothesis using choice experiments:

Hypothesis 2: *The wider public as well as forest managers do not take soil biodiversity properly into account to express preferences for management scenarios because they are not aware of its role. Information transfer about this topic will alter preferences to sustainable management scenarios, supporting soil biodiversity.*

Based on the findings of this research, country specific communication strategies and policy instruments will be identified to provide sound scientific information to policy makers and the wider public.

2. Methods

2.1 Rationale

Data will be collected covering two gradients: a spatial gradient and an expertise gradient. The spatial gradient corresponds with the extended network of study sites used in the SoilForEurope project, covering the major European forest types and a wide climatic gradient. The expertise gradient classifies forest stakeholders according to expertise level, ranging from forest experts (forest scientists and managers) to laymen (wider public).

In each study site, the knowledge on soil biodiversity and its role, held by the different groups of forest stakeholders, will be compared to study the flow of knowledge. The methods used will be adapted to the stakeholder type: the knowledge held by forest scientists and managers will be mapped explicitly and a standardised questionnaire will be used for the forest managers and the general public. Next, the influence of information transfer about the role of soil biodiversity on preferences for management scenarios will be assessed among the forest managers and wider public using a choice experiment that will be incorporated in the standardized questionnaire. By comparing the results from the study sites, the influence of tradition, culture and local context will be assessed. Lastly, communication strategies and policy instruments will be identified to support a change in behaviour.

The data collection will start in Belgium and will be expanded to the remaining study sites depending on the support available.

2.2 Conceptual framework

The DPSIR framework (Smeets & Weterings, 1999) will be used in the face-to-face interviews as a methodological framework to delineate the subject. The core of this framework is depicted in figure 1. The framework is developed by the European Environment Agency (EEA). The DPSIR framework was used to demonstrate and analyze the relations between human and environmental systems. Driving forces exert pressure on the environment which alters its state. This leads to impacts on the human and environmental system that may elicit responses on all previous components.

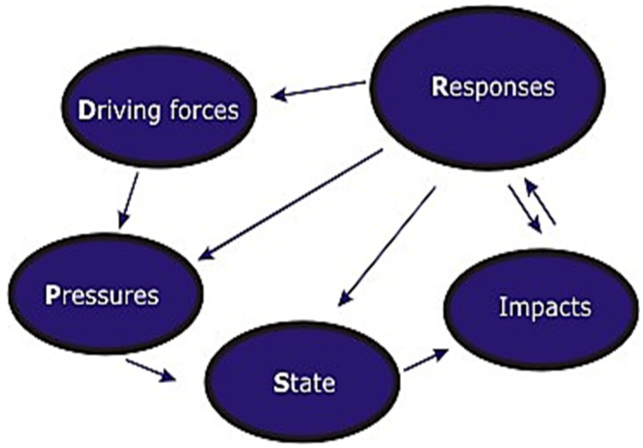


Figure 1: DPSIR framework (developed by EEA (European Environment Agency))

In this project, the DPSIR framework is adapted to investigate the role of forest soil biodiversity (figure 2). The framework offers a structure to assess the relationships between the topics studied: soil biodiversity, its impact on the delivery of ecosystem services through ecosystem functions and the impact of forest management with a focus on the relation with aboveground tree diversity. By building up the interview according to this framework, it will be easier to define and respect the system boundaries. This will result in a better understanding and overview of the system in which soil biodiversity plays a crucial role.

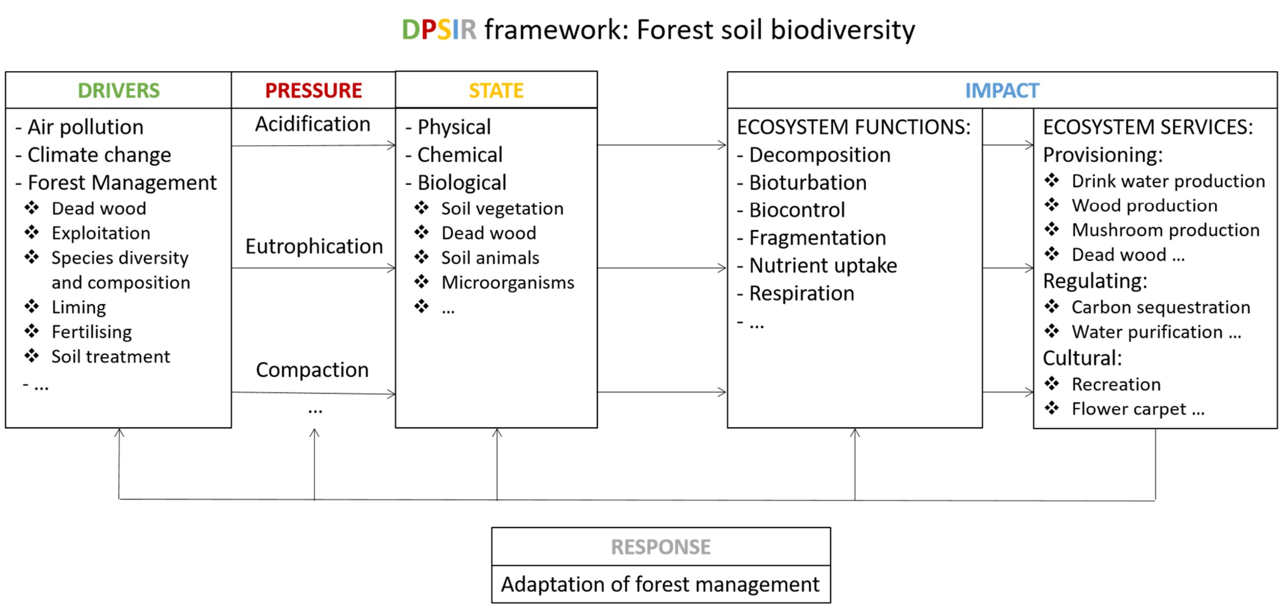


Figure 2: DPSIR framework adapted to study the role of soil biodiversity in forests

2.3 Forest experts: Scientists and Managers

The current knowledge held by forest scientists and managers about the role of soil biodiversity will be assessed using a mixed-method approach. In the first stage a qualitative method using face-to-face interviews will be applied, whereas in the second stage a quantitative method using standardised questionnaires will be used. For forest scientists, the second stage will only be adopted if the first stage does not yield sufficient information.

2.3.1 Knowledge mapping based on expert interviews

In the first stage, the current knowledge will be mapped through semi-structured face-to-face interviews with a limited number of forest scientists and managers (minimal 2-3 per type). Ideally, a (visual) knowledge map will be created based on these interviews using the AKT5[1] software. This knowledge map depicts the current knowledge on soil biodiversity and the relationships between the topics present in the knowledge map. An iterative process with repeated interviews will be used to omit contradictions and create a valid knowledge map. An example of a knowledge map constructed with the AKT5 software, can be found in appendix A. However, if the construction of a knowledge map is not feasible (because it takes too much time or results are not meaningful), the face-to-face interviews will still be useful to build up the standardised questionnaire in stage 2.

In Belgium, we will start by interviewing two forest scientists and four managers. The managers will be selected in the region of the Zedelgem site of the Forbio experiment in Flanders. In particular, we aim to interview the forest ranger of the site, the regional manager, the forest manager of the region to which the Zedelgem site belongs and a forest ranger of an adjacent forest without participation in scientific experiments. If the knowledge maps shows inconclusive results, additional interviews will be conducted. The variation in knowledge across countries possessed by the scientific community is assumed to be small (all scientists have access to similar international literature). The forest managers, on the contrary, possess local, context dependent knowledge. Therefore, we aim to conduct the face-to-face interviews with forest managers in all countries present in the network of study sites (Poland, Romania, Italy, Finland, Belgium and France). By constructing a knowledge map for each expert type, the knowledge held by both groups will be compared. Additionally, the knowledge possessed by forest managers will be compared across countries.

2.3.2 Assessment of management preferences based on quantitative surveys

In a second stage, the knowledge obtained from the face-to-face interviews in the knowledge map will be verified using online quantitative standardised questionnaires spread among a large sample of forest managers (and scientists) (general public: see further). Additionally, the standardised questionnaire distributed among forest managers, will analyse the determinants of a change in attitude and stated behaviour concerning forest management. For this, we will rely on the Protection Motivation Theory (Maddux & Rogers, 1983; Rogers, 1975). According to this theory, adaptive behaviour is a function of a threat appraisal, focusing on the source of the threat, and a coping appraisal, focusing on the ability to cope with the threat (figure 3). The threat appraisal consists of three components: severity, vulnerability and rewards. Applied to this research, the severity corresponds with the degree to which soil biodiversity state is threatened (by climate change, etc.). The vulnerability is the probability that

[1] http://akt.bangor.ac.uk/

your forest will experience harm. Thirdly, rewards refer to the benefits obtained by the current practice and state of the soil biodiversity. The coping appraisal, on the other hand, comprises the response efficacy, the self-efficacy and the response costs. In this research, the response efficacy points to the extent to which, according to the respondent, measures can be taken to offset a declining soil biodiversity (e.g. change in forest management). The self-efficacy focusses on the extent to which the respondent considers him/herself able to execute these measures. Lastly, the response costs depict the costs associated with this change in behaviour to improve soil biodiversity.

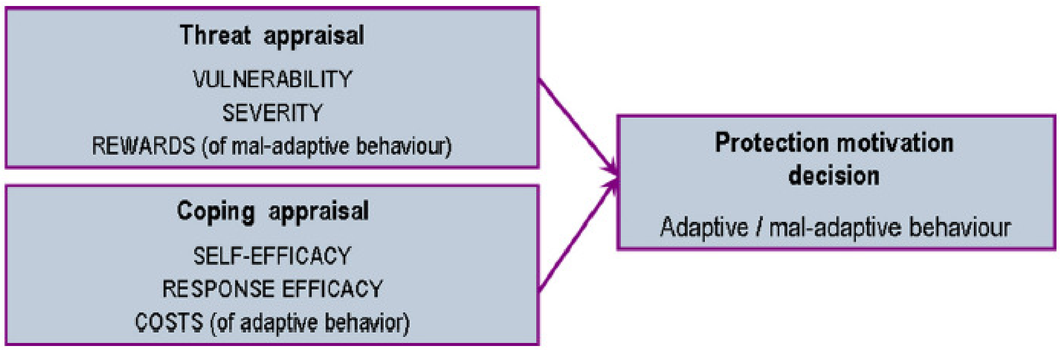


Figure 3: Overview Protection Motivation Theory (from: Bockarjova & Steg, 2014)

A two-stage choice experiment will be added to the quantitative standardized survey distributed among the forest managers. This choice experiment will assess preferences for management scenarios and the effect of information transfer on these preferences. The transfer will include information on the role of soil biodiversity in the provision of ecosystem services and will be provided through short videos (knowledge clips).

Multiple choice cards, each depicting a limited number of management scenarios, are offered to the respondents. Based on the attributes and their levels, respondents choose one of the alternatives. The most important attributes and realistic levels, adapted to the research question, need to be used to obtain meaningful results. A focus group session will be held with forest scientists, managers and forest users (i.e. wider public) to decide on the attributes and levels. Some examples of potential useful attributes are: cost price, soil biodiversity, visual characteristics and goods or services provided by the forest. The visual aspect is likely very important for the general public since they mostly use the forest directly to recreate. This will influence the nature value and soil biodiversity of forests (e.g. presence of dead wood), often in an unintended negative way leading to a decrease in ecosystem services.

2.4 Laymen: Wider public

2.4.1 Knowledge assessment based on quantitative survey

The knowledge possessed by the wider public will be assessed using online standardized questionnaires spread among a large sample. These questionnaires are based on the information retrieved from the experts' knowledge maps. The construction of a knowledge map for the wider public using face-to-face interviews is not feasible since it is impossible to select a representative sample of a limited number respondents.

2.4.2 Assessment of management scenario preferences based on quantitative survey

A two-stage choice experiment will be added to the quantitative standardized survey, similar to the choice experiment presented to the forest managers. In this way, preferences for management scenarios and the effect of information transfer on these preferences will be assessed. The information transfer about the role of soil biodiversity in the provision of ecosystem services and the attributes and levels used in the choice experiment will be adapted to be relevant and understandable for the wider public.

2.5 Timing

We will start the data collection in Belgium (Flanders). Simultaneously, the method will be developed and refined. Depending on the support and infrastructure available, the remaining countries will be sampled in the following months/years.

3. Call for support

To be able to analyse the effect of tradition, culture and local context on knowledge and preferences for management scenarios and compare these between countries, support of other project participants would be highly appreciated. We aim to conduct the face-to-face interviews with forest managers and quantitative surveys among forest managers and users using standardised questionnaires (including the choice experiment) in the countries with project study sites. Specifically, following support is needed:

For the face-to-face interviews:

1. Input on which forest managers to interview
2. Interpreter(s) (if managers are not familiar with English)

For the standardised surveys, we would like to enquire whether we could rely on local support to:

1. spread the surveys to a representative sample of forest users and managers through internet if internet is sufficiently available among the stakeholders.
2. translate the survey into the local knowledge.
3. conduct face-to-face interviews for the quantitative survey if internet is insufficiently available among stakeholders. This would mainly imply that additional manpower (enumerators or interviewers) is needed.

Both for the face-to-face interviews as well as for the internet survey, manpower is needed. We would also like to enquire whether it would be possible to involve master and/or PhD students in the data collection process.

The planning will depend on the support available and the speed of the data collection in Belgium. In each country, about 1 to 2 weeks are needed to conduct the face-to-face interviews with forest managers.

In conclusion, we would like to ask :

1. to which extent you can support the socio-economic data collection with semi-structured face-to-face interviews and standardised surveys in your country (provision of manpower, translation of the survey, etc.).
2. in which month/season/year the data collection would be feasible in your country.

References

Cerdan, C.R., Rebolledo, M.C., Soto, G., Rapidel, B. & Sinclair, F.L. (2012). Local knowledge of impacts of tree cover on ecosystem services in smallholder coffee production systems. *Agricultural Systems* 110, 119-130.

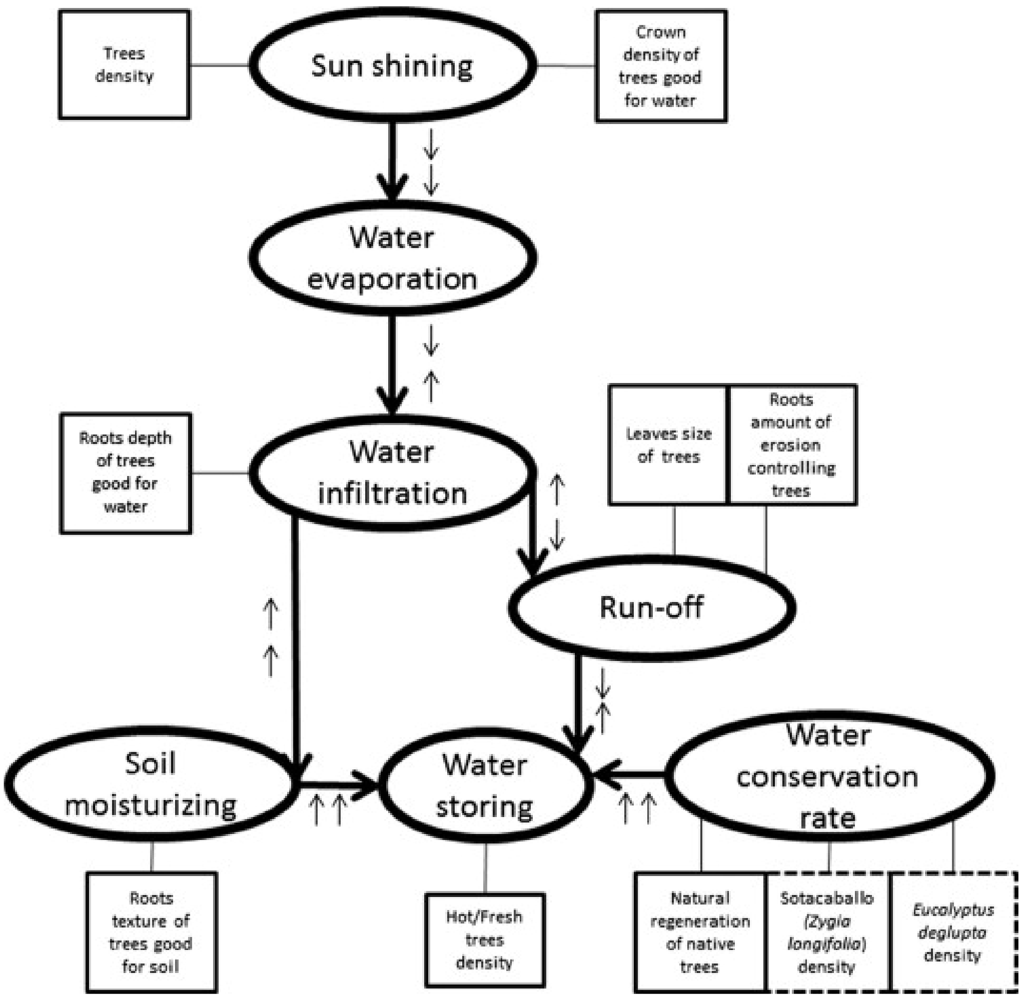
Maddux, J.E. & Rogers, R.W. (1983). Protection Motivation and Self-Efficacy: A Revised Theory of Fear Appeals and Attitude Change. *Journal of Experimental Social Psychology* 19, 469-479.

Rogers, R.W. (1975). A Protection Motivation Theory of fear appeals and attitude change. *The Journal of Psychology* 91, 93-114.

Smeets, E. & Weterings, R. (1999). Environmental indicators: Typology and overview. *European Environment Agency,* Copenhagen. 19 p.

Appendix

Example of a knowledge map, build using the AKT5 software (Cerdan et al., 2012)



APPENDIX G: SCIENTIFIC PAPER 1: What do scientists and managers know about soil biodiversity? Comparative knowledge mapping for sustainable forest management.

Accepted for publication by the Journal of Forest Policy and Economics:

Ref: FORPOL_2019_456_R2
Title: What do scientists and managers know about soil biodiversity? Comparative knowledge mapping for sustainable forest management.
Journal: Forest Policy and Economics

Dear Ms. Vanermen,

I am pleased to inform you that your paper has been accepted for publication. My own comments as well as any reviewer comments are appended to the end of this letter.

Your accepted manuscript will now be transferred to our production department. We will create a proof which you will be asked to check. You can read more about this here. Meanwhile, you will be asked to complete a number of online forms required for publication. If we need additional information from you during the production process, we will contact.

Thank you for submitting your work to Forest Policy and Economics. We hope you consider us again for future submissions.

Kind regards,

Lukas Giessen
Editor-in-Chief
Forest Policy and Economics

Comments from the editors and reviewers:
- **Editor**

-

Have questions or need assistance?
For further assistance, please visit our Customer Support site. Here you can search for solutions on a range of topics, find answers to frequently asked questions, and learn more about EVISE® via interactive tutorials. You can also talk 24/5 to our customer support team by phone and 24/7 by live chat and email.

What do scientists and managers know about soil biodiversity? Comparative knowledge mapping for sustainable forest management.

Authors: Iris Vanermen[a*], Bart Muys[b], Kris Verheyen[c], Frederic Vanwindekens[d], Laura Bouriaud[e], Paul Kardol[f] and Liesbet Vranken[a]

Affiliations:

[a] Division of Bioeconomics, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200 E – Box 2411, 3001 Leuven, Belgium. – liesbet.vranken@kuleuven.be

[b] Division of Forest, Nature and landscape, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200 E – Box 2411, 3001 Leuven, Belgium. – bart.muys@kuleuven.be

[c] Forest & Nature Lab, Department of Environment, UGent, Geraadsbergsesteenweg 267, 9090 Gontrode, Belgium. – kris.verheyen@ugent.be

[d] Agriculture and Natural Environment Department, Walloon Agricultural Research Center, Rue de Liroux 9, 5030 Gembloux, Belgium – f.vanwindekens@cra.wallonie.be

[e] Faculty of Forestry, University Stefan cel Mare of Suceava, str. Universitatii nr. 13, 720229 Suceava, Romania. – bouriaud@usv.ro

[f] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, 901 83 Umeå, Sweden – paul.kardol@slu.se

*Corresponding author: iris.vanermen@kuleuven.be

Declaration of Interest: None

Highlights:

- Forest managers are aware of the crucial role of soil biodiversity, but do not consider it as an explicit management goal.
- Improved information for forest managers should focus on ecosystem processes and functions.
- This information should also be tailored towards managers' socio-economic and forest management context.
- Scientists have more in-depth understanding, that is, however, also affected by their context.
- Policy design should enhance conditions for knowledge exchange about soil biodiversity.

Abstract:

Soil biodiversity is crucial for maintaining forest health and safeguarding forest ecosystem services delivery, but it is under increasing human pressure. Forest management puts pressure on soil biodiversity, but has also the potential to support soil biodiversity recovery, depending on which decisions forest managers make. These decisions are highly influenced by managers' perception and understanding. Nevertheless, insights into forest managers' understanding of soils and their biodiversity are largely lacking. This paper addresses this gap by studying private and public forest managers' understanding of soil biodiversity and comparing their level of knowledge with scientists' knowledge. In addition, this paper assesses the effects of context on understanding by comparing between two regions (NW of Flanders, Belgium, and NE of Romania). Specifically, knowledge was elicited using semi-structured interviews based on an integrated framework. The interviews were coded and analyzed using a Fuzzy Cognitive Mapping approach. In total, 24 interviews were conducted after selecting respondents using a purposive sampling design. Our results indicate that forest managers are aware of the crucial role of soil biodiversity and possess practical and context-specific understanding, but lack in-depth knowledge related to ecosystem processes and functions and soil state variables, compared to scientists. In addition, managers did not seem to explicitly consider soil biodiversity in their management decisions, but instead seemed to treat soil more as a black box. While scientists had a more detailed understanding, their understanding also depended on their background as researchers and mostly overlooked practical, site-specific implications. Moreover, we found that local context influenced respondents' understanding, especially related to drivers and pressures that affect soil biodiversity. Hence, communication strategies oriented towards forest managers seem suitable to maximize adoption of adaptive management practices that support soil biodiversity. These strategies should go beyond awareness raising and specifically explain ecosystem processes and functions linked to forest soil biodiversity to improve managers' in-depth understanding, while taking their socio-economic and forestry context into account. Further, policy design should enhance conditions for knowledge exchange and discussion about soil biodiversity. The methodology presented in this study might help such knowledge integration of scientists and forest managers in order to combine in-depth understanding of soil biodiversity and applicability of management practices in specific forest contexts.

Key words: Social-ecological system; soil biodiversity; sustainable forest management; fuzzy cognitive mapping; knowledge comparison; context dependency

1. Introduction

Forests form the most widespread terrestrial ecosystem in the EU, covering about 38% of its total area (Eurostat, 2015). Forests are highly valued for the numerous ecosystem services that they deliver such as timber production, carbon sequestration and recreation space (Brockerhoff et al., 2017; MEA, 2005). This delivery of forest ecosystem services crucially depends on the forest's capacity to sustain ecosystem functions, which results from the forest's biophysical structure. This chain is referred to as the 'ecosystem service cascade model' (Haines-Young and Potschin, 2010). An essential component of the biophysical structure is forest biodiversity through its effect on ecosystem functioning (Brockerhoff et al., 2017; Cardinale et al., 2012; MEA, 2005). While, in the past, research mainly focused on aboveground biodiversity and tree species richness in particular, belowground biodiversity has received increasing attention during the last decade. Specifically, awareness has raised on soil as a non-renewable resource and the soil's crucial role in ecosystem functioning and global cycles (Bardgett and Van Der Putten, 2014). Soils host immense biological diversity in the form of a highly complex soil food web in which a range of key forest ecosystem functions such as nutrient and carbon cycling and soil formation are fulfilled (Nielsen et al., 2015). Moreover, soil biodiversity is linked to aboveground biodiversity through plant-soil feedbacks and hence supports also aboveground ecosystem services (Adhikari and Hartemink, 2016; Korboulewsky et al., 2016).

Nevertheless, forest soils and their biodiversity are being threatened by soil degradation processes such as acidification and soil compaction. Soil degradation is mainly caused by human-induced processes like atmospheric deposition, intensive recreation and forest management (Hartmann et al., 2014; Jones et al., 2011). Currently, there is broad agreement on the need for sustainable soil management to durably improve soil quality, including soil biodiversity (Juerges and Hansjürgens, 2018). Nevertheless, soil degradation continues and clear strategies for sustainable soil management are largely lacking. Additionally, soil biodiversity is generally not explicitly considered in forest management decisions, which leads to unintentional pressures, such as organic matter removal and soil compaction during harvest (Addison et al., 2019; Prager and Curfs, 2016). This lack of attention is largely caused by the soil's poor visibility due to its location belowground, slow rates of change and complex interactions between biotic and abiotic components (Prager and Curfs, 2016). Moreover, forest management faces the challenge of slow changes and a long time span between management decisions and results obtained, which hampers accurate evaluation and mitigation actions (Meyfroidt, 2013). Research efforts have started to increase, resulting in reliable data on spatial and temporal distributions of soil organism groups and their role in processes (Orgiazzi et al., 2016). Nevertheless, a standardized procedure to measure soil biodiversity, a holistic overview of the belowground system and precise insights on the effect of management on soil biodiversity are still missing (Bardgett and Van Der Putten, 2014; Cambi et al., 2015; Lemanceau et al., 2015).

Despite these challenges, forest management has to preserve soil biodiversity to safeguard future delivery of forest ecosystem services (Lukac, 2017; Thees and Olschewski, 2017). Mismanagement of ecosystems may cause increasing losses in ecosystem services that are very hard to recover (Birgé et al., 2016). To achieve this objective, forest managers' understanding and perception of forest soil, its biodiversity and the interaction between the human and ecological system, are crucial (Baveye et al., 2016; Lamarque et al., 2014). This perception determines the attitude that a manager adopts towards soil biodiversity and eventually what management decisions are taken (Prager and Curfs, 2016; Yousefpour et al., 2017). As such, it is essential to assess whether and where improvement in soil biodiversity understanding is needed (Kontogianni et al., 2012). These insights allow the design of effective policies and communication strategies oriented towards facilitating adoption of conservation strategies. Research has shown that awareness does not automatically lead to implementation, especially concerning soil protection, and stressed the need for knowledge and information strategies to translate perception into action (ElSawah et al., 2013; Juerges and Hansjürgens, 2018; Sousa-Silva et al., 2018). Furthermore, environmental and social context, attitudes, values and beliefs influence interpretation of information and understanding, referred to as selective perception, and should therefore be taken into account (Carnol et al., 2014; Gray et al., 2014; Ingram et al., 2010; Prager and Curfs, 2016). In this perspective, some studies have investigated the differences and similarities in understanding between countries or regions, although being relatively scarce. For example, Ingram et al. (2010) compared farmers and scientists' understanding of soil across three case studies in different European countries. They found that similarities existed in the type of understanding of scientists versus managers over the three case studies, as well as in understanding within specific groups over the case studies. On the other hand, Van Der Sluis et al. (2018) concluded that fundamental differences existed in perspectives on landscape change processes across six European countries, which requires specific policies instead of a one size fits all approach. This contrasting conclusions point at a need for further insights in the effect of regional context on understanding. Moreover, insights in forest stakeholders' understanding of soil biodiversity are still lacking, as well as information on how to communicate taking the needs of different groups into account (Lähtinen et al., 2017). Insights in which factors (for example related to regional context) cause differences in understanding are expected to facilitate harmonization across groups, and hence improve decision making (van den Broek, 2018).

Recently, mental models are gaining interest to study stakeholders' understanding, but applications in soil degradation research remain limited (Lamarque et al., 2014; Prager and Curfs, 2016). Mental models are defined as internal representations, constructed by the human mind, of external reality. In order to visualize and study such models, fuzzy cognitive mapping (FCM) is widely applied. This methodology creates cognitive maps that are physical constructs depicting directed and weighted causal relationships between concepts, or variables, of a system (Özesmi and Özesmi, 2004). During the last two decades, FCM has been increasingly applied in a wide variety of disciplines, including environmental management and modelling (Jetter and Kok, 2014). However, consensus on the detailed steps to construct fuzzy cognitive maps and translation into specific tools is still lacking (Jetter and Kok, 2014). Vanwindekens et al. (2013) extended the original approach of Özesmi & Özesmi (2004) and applied FCM to study 'systems of practices' by developing the tool CMASOP (Cognitive Mapping Approach for analyzing Systems Of Practices) and the R package 'cogmapr' (Vanwindekens et al., 2019). In their work, they used the tool to study management of grassland-based livestock farming systems. Their approach can be easily extended to other topics related to environmental management, such as forest management and its relationship with soil biodiversity (Vanwindekens et al., 2013).

To evaluate forest managers' level of understanding, scientists can serve as a benchmark, while acknowledging the relevance of both groups as different but complementary local knowledge sources (Jabbour et al., 2014; Prager and Curfs, 2016; Raymond et al., 2010). The impact of changing soil biodiversity levels and the effect of management are difficult to observe and mostly felt in the long run. Additionally, the links within the ecosystem services cascade are often not clear in real life due to confounding factors. Therefore, it is hard for managers to understand these linkages between management and soil biodiversity, while scientists are expected to have a better understanding as they mostly control environmental factors in experimental studies on soil biodiversity that may test the effect of alternative management practices (Gray et al., 2014).

The objective of this paper is to explore forest scientists' and private and public forest managers' understanding of the role of soil biodiversity in forest functioning and of the effect of management decisions on soil biodiversity. We aim to assess the similarities and differences in knowledge related to soil biodiversity between forest scientists and managers, and investigate the type of understanding that both groups adhere. Furthermore, we study the effect of ecological and socio-economic context on this understanding by comparing two contrasting European regions: Flanders (Belgium) and Romania. To achieve these objectives, we apply an FCM approach based on CMASOP using semi-structured interviews to study forest scientists' and private and public forest managers' understanding of soil biodiversity. These results can serve the development of communication strategies to safeguard and improve forest soil biodiversity through sustainable forest management.

2. Conceptual framework

Forests and their soils are complex and dynamic systems, that include multiple feedback loops between the human and natural system through forest management, soil degradation and ecosystem services delivery. These systems are referred to as social-ecological systems (Berkes et al., 2008; Meyfroidt, 2013). In order to facilitate knowledge elicitation and representation of such complex systems using CMASOP and semi-structured interviews, we adapted the approach of Müller and Burkhard (2012), integrating three frameworks: (i) the ecosystem service cascade (ESC) model (Haines-Young and Potschin, 2010), (ii) the driver-pressure-state-impact-response (DSPIR) framework (Smeets and Weterings, 1999) and (iii) the adaptive management cycle (Figure 1). (i) The ESC model connects human and environmental systems through ecosystem functions and ecosystem services, as explained in section 1. Specifically, the biophysical structures and processes that underpin ecosystems, such as soil biodiversity, deliver ecosystem services to society through the ecosystem functions that they fulfill. These ecosystem services are valued by society and hence can benefit human well-being. Through valuation of ecosystem services and their perceived benefits to society, humans decide upon their behavior, such as management, that then affects the biophysical ecosystem structure. The interested reader is referred to Haines-Young and Potschin (2010) for a detailed explanation of this cascade. (ii) The DPSIR framework is a problem structuring framework for complex causal interactions that allows categorization and better understanding of the different aspects of a problem. Specifically, the framework includes socio-economic and environmental "drivers" that exert "pressures" on soil biodiversity and hence intentionally or unintentionally alter the soil's "state". This state causes "impacts" on forests and society. Human "responses" react on these "impacts" by taking measures targeted at one of the previous components (Baldwin et al., 2016). The interested reader is referred to the original publication of Smeets and Weterings (1999) for further explanation. (iii) Adaptive forest management is one example of such a response that can be undertaken by forest managers (Yousefpour et al., 2017). In adaptive management, decision making relies on monitoring, learning and feedback to respond to uncertainty. A detailed description can be found in Lawrence and Gillet (2011).

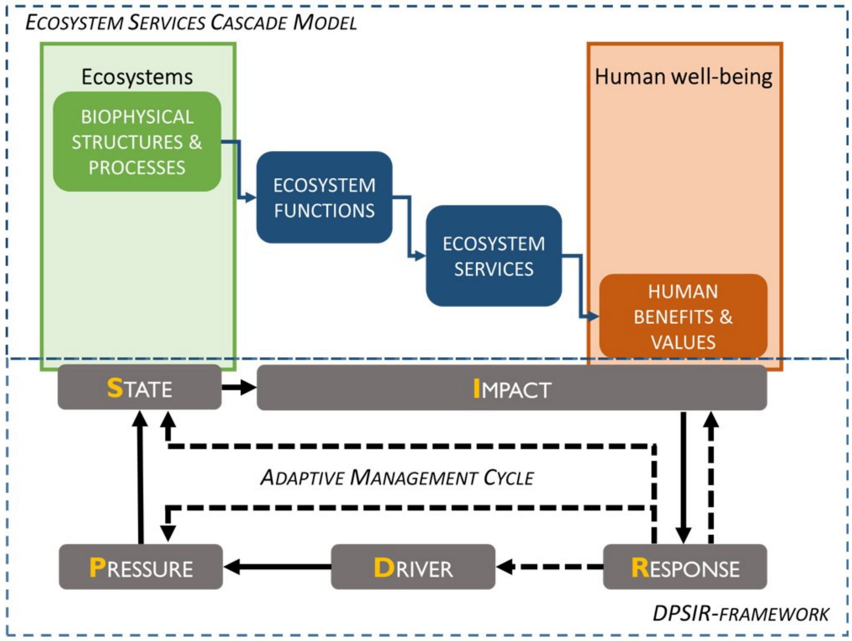


Figure 4: Integrated ecosystem services cascade (ESC), Driver, Pressure, State, Impact, Response (DPSIR) and adaptive management cycle framework to structure the complexity of social-ecological systems. Adapted from Müller and Burkhard (2012).

Although being widely used for its transparency and ability to simplify complex systems, the DPSIR framework is also criticized for inconsistent use of definitions and terminology, and its one-to-one and unidirectional relationships (Bell, 2012; Gari et al., 2015). Therefore, suggestions were made to integrate the framework in a multi-methodology approach (Bell, 2012; Mehryar et al., 2017). This paper intends to meet these suggestions by combining the integrated framework with an FCM approach for analysis.

3. Methods

3.1 Case study

The study was carried out in two contrasting regions in a European context: the North-West (NW) of Flanders (Belgium) and the North-East (NE) of Romania. These regions differ in topography, forest area, forest ownership, forest policy and governance, and socio-economic characteristics, while climate (temperate), soil fertility (low to medium) and tree species composition (deciduous or mixed) are more or less similar. The most important differences are listed in detail in table 1. Generally, the NW of Flanders is flat, has a low forest cover (6%) and forest patches are scattered and small in area. Forest ownership is approximately equally distributed between public and private, and public forest management is a regionalized (i.e. non-federal) matter, executed by the Flemish administration "Agentschap Natuur en Bos". The Flemish study region has a high human population density and is considered a knowledge region, investing in innovation and scientific research (Castellacci and Archibugi, 2008). The NE of Romania is located at the transition between a hilly region and the Suceava river valley.

It has a low human population density, a high forest cover (66%) and forests are large and have often been present for centuries. Forests are mostly publicly owned. Forest regulation is state-centered and top-down regulated, including a set of compulsory rules (Nichiforel et al., 2018). The autonomous administration governing public Romanian forests is called ROMSILVA. So far, it has placed less focus on advanced knowledge exchange, partially due to the top-down regulation hindering knowledge creation amongst forest experts (Castellacci and Archibugi, 2008; World Bank, 2009). In addition, both regions are connected to the FunDivEUROPE network (Baeten et al., 2013) that was set out as a platform to study tree species diversity in European forests and is currently being used in the SoilForEUROPE project to study the relationship between tree diversity and soil biodiversity. Our study is part of the SoilForEUROPE project and relies on the presence of such network to sample forest managers that are familiar with scientific experiments, as well as managers that have no direct contact with science, as will be explained in section 3.2.1.1. Specifically, the Flemish region is situated around the FORBIO site in Zedelgem, whereas the Romanian region is located around Râşca in Suceava County. A detailed description of these sites can be found in Verheyen et al. (2013) for the FORBIO site in Flanders and in Baeten et al. (2013) for the Romanian site near Râşca.

Table 1: Summary of the most important socio-economic and environmental characteristics between the case study regions (North-West of Flanders and North-East of Romania)

	Belgium: North-West of Flanders	**Romania: North-East of Romania**
Climate	Temperate-maritime	Temperate-continental
Topography	Lowlands (5-20 m.a.s.l.)	Low mountains (400-1000 m.a.s.l.)
Soil type	Mainly Cambisol, Luvisol and Retisol	Brown soils (Eutric Cambisol and Dystric Cambisol on 89% of the area)
Population density	444 inhabitants/square km	24 inhabitants/square km
Forest cover	6%	66%
Forest type	Mainly deciduous forests (Lowland oak-beech forest)	Mixed forests (49% coniferous, 41% beech, 10% other deciduous species)
Forest ownership	40% State owned, 60% Privately owned	100% State owned
Forest policy and governance	Regionalized: Flemish administration "Agentschap Natuur en Bos"	State-centered: Autonomous administration "ROMSILVA"
Total area of the region	4000-5000 km^2	10.00-15.0 ^{2}

3.2 Methodological approach

The method used in this study comprises five steps and is based on the CMASOP approach developed by Vanwindekens et al. (2013), taking recommendations of Olazabal et al. (2018b) into account.

3.2.1 Step 1: Data collection

3.2.1.1 Respondent selection

A limited number of key forest stakeholders was selected to gather in depth data through interviews, using a purposive sampling technique following the scheme in Table 2 (Robinson, 2014). Forest scientists were selected at universities and research institutes, and gender and experience were used as selection criteria. Concerning the selection of forest managers, a distinction was made between regional and local managers, as well as between public and private managers. Three groups of managers were included: regional public managers, local public managers and local private managers. The first two groups are paid employees responsible for public forests, owned by public organizations (state), at regional or local level respectively. Whereas regional level refers to a level comparable to provinces, local level reflects a lower level, comparable to a set of municipalities. Local private managers, on the contrary, possess a forest of their own or manage a forest owned by a private person or organization. Furthermore, direct contact with science was taken into account for the selection of forest managers through the FunDivEUROPE network. As explained in section 3.1, this network encompasses sites in which scientific experiments were conducted in the past, bringing managers into contact with the scientific world (e.g. Jucker et al., 2015). As scientific contact might have influenced managers' knowledge on forest ecosystem functioning, the presence of this network was used for sampling forest managers. Specifically, the regional and local public manager of the study site were interviewed, as well as the regional and local public manager of an adjacent region with similar climatic and soil conditions, but without previous involvement in experimental scientific studies. Local private managers were contacted through a cooperative association that was active in the same area as where the publicly managed forests were located. This association unites private forest owners and managers and provides them training, advice and assistance. In order to reflect the ownership situation, local private managers were only interviewed in Flanders (Belgium). The respondent selection resulted in 26 stakeholders sampled in 24 interviews, of which 10 Belgian forest managers, 7 Belgian forest scientists, 6 Romanian forest managers (in 4 interviews) and 3 Romanian forest scientists. In the remainder of this paper, 'N' refers to the number of respondents while 'N_I' refers to the number of interviews. Additionally, the general term 'managers' will be used to refer to both private and public managers.

Table 2: Scheme for selecting forest scientists and managers in Flanders and Romania using purposive sampling. Number of respondents per group sampled are included, as well as the main selection criteria.

	Forest scientists	Forest managers		
		Regional (~ province)	**Local (~ one or multiple municipalities)**	
		Public	**Public**	**Private**
Selection criteria	institute, gender, experience	location, scientific experience	location, scientific experience	institute, location
Flanders	**7**	**3**	**4**	**3**
Romania	**3**	**1**	**5**	**/**

3.2.1.2 Semi-structured interview

As soil biodiversity is considered to be generally poorly known, we are interested in eliciting more generic mental models to better understand fundamental differences and similarities between groups (Jones et al., 2014). In order to organize the complexity of the forest soil biodiversity system and set boundaries to the system for knowledge elicitation, the integrated ESC-DPSIR-Adaptive management cycle framework, explained in section 2, was used for the semi-structured interviews. This framework can help respondents to structure and express their understanding of the forest soil system, as is also mentioned by Lewison et al. (2016). Based on a literature screening, the framework was reconstructed and applied to forest soil biodiversity and its role in ecosystem services delivery. The final framework served as a basis for the interview guide that included five sections:

(i) “state” with a focus on the definition of soil biodiversity, physical, chemical and biological soil quality and their relationship. Amongst others, following questions were asked: “What does soil biodiversity mean to you?”, “Which chemical factors or processes do you think determine soil quality?”,

(ii) “impact” focusing on ecosystem services delivery and ecosystem functions connecting “state” and “impact”. An example question is: “Where can soil biodiversity be useful for in your opinion?”,

(iii) “drivers” and “pressures” of human and natural origin that impact forest soils and their biodiversity. This section included questions such as: “Which driving factors do you think cause pressures on forest soil and its biodiversity?”,

(iv) “response” focusing on soil biodiversity state, interventions to support soil biodiversity including forest management and current forest management practices in view of soil biodiversity. Example questions are: “Does forest management influence soil biodiversity in your opinion?” and “Which management interventions do you think influence soil biodiversity?”,

(v) Lastly, a fifth section was added in which the relationship between soil biodiversity and tree biodiversity was discussed, for example through following question: “Do you think that soil biodiversity and aboveground tree biodiversity are connected?”.

A detailed outline of the questions that were used during the semi-structured interviews is added in appendix A. All interviews were executed by the same researcher. Specifically, the sections were introduced at the start of the interview, but interviewees were informed that they could change the order of the sections or bring up new topics whenever they wanted. Each section included open questions that asked about the specific aspects of the framework such as ecosystem functions, environmental pressures or drivers. The first question of the interview asked for a definition of soil biodiversity, after which an additional explication was provided in case of an incomplete answer. This ensures a shared understanding of the concept soil biodiversity across interviewees before proceeding the interview. Interviewees were encouraged to express their full knowledge and examples of related fields were provided upon request. Furthermore, the interviewer could ask additional questions to pursue deeper understanding, which increased flexibility and improved elicitation. Such probing questions were asked in multiple situations, mostly to clarify an answer or get more information if interviewees remained rather superficial and general in their answers. Moreover, interviewees were asked regularly if they had anything to add to a specific topic or section that was discussed. Respondents’ informed consent was verbally obtained and recorded at the start of the interview and respondents’ anonymity was ensured.

In Romania, the interviewer was accompanied by a translator for the interviews with forest managers. This translator was a local expert in forest and nature management with an academic background and an excellent level of English. Up front, the interviewer informed the translator on the questions of the semi-structured interview and clarifications were provided to make sure the translator correctly interpreted the questions. During the interviews, the translator directly translated the questions in Romanian and directly translated the answers back to English. The interviewer noted the most important information and asked additional questions if needed. Moreover, the translator asked interviewees for further explanation in case he was unsure if his interpretation of their answers was correct. The entire interview was recorded and the English sections were fully transcribed. Moreover, the recordings allowed consulting the original Romanian answers in case of vagueness. Nevertheless, this was not needed as the translator felt sure about his translations, which is probably linked to the general level of knowledge elicitation and the background of the translator. While the use of a translator was unavoidable, we acknowledge that it might have impacted knowledge elicitation, because of the interference of an additional person compared to interviews in Flanders and interviews with Romanian scientists. Additionally, Romanian scientists were interviewed in English, which omits the possible effect of a third-person. Nevertheless, the use of English might still have affected knowledge elicitation as Flemish participants were interviewed in their native language. We acknowledge the implications of the knowledge elicitation language when discussing the results.

3.2.2 Step 2: Transcript coding

The interview recordings were fully transcribed using a basic word processor. Next, the transcriptions were coded by manually identifying concepts and linking them through relationships in the open source and freeware R-package qcoder 0.1.0 (Duckles et al., 2007). One researcher performed the coding, in line with the approach of Vanwindekens et al. (2013). The manual coding could affect the results through the researcher's interviewing and mapping skills, and her own perception and preferences (ElSawah et al., 2013; Jones et al., 2011; Mehryar et al., 2017; Vanwindekens et al., 2013). Nevertheless, this influence is partly mediated by the relatively straightforward structure of the interviews which limits the need for interpretation (Vanwindekens et al., 2013) and the comparative focus of the analysis as explained in section 3.2.5. Moreover, a list of 58 concepts was predefined based on the integrated framework that was reconstructed from literature, a thorough reading of the transcripts and iterative expert consultations. This bounds the freedom of interpretation during the coding process and hence allows the coding process to be more standardized. Specifically, the concepts that were included in the integrated ESC-DPSIR-Adaptive Management Cycle framework reconstructed for soil biodiversity from literatire were listed. Next, the interview transcripts were read through once to identify recurring missing concepts. Experts were consulted iteratively to discuss the names and definitions of concepts and assess the need for merging or splitting concepts. Moreover, concepts could still be added during the coding process. Whenever a possible new concept appeared during the coding, the definitions of the predefined concepts were checked and if the concept could not be added to an existing concept, a new concept was defined. This procedure resulted in a total set of 62 concepts, that are listed in Appendix B (Table B.1). The use of the framework that served as an umbrella for the interview and the general level of knowledge elicitation made it easier to detect overlapping concepts and synonyms, both within and between languages. As a result, the coder did not encounter any significant problems in deciding whether respondents were discussing similar concepts. In addition, the researchers attributed each concept to one of following classes, based on the integrated framework: driver, pressure, soil characteristic, ecosystem function, ecosystem service or management practice. In order to allow for aggregation of cognitive maps per group, interviewed participants were categorized, based on stakeholder type (forest scientist or forest manager) and region (Flanders or Romania).

No weighting of relationships based on importance was implemented, as interviewees were generally unsure about these values. Instead, presence or absence of a relationship was coded, corresponding with a weight of 1 or 0, respectively. In this way, each interview was transformed into an adjacency matrix that places the 62 concepts in rows and columns and depicts the weight of the relationship (0 or 1) on the cross-section.

To increase reliability of the manual coding, a double check was executed after the manual coding by the main researcher. Firstly, two interview transcripts were coded twice by the same researcher at the start and end of the coding process to detect possible issues linked to changes in interpretation of particular recurring sections throughout the entire coding process. Secondly, two randomly selected interview transcripts were coded independently by a second researcher which gives an indication on the robustness of the initial codings. For both checks, the share of identical concepts was calculated, as well as the share of identical individual relationships. The first check resulted in a relatively high agreement. Specifically, on average over both interviews, 94% of concepts were shared and 86% of the relationships. These figures were somewhat lower for the second check, but are still considered acceptable. In particular, the share of identical concepts between the independent coding of both researchers was on average 85%, whereas the share of identical relationships was on average 64%. Relationships that were different between the codings of both researchers often involved related concepts, for example *acidification → soil organisms*, versus *pH → soil organisms*.

3.2.3 Step 3: Individual cognitive mapping

Using the coded relationships, an individual cognitive map (ICM) was constructed per interview using the open source and freeware Rpackage cogmapr 0.9.1 (Vanwindekens et al., 2019). The ICM is a graphical network in which concepts are nodes that are linked by arrows or relationships. The package uses the adjacency matrix to construct the ICM. More information on this procedure can be found in Vanwindekens et al. (2013).

3.2.4 Step 4: Social cognitive mapping

Next, the ICM were aggregated into social cognitive maps (SCM) per group by an arithmetic addition of the individual adjacency matrices. In this way, the 'weight' of a relationship in the SCM corresponded with the number of respondents having discussed the relationship. These SCM give information on the knowledge content and structure of a group, aggregating individual perceptions.

3.2.5 Step 5: Data analysis

FCM can be analyzed using a wide variety of techniques and approaches, but to date there is no general agreement on which metrics to use and their interpretation (Yoon and Jetter, 2016). In this study, a comparative analysis was performed in order to compare understanding between groups, focusing on a comparison of knowledge between scientists and managers (Yoon and Jetter, 2016). By focusing on the SCM, the role of the coder in performing the transcript coding is reduced.

In order to assess if sample sizes were sufficiently large, accumulation curves were reconstructed based on the number of new relationships, following the method described in Vanwindekens et al. (2013). These curves were calculated for the four groups that are analyzed in this study (scientists, managers, Flemish forest stakeholders and Romanian forest stakeholders) and are included in Appendix C (Figure C.1). A saturation was found for forest scientists, forest managers and Flemish forest stakeholders, indicating sufficiently large sample sizes for these groups. While no saturation occurred for Romanian forest stakeholders, the curve seemed to be levelling off, which suggests that the Romanian sample size is still adequate. Moreover, the sample sizes are comparable to sample sizes used in other studies where no saturation curves were constructed or saturation curves were constructed for the entire sample (e.g. Bosma et al., 2017; Olazabal et al., 2018a; Vuillot et al., 2016). In addition, the application of a framework in this study might lower sample size needs by offering respondents a structure (Bosma et al., 2017; Gray et al., 2012; Jetter and Kok, 2014). Nevertheless, because of the implications that the limited sample size might have, we focus on the comparison between scientists and managers and acknowledge that caution is needed when interpreting the results of the comparison between Flanders and Romania.

The SCM were analyzed and compared based on their structure and content. The structural analysis relied on the number of concepts and relationships, as well as graph theory indicators defined by Özesmi & Özesmi (2004). Specifically, these indicators include the link-node ratio, a concept's indegree and outdegree, which determines receiver or transmitter nature, as well as a concept's centrality. Definitions and formulas of these indicators are included in Table 3. The content analysis focused on the SCM. Specifically, a condensed version of the SCM was constructed by including only relationships that were mentioned by at least half of the sample. To ease comparison between groups, nodes that were shared between SCM, were placed at more or less the same location. In addition, concepts' centrality values were calculated and normalized by dividing the centrality values by the sample size of each group, represented by the number of interviews. Hence, normalized centrality values reflect the total weight, or number, of relationships coming in to and going out from a concept, as would be mentioned by one average member of each group. These normalized centrality values were also used as the node size in the condensed SCM, while the arrow sizes in the condensed SCM reflected relationship weights. Furthermore, an explorative comparative analysis was performed on the relationship weights. The aim of this explorative analysis was to asses which relationships deserve further investigation in follow-up research rather than concluding true significance. Specifically, relationship weights were compared between groups, through a contingency table and Fisher Exact Tests that are suited for low sample sizes, as explained in Vanwindekens et al. (2014). Nevertheless, caution should be taken when interpreting the results of these tests for the assessment of the context dependency effect because of the relatively large difference in sample size between Flanders ($N_I = 17$) and Romania ($N_I = 7$) and the rather low sample size for Romania. Lastly, findings on concepts' centrality and relationship weights were combined to get deeper insights in clusters of relationships and detailed analysis of these clusters was performed using the quote-retrieving module that is part of the Rpackage cogmapr.

Whereas the analysis focused on the comparison of soil biodiversity between groups, heterogeneity within groups was also assessed using the ICM. This analysis calculated the mean and standard deviation of the graph theory indicators (see formulas in Table 3) based on the ICM within each group. In addition, a dissimilarity matrix was constructed for each group, that depicts the degree of dissimilarity in included concepts between each pair of ICM in that group. This matrix was calculated through the 'dist' function in R and relied on the Jaccard Similarity Index, which is equal to the intersection of concepts between a pair of ICM divided by the union of concepts in that pair of ICM (Olazabal et al., 2018a). The R function 'dist' of the stats package transform this similarity index (S) in a dissimilarity index (D) by subtracting the similarity index from 1 ($D = 1 - S$) (Borcard et al., 2011).

Table 3: Formula and definition of main graph theory indicators for analysis of CM structure. Adapted from Yoon & Jetter (2016) and Özesmi & Özesmi (2004).

Indicator	Formula	Definition
Number of concepts	N	- Total number of concepts articulated in a map.
Indegree	$Id_i = \sum_{k=1}^{N} \lvert a_{ki} \rvert$	- Sum of weights of all relationships arriving at a node or concept. - Cumulative strength of relationships (a_{ki}) through which a concept is affected by other concepts.
Outdegree	$Od_i = \sum_{k=1}^{N} \lvert a_{ik} \rvert$	- Sum of weights of all relationships (a_{ik}) departing from a node or concept. - Cumulative strength of relationships with which a concept influences other concepts.
Transmitter	$T\ (Od_i \neq 0\ and\ Id_i = 0)$	- A concept is a transmitter if it only influences other concepts (i.e. forcing variables or tails).
Receiver	$R\ (Od_i = 0\ and\ Id_i \neq 0)$	- A concept is a receiver if it is only influenced by other concepts (i.e. utility variables or heads).
Ordinary	$O\ (Od_i \neq 0\ and\ Id_i \neq 0)$	- A concept is ordinary if it is influenced by and also influences other concepts.
Centrality	$c_i = Od_i + Id_i$	- Degree to which a concept is connected to other concepts expressed as the sum of all relationship weights coming in to or going out from that concept.
Number of relationships	C	- Total number of connections, linking two concepts, in a map.
Link-node ratio	C/N	- Degree of connectivity between concepts. Higher ratio indicates that connections between concepts are denser.

4. Results

Prior to the cognitive mapping analysis, the integrated framework was reconstructed per group based on the individual interview transcripts and focusing on the most frequently mentioned concepts. The results of this step are added in Appendix D and will not be further discussed here. In total, 1604 quotations were coded as relationships between two concepts. The number of quotations per individual ranged from 23 to 146 with an average of 65.9 and a standard deviation of 33.0. An example of an individual cognitive map, including an example of the coding process, is added in Appendix E.

4.1 Comparison of soil biodiversity understanding between scientists and forest managers

This section compares the social cognitive maps (SCM) of scientists and managers, of which a condensed version is shown in Figure 2, taking together Flemish and Romanian respondents and depicting only relationships that are mentioned by at least half of the sample for both groups. Scientists seemed to share a higher number of relationships between at least half of their sample, compared to managers. All concepts present in managers' condensed SCM were also included in scientists' SCM, except for the forest ecosystem services *water regulation* and *carbon sequestration*. Ten concepts were present in the scientists' condensed SCM and not in the managers' condensed SCM.

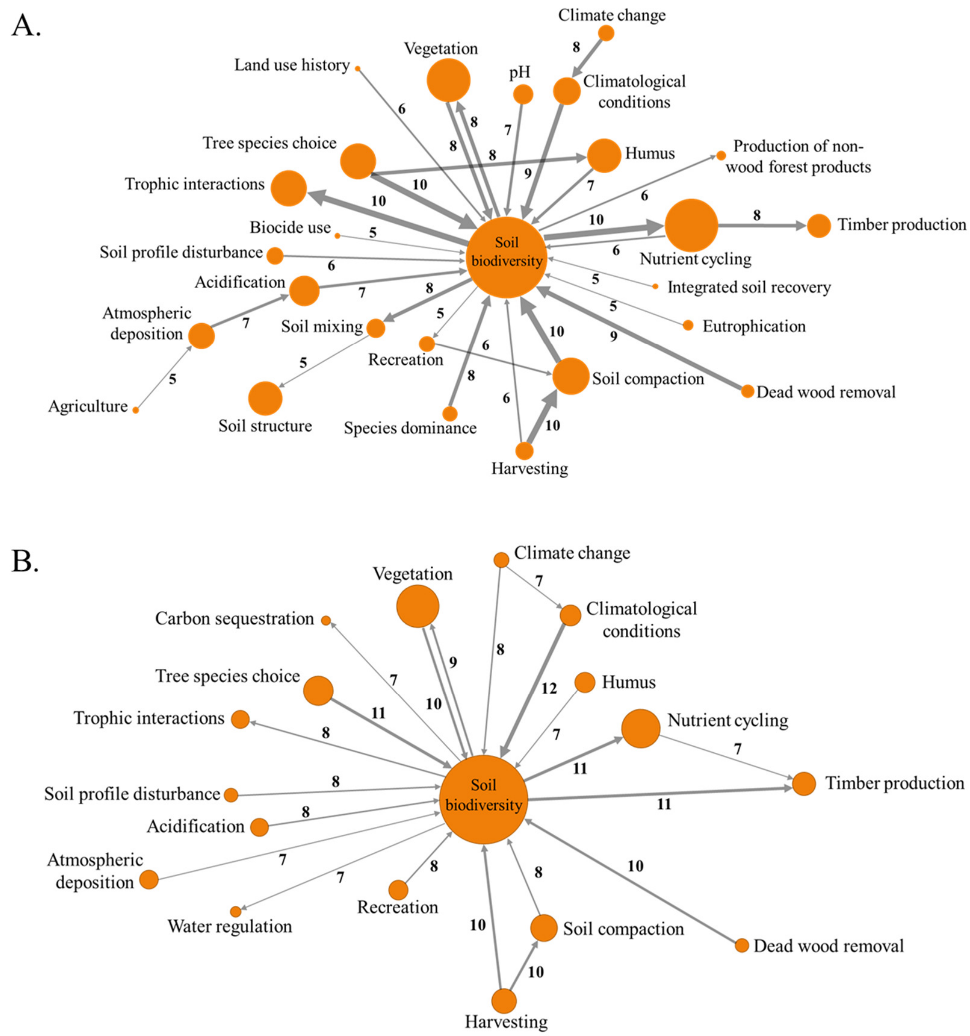


Figure 2: Condensed social cognitive maps (SCM) related to forest soil biodiversity of forest scientists (A) (N_I=10) and forest managers (B) (N_I=14). Only relationships being mentioned by at least half of the sample are shown, corresponding with a minimal weight of 5 and 7, for scientists and managers respectively. Node size reflects concepts' centrality, normalized for sample size, and arrow size reflects relationship weight. Nodes present in both SCM are placed at more or less the same location to facilitate comparison.

Scientists included 62 concepts and 238 relationships, whereas managers mentioned 58 concepts and 209 relationships (Table 4). Lastly, the link-node ratio was similar for scientists (3.84) and managers (3.60), which reflects comparable connectivity for both groups.

Table 4: Graph theory indicators of social cognitive map for forest scientists and managers.

	Forest scientists	Forest managers
No of individual maps	10	14
No of concepts	62	58
No of transmitter concepts	14	18
No of receiver concepts	7	7
No of ordinary concepts	41	33
No of relationships	238	209
Link-node ratio	3.84	3.60

The centrality values are included in Appendix F (Table F.1), while the concepts with highest centrality values, selected over all groups, are depicted in a radar chart in Figure 3. As expected, *soil biodiversity* had highest normalized centrality, which can be linked to the interview format that focused on *soil biodiversity* as the central component of the framework. Therefore, this concept will not be taken further into consideration. The normalized centralities for this set of concepts ranged from 1.3 to 5.6. Scientists included *nutrient cycling* as the most central concept, followed by *vegetation*, *soil compaction*, *tree species choice*, *trophic interactions* and *humus*. On the other hand, managers attributed highest centrality to *vegetation*, followed by *nutrient cycling*, *tree species choice*, *soil compaction*, *harvesting* and *timber production*. Centrality values were at least one unit higher in scientists' SCM for *soil compaction*, *nutrient cycling*, *atmospheric deposition*, *soil structure*, *acidification*, *humus* and *trophic interactions*. Only *harvesting* and *recreation* had a slightly higher normalized centrality in managers' SCM, although this difference seems negligible. Hence, whereas the four most central concepts corresponded between both groups, scientists seemed to attribute higher importance to processes, such as *trophic interactions* and *acidification*, and concepts describing specific soil related characteristics, such as *humus* and *soil structure*. Moreover, as can be derived from Table 4, scientists included four concepts that were absent in the managers' SCM. Two of them describe "ecosystem functions" (*gas exchange* and *soil forming processes*), whereas the other two are "ecosystem services" directly delivered by soil (*heritage appreciation* and *soil conservation*).

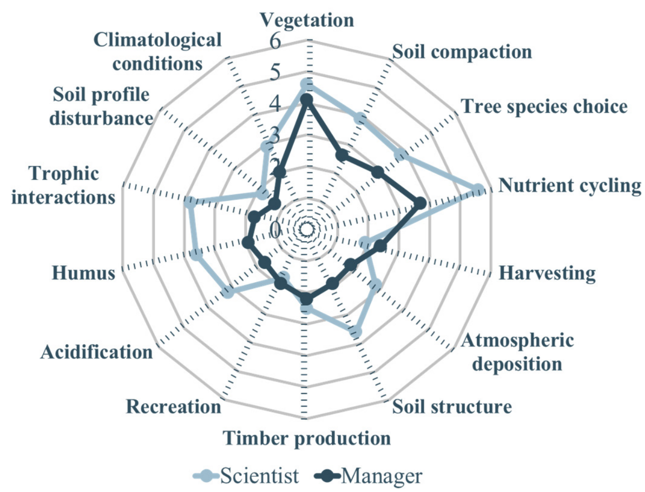


Figure 3: Radar chart of normalized centrality values of concepts with overall highest centrality for forest scientists and managers. Centrality values are normalized for different sample sizes by dividing them by the number of interviews in each group ($N_{I,\ scientists}$=10; $N_{I,\ managers}$=14). Normalized centrality values reflect the total weight, or number, of relationships coming in to and going out from a concept, as would be mentioned by one average member of each group.

Using a significance level of 0.05, seven relationships had a higher weight in scientists' SCM and one relationship had a higher weight in managers' SCM (Table 5).While p-values are rather high to conclude true significance, they give an indication on which relationships potentially encompass differences in knowledge. Scientists seemed to include more relationships linked to process concepts in their SCM, such as *nutrient cycling*, *soil compaction*, *soil mixing* and *eutrophication*. These process concepts belong to the framework sections "driver", "pressure" or "ecosystem functions". In addition, they seemed to incorporate more often relationships with descriptive soil "state" concepts such as *nutrient content*, *pH* and *soil structure*. Scientists also seemed to value the direct or inherent value of soil biodiversity more, as suggested by the relationship between *soil biodiversity* and *biodiversity conservation*. On the other hand, managers seemed to attribute higher weights to a direct relationship from *recreation* to *soil biodiversity*, stressing the pressure that recreation puts on soil biodiversity.

Table 5: Significantly different relationships between forest scientists and managers based on relationship weight, taking different sample sizes into account (Fisher Exact test, α=0.05, ranked by p-value). N_I represents the number of interviews or maps per group.

	Scientists $N_I = 10$	Managers $N_I = 14$	p-value	Significance
Soil biodiversity → Biodiversity conservation	4	0	0.020	S>M
Nutrient cycling → Nutrient content	4	0	0.020	S>M
Soil compaction → Soil biodiversity	10	8	0.024	S>M
pH → Soil biodiversity	7	3	0.035	S>M
Soil biodiversity → Soil mixing	8	5	0.047	S>M
Eutrophication → Soil biodiversity	5	1	0.050	S>M
Soil mixing → Soil structure	5	1	0.050	S>M
Recreation → Soil biodiversity	1	8	0.033	S<M

Based on the most important differences found at broader level, three clusters of relationships were selected to study in detail (Figure 4). Focusing on *soil structure* and *soil mixing*, a cluster of relationships was drawn as shown in panel A of Figure 4. Whereas managers mainly referred to *soil structure* through a direct link from *soil biodiversity*, scientists further specified this relationship through the process of *soil mixing*. Furthermore, *soil structure* served as a connection between *soil biodiversity* and *water regulation* in scientists' SCM, whereas managers mainly reported a direct link between *soil biodiversity* and the ecosystem service *water regulation.* Looking at the quotations, managers referred to *soil structure* mostly from an observational perspective, using vocabulary such as "hard", "soft", "air", "water", "wet". On the other hand, scientists generally adopted scientific terminology such as "soil porosity", "water retention capacity" and "bulk density".

Secondly, we focused on *atmospheric deposition, acidification* and *tree species choice* (Figure 4.B). Whereas managers mostly mentioned a direct relationship between *atmospheric deposition* and *soil biodiversity*, scientists seemed capable of providing further explanation of this relationship through the processes *acidification* and *eutrophication*. Nevertheless, managers were generally aware of the effect of *acidification* on *soil biodiversity*. Scientists linked *tree species choice* directly to *acidification*, as well as through *atmospheric deposition*, whereas managers only included the direct effect of *tree species choice* on *acidification.* Examining the quotations, scientists explained that specific tree species are more susceptible to capturing atmospheric deposition than others. This capturing effect would influence soil biodiversity by its effect on acidification. Managers did not mention this relationship between tree species choice and atmospheric deposition in their SCM.

Lastly, Figure 4.C highlights the relationship between *soil biodiversity* and *timber production*, encompassing the central concepts *nutrient cycling* and *trophic interactions* for both groups. Whereas managers focused on the direct link between *soil biodiversity* and *timber production*, and the link through *nutrient cycling*, scientists explained this relationship through both *nutrient cycling* and *trophic interactions*. Furthermore, scientists linked the functions *nutrient cycling* and *trophic interactions* to other ecosystem services than *timber production*, namely *carbon sequestration* and *biological control,* while these relationships were not mentioned by managers. Similarly, *nutrient cycling* was linked to two soil "state" concepts, *nutrient content* and *soil structure*, only by scientists. In addition, detailed understanding of the relationship between *soil biodiversity* and *nutrient cycling* differed between both groups, assessed through the quotations. Scientists demonstrated more detailed knowledge of this relationship by including links between a higher number of concepts, focusing on the inherent soil characteristics and using numbers and scientific terminology. On the other hand, managers' understanding of the relationship seemed to remain at a general level and referred directly to aboveground services and observations.

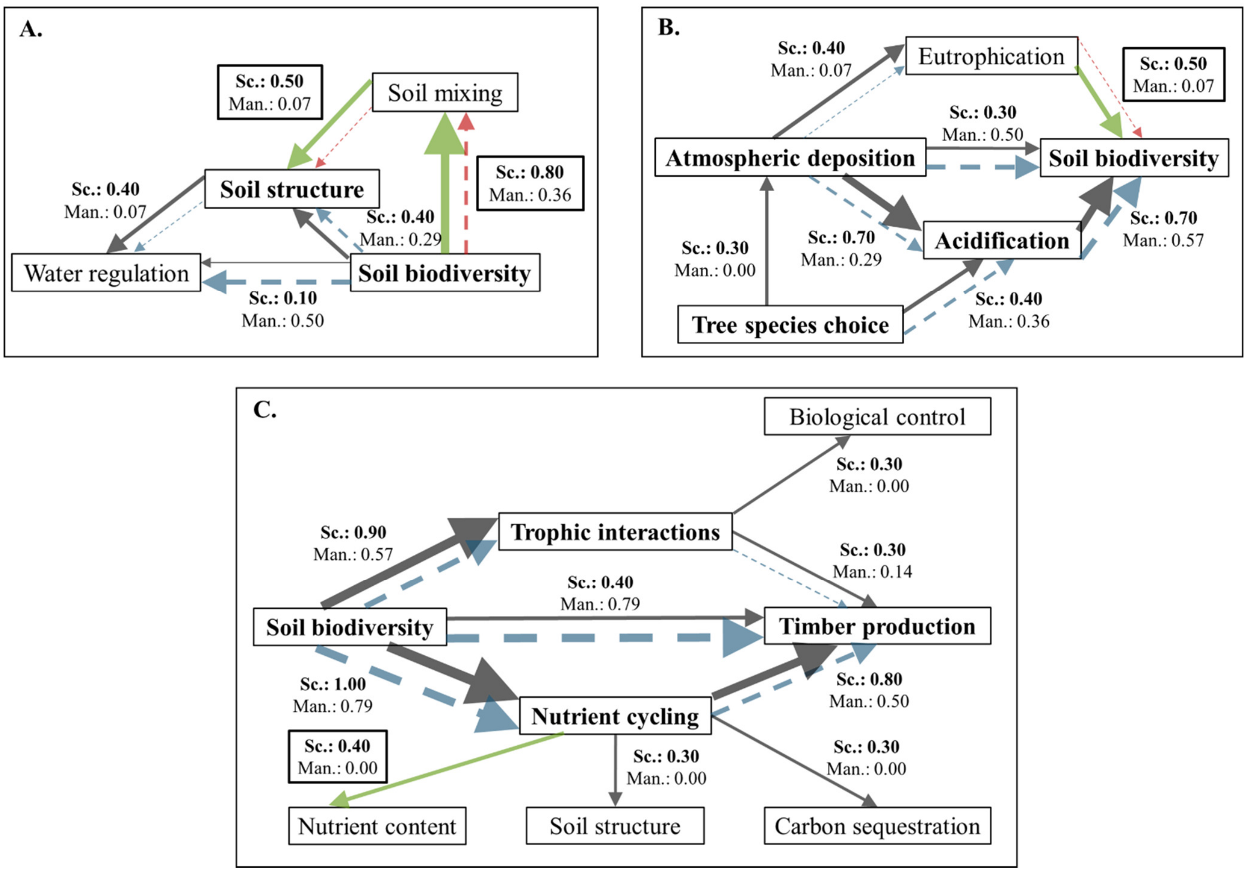


Figure 4: Three clusters of relationships (A, B and C) selected around concepts with high centrality and/or relationships that differed significantly between forest scientists and managers in the explorative Fisher Exact tests. Cluster A is built around *soil structure* and *soil mixing*, cluster B around concepts linked to *atmospheric deposition* and *acidification,* and cluster C around *nutrient cycling, trophic interactions* and *timber production.* Values correspond to relationship weight, normalized for the sample size of each group. The top values in bold reflect relationship weights of scientists (Sc.) and the bottom values reflect relationship weights of managers (Man.). The size of the arrows reflects these normalized relationship weights for scientists (dark grey solid line) and managers (blue dashed line). Concepts with high centrality are shown in bold and relationship weights that are significantly different are highlighted by a square. Moreover, for significant relationships, the arrow with the highest weight is indicated by a green arrow, while the arrow with the lowest weight is indicated by a red arrow.

4.2 Context dependency of soil biodiversity understanding

This section compares the SCM of Flemish and Romanian respondents, combining scientists and managers. The condensed SCM related to each region is shown in Appendix G and depicts only relationships that are mentioned by at least half of the sample (Figure G.1). Flemish interviewees shared concepts and relationships more intensively among themselves, compared to Romanian interviewees. In general, concepts present in the Romanian condensed SCM were also included in the Flemish condensed SCM, except for *soil profile disturbance* and *pH*. In contrast, the condensed SCM of Flemish respondents included *atmospheric deposition*, *acidification*, *recreation*, *humus, soil mixing*, *agriculture*, *biocide use* and *land use history* that were absent in Romanian respondents' condensed SCM.

A comparison of the graph theory indicators between the Flemish and Romanian SCM is added in table G.1 (Appendix G). Flemish respondents mentioned 62 concepts and 293 relationships, compared to Romanian respondents that reported 47 concepts and 114 relationships. The diverging number of concepts largely stems from a difference in ordinary or intermediate concepts, namely 41 for Flemish respondents compared to 25 for Romanian respondents. Lastly, the link-node ratio seems considerably higher for the Flemish SCM (4.73) compared to the Romanian SCM (2.43).

The analysis in this section focuses on the normalized centrality values that are listed in Appendix F and of which the radar chart is shown in Figure 5. The centrality values for this set of concepts ranged from 0 to 4.6 and were in general higher in the Flemish SCM than in the Romanian SCM. Flemish interviewees attributed highest centrality to *nutrient cycling*, followed by *vegetation*, *tree species choice*, *soil compaction* and *soil structure*. On the other hand, *nutrient cycling* was the most central concept in the Romanian SCM, followed by *vegetation*, *climatological conditions*, *trophic interactions* and *soil profile disturbance*. The largest gap in centrality between both regions was present for *atmospheric deposition*, with a value of 3.1 for Flanders compared to 0 for Romania, indicating that this concept was absent in the Romanian SCM. In addition, *soil compaction*, *tree species choice*, *recreation* and *acidification* had a centrality value that was more than one unit higher in the Flemish SCM compared to the Romanian SCM. In contrast, Romanian interviewees connected a higher centrality to *climatological conditions* and *soil profile disturbance*, compared to Flemish interviewees. The Flemish SCM included 62 concepts, compared to 47 in the Romanian SCM. Focusing on the concepts with highest centrality for Flanders, following concepts were absent in the Romanian SCM: *atmospheric deposition, agriculture, nutrient imbalance*, *liming and fertilizing*, *water level regulation* and *eutrophication*.

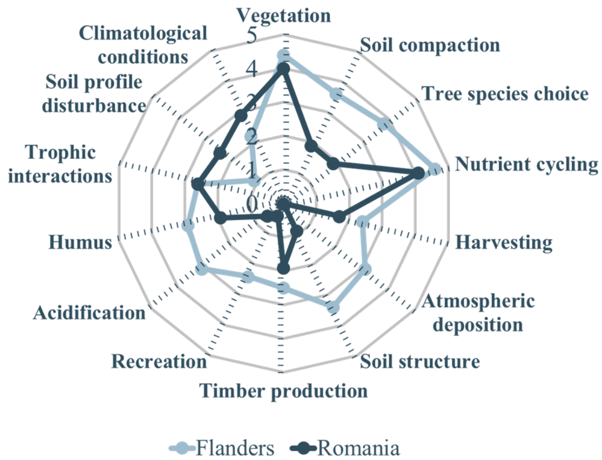


Figure 5: Radar chart of normalized centrality values of concepts with overall highest centrality for Flemish and Romanian interviewees. Centrality values are normalized for different sample sizes by dividing by the number of interviews in each group ($N_{I,\ Flanders}$=17; $N_{I,\ Romania}$=7). Normalized centrality values reflect the total weight, or number, of relationships coming in to and going out from a concept, as would be mentioned by one average member of each group.

The results of the explorative Fisher-exact tests for comparing relationship weights between Flanders and Romania are shown in Appendix G (Table G.2). Half of the relationships with significant differences in weight involved concepts that were only present in the Flemish SCM such as *atmospheric deposition* → *acidification*, *agriculture* → *atmospheric deposition and atmospheric deposition* → *soil biodiversity*. In addition, the relationship in both directions between *soil biodiversity* and *recreation* had significantly higher weight in the Flemish SCM. On the other hand *climatological conditions* → *soil profile disturbance* had a significantly higher weight in the Romanian SCM (α=0.05).

4.3 Comparison of soil biodiversity understanding within groups

In addition to the comparison between groups that was described in sections 4.1 and 4.2, the heterogeneity within groups is described in this section based on the ICM. Firstly, table H.1 of Appendix H shows the mean and standard deviation for the graph theory indicators calculated based on the ICM for each group. Substantial heterogeneity was found for all indicators in all groups. The average number of concepts and relationships was highest for scientists, followed by Flanders, managers and Romania. Secondly, the dissimilarity matrix was calculated for all groups and is displayed in Fig H.1 of Appendix H. This matrix presents the dissimilarity in the presence of concepts between each pair of ICM within each group. Darker cells correspond with higher rates of dissimilarity. Dissimilarity between ICM is lowest for Flemish respondents and scientists whereas it is highest for managers. For Romanian interviewees, dissimilarity seems at an intermediate level. This suggests that the concepts included in managers' ICM are most different from each other, which can be linked to the working landscape that is highly diverse over managers operating in their own environment. On the other hand, dissimilarity is lower for scientists that operate at a more general level executing similar experiments, are in closer contact and have similar access to international literature. Moreover, the low dissimilarity for Flemish interviewees could indicate the importance of context in determining which concepts are included in the ICM. Whereas this is not entirely confirmed by the intermediate level of dissimilarity for Romanian respondents, this could also be due to the relatively small sample size and the use of a translator for Romanian managers versus elicitation in English for Romanian scientists.

4.4 Forest management and soil biodiversity

Harvesting and *tree species choice* were among the most important concepts overall. Both scientists and managers referred to them as "response", as well as "driver", indicating that they can influence soil biodiversity both positively and negatively. Specifically, interviewees articulated that *tree species choice* negatively impacts soil biodiversity through using monocultures and exotic tree species whereas it can have a positive effect by favoring mixed and native species stands with a diversified structure. Similarly, interviewees, especially in the Flemish case study, mentioned that *harvesting* results in the pressure *soil compaction* through use of heavy machinery throughout the entire forest, while machines with adjusted tires that are only allowed to drive on fixed logging roads with additional protection, could protect soil biodiversity. Nevertheless, scientists attributed higher importance to *biocide use, integrated soil recovery* and *liming & fertilizing*. Scientists mostly referred to the latter two as subjects of scientific experiments with potential, but currently not (yet) applicable at large scale while *biocide use* was usually reported as a "pressure" that has recently been dealt with and is generally not applied anymore. Managers, on the other hand, focused on the most common practices *harvesting, tree species choice* and *dead wood removal.*

Managers articulated taking soil biodiversity inexplicitly into account in their management decisions, by considering soil as an umbrella concept. Soil was seen as a crucial component for the delivery of ecosystem services and therefore needed to be taken care off, but examination was rather superficial without soil monitoring or sampling. Managers paid only limited attention to specific soil components such as soil structure and soil biodiversity. Management decisions were primarily based on aboveground goals such as timber production. Despite managers' interest in increasing their knowledge on soil biodiversity, many believed that indirect consideration in management would already be beneficial for soil biodiversity. The following quotations illustrate some of these findings:

"I think we take soil biodiversity indirectly into account in our management, but not as primary focus. We see, this soil is now too compacted to realize a regeneration of trees, then we see it as a problem. But if it is not visible, we will not really take it into account." (Public forest manager, Belgium)

"I would say, this function of soil is addressed [in management], not necessarily linked to soil biodiversity but linked to preservation of soil to provide better quality of timber." (Forest scientist, Romania)

Additionally, reasons for low consideration of soil biodiversity in their forest management decisions were discussed. Soil's hidden character and slow rates of change were amongst the major reasons. Furthermore, the complexity of soil food webs and the lack of easy techniques to measure soil biodiversity were put forward as barriers to consider soil biodiversity explicitly in their management decisions. Additionally, managers addressed the need for translating and simplifying scientific knowledge into practical knowledge and location-specific management recommendations. Scientists agreed, but also acknowledged that scientific knowledge is not yet complete and managers should be more engaged. Soil biodiversity might be increasingly considered by strengthening awareness and understanding, using for example exhibitions, excursions and participatory actions. Some of these findings are illustrated by the following quotations:

"Yes, but it is also, well, it is poorly known, I'll put it like this, it is not very visible. When you do an intervention and new plants start to grow or other plants disappear, you directly observe it. But if your soil is compacted … you don't see the direct consequences of that, so you will be less triggered to take measures." (Public forest manager, Belgium)

"An important reason, I think, causing limited attention currently, is that everyone knows that it is important but it is very difficult to prove and to measure. It is not like you drill a hole in the soil or you take a soil sample and perform a cheap analysis. It doesn't work that way, it is difficult to measure, the soil biodiversity. It is also not visible, it is all hidden belowground." (Forest scientist, Belgium)

5. Discussion

This study uses a double check to reduce the effect of manual coding by a single researcher on the findings. While this double check increases reliability of the findings, the possible effect of a single principal coder should be kept in mind when interpreting the results. Specifically, the rate of agreement on concepts was relatively high for both checks (94% and 85%), indicating robustness in the included concepts. On the other hand, the interrater agreement on individual relationships was acceptable, but somewhat lower (64%). Nevertheless, this study focuses on the social cognitive maps, and specifically the centrality values and clusters of relationships that use values normalized for different sample sizes. Therefore, the effect of differences in individual relationships is somewhat reduced as the value of this relationship ("1") is divided by the number of respondents per group in the social cognitive map. Moreover, the study focuses on a comparison across groups, using a framework to facilitate knowledge elicitation. The consistency in coding found over time (check 1) suggests sufficient robustness.

5.1 Comparison of soil biodiversity understanding between scientists and forest managers

In general, scientists and managers selected a comparable set of concepts and relationships as most important. This finding is supported by previous studies, comparing mental models on a wide range of topics (Ingram et al., 2010; Lamarque et al., 2011; Vasslides and Jensen, 2016). Nevertheless, the structure of the condensed SCM and lower level of within group dissimilarity suggested that scientists had more knowledge in common with their peers. Specifically, the condensed SCM of scientists included a higher number of concepts and relationships compared to the condensed SCM of managers. In addition, scientists' (condensed) SCM covered a broader range of concepts and relationships. They included most concepts that were mentioned by managers in their condensed SCM, but added 10 concepts (out of 25). Managers' knowledge seemed to differ more between individuals, probably linked to their specific forest and management conditions, but also included practical considerations on forest management. In addition, scientists typically used specific terminology, referred to soil's intrinsic value and included management practices outside of what is currently widely performed. Scientists also explained relationships in more detail, especially related to "driving processes", "ecosystem functions" and soil "state" concepts, even for concepts that were important in both scientists' and managers' SCM, such as *nutrient cycling*. In contrast, managers mostly did not mention the soil's intrinsic value, focused on feasible improvements of the main current management practices and emphasized direct relationships, for example between *soil biodiversity* and "ecosystem services", without disclosing "ecosystem functions". Similar conclusions were drawn by Ingram et al. (2010), when they compared understanding of soil management between farmers and scientists. Specifically, they refer to deep but broad understanding of scientists as "know-why", whereas the practical knowledge of managers is categorized as "know-how" (Prager and Curfs, 2016). Furthermore, our findings can be related to differing objectives and personal experience, as was also suggested by Jabbour et al. (2014), Lamarque et al. (2011), Vasslides & Jensen (2016) and Wagner (2007). Scientists typically work with experimental set-ups to understand complex soil functioning and processes, and answer specific research questions, while managers mainly focus on successful "production" through site-specific and cost-efficient management practices, relying on both personal experience and that of co-workers. So, while we found that scientists have more detailed knowledge of soil biodiversity, the understanding of both scientists and managers depends on the environment or context in which they act. This context dependency is also related to "problem frames" that reflect how problems and goals are defined and perceived by different stakeholder groups (Juerges & Hansjurgens, 2018). These "problem frames" often differ between managers and scientists, but are both valid perspectives of a common problem. For example, managers may reason from an aboveground perspective as a related domain that they are familiar with, that they perceive as similar and that is the main focus of their daily activities (Jones et al., 2011). Scientists, on the other hand, may reason from the belowground system and are often very knowledgeable on a specific component of that system. However, they might overlook the general system at a landscape level in which managers have to make their decisions and for which knowledge of scientists with different specialties has to be merged.

Despite general understanding of the effect of forest management on soil biodiversity, especially related to *tree species choice, harvesting* and *dead wood removal,* results suggested that managers' decisions were mostly made to safeguard aboveground productivity and diversity, treating soil as a black box. Our results indicated that this focus on aboveground forest functioning seems to be mainly caused by the soil's hidden location belowground and lack of detailed understanding of belowground forest functioning. The latter was also detected as a main factor influencing mental models related to multiple topics in past research (Jones et al., 2011; Wagner, 2007). The concept 'adaptive management for soil ecosystem services', and more specifically ecosystem functions, is lately gaining more attention and seems promising to increase the consideration of soil biodiversity in forest management (Birgé et al., 2016; Juerges and Hansjürgens, 2018). As we found that managers mostly focus on ecosystem services, approaching sustainable forest management through these services could trigger managers to consider soil and soil biodiversity more explicitly. Additionally, linking ecosystem services to ecosystem functions in this management concept, might facilitate uptake of information on "ecosystem functions" and soil "state" variables, which we found to be lacking in managers' understanding. Similarly, Hartmann et al. (2014) mention that management mostly impacts soil processes and hence denotes these processes as crucial for future delivery of ecosystem services, instead of soil biodiversity per se, stressing the need for a good understanding of these processes and functions.

5.2 Context dependency of soil biodiversity understanding

The comparison between two contrasting regions revealed differences in understanding at the broader level of concepts, particularly related to "drivers" and "pressures". Despite these differences, both regions also included similar concepts and relationships linked to "ecosystem functions", "ecosystem services" and the soil's "state".

Whereas Flemish respondents stressed the importance of *atmospheric deposition*, *soil compaction*, *recreation* and related concepts, Romanian respondents put more emphasis on *soil profile disturbance*. These findings could be related to the social and forestry context of both regions. The Flemish case study is densely populated (444 inhabitants/square kilometer) and industrialized with few forests (6% forest cover), that are fragmented and often relatively young (Campioli et al., 2012). There is high competition for land leading to environmental "pressures" such as *atmospheric deposition*, causing *acidification* and *eutrophication,* and *soil compaction* due to amongst others, excessive *recreation* (VMM, 2018). In contrast, the Romanian region has a large forest cover (66%), experiences less environmental pressure, and hosts some primary forests (Knorn et al., 2012). These forests are often located on hilly terrain (400-1000 m.a.s.l.) making them relatively inaccessible. Specifically, about 6% of the total forest area in the Romanian region is conserved because it is located in a soil-sensitive area due to slopes higher than 30 degrees and another 2% that is conserved because of sensitivity to soil erosion and landslides (APM, 2020). These topographic characteristics could explain the importance of concepts related to *soil profile disturbance* (and *topography*) in the Romanian SCM. Similar to our findings, Dumitrascu and Stefanescu (2018) concluded that Romanian interviewees perceived erosion as the main threat for soil protection. Focusing on management practices, Romanian forest managers need to follow strict guidelines limiting their *tree species choice* (Nichiforel et al., 2018), which might explain why Romanian interviewees attributed less weight to this concept in our study, compared to Flemish interviewees. Furthermore, Flemish interviewees included *water level regulation*, while this concept was absent in the Romanian SCM. This difference might be linked to the case study area in Flanders, in which drainage systems were installed in the past to evacuate excessive water. While not being used anymore, these systems still influence water movement and level. Moreover, the hilly terrain of the Romanian case study more easily evacuates excess water resulting in no need for *water level regulation*. Similar to our findings, the influence of contextual factors, such as location, soil type, socio-economic and political factors on individual understanding and management decisions is widely acknowledged in previous research (e.g. Carnol et al., 2014; Goldmann et al., 2015; Hartmann et al., 2014). In particular, Feliciano et al. (2017) detected different forest management paradigms between Western and Eastern Europe, linked to the socio-political system and history. While Western Europe mostly stresses the importance of forest as ecosystems, Eastern Europe focuses more on forests' economic aspect, narrowing its attention compared to Western Europe. Lastly, Romanian respondents included 15 concepts less than Flemish respondents in our study (47 versus 62, respectively). This difference could be due to the specific context of each region, but could also suggest more limited knowledge of forest ecosystem functioning for Romanian respondents. The lower level of knowledge could then be linked to the strict and compulsory regulatory policy-making in Romania that hinders knowledge formation and exchange (Blujdea, 2005; Sousa-Silva et al., 2018). Nevertheless, the need for a translator in Romanian interviews with forest managers and the lower Romanian sample size might also have affected these results, as explained in sections 3.2.1.2 and 3.5.

5.3 Further research

This study was confronted with three main challenges, for which specific actions have been taken to limit their effects on the findings, as explained in the methodology description (section 3.2). Nevertheless, further research could improve our approach. As mentioned in section 3.2.1.2, respondents could also draw the cognitive map themselves instead of using semi-structured interviews, which was for example used by Gray et al. (2012). As soil biodiversity suffers from low visibility due to its location belowground, we considered knowledge mapping through semi-structured interviews the best approach. Nevertheless, respondents could be asked to draw a cognitive map of forest soil biodiversity at the end of the interview to summarize the discussion or could be contacted for feedback on the maps constructed through the coding process (Cunha et al., 2016; Gray et al., 2014). Secondly, the study could benefit from increased sample sizes, although this would require additional time and expense. Larger sample sizes could allow further in-depth analysis of knowledge both between and within groups. In addition, relationships could also be weighted for their strength, which would allow scenario analysis such as the effect of decreased removal of dead wood on soil biodiversity (e.g. Mehryar et al., 2017). Thirdly, this paper reports a small post hoc interrater agreement test performed after the transcript coding (see section 3.2.2). Ideally, this would be an iterative procedure in which two (or more) researchers code a limited number of interview transcripts independently at the start of the coding process, followed by discussion and alignment of differing interpretation in a number of cycles (McAlister et al., 2017). Therefore, future researchers are recommended to follow such approach to increase replicability of the codings and reliability of the findings. Moreover, while the differences in interview language were unavoidable, future research could strengthen the translation process by having the original translations back-translated by an independent researcher. This would especially add value in case of more complex topics. Lastly, through the integrated framework we tried to map the entire social-ecological system around forest soil biodiversity. Therefore, we were only able to compare understanding at a relatively broad level. By focusing on specific components of the system, for example related to effects of specific tree species, more detailed and practical knowledge could be obtained, which would probably differ between scientists and managers.

5.4 Policy implications

Despite an overall increasing attention for and awareness about soils and their biodiversity, soil is mostly indirectly implemented in (forest) policy and management causing continued soil issues (Montanarella and Lobos Alva, 2015). For example, no specific regulation on soils is present at EU-level, despite attempts starting from the Soil Thematic Strategy (Commission of the European Communities, 2006). This shortcoming is mainly caused by incomplete knowledge and suboptimal recognition of the crucial role of soils in the delivery of services and the current soil degradation issues (Montanarella and Lobos Alva, 2015). Nevertheless, forest management needs to take soil biodiversity into account in order to safeguard future delivery of crucial forest ecosystem services. Previous research found that managers often state the lack of information as main barrier to close the attitude-behavior gap concerning sustainable management (Juerges and Hansjürgens, 2018; Lähtinen et al., 2017; Sousa-Silva et al., 2018). Moreover, differences in mental models can be problematic for collaboration (van den Broek, 2018). To ensure effectiveness and uptake, past research considers it essential to integrate formal instruments, such as communication strategies, with insights into perceptions and knowledge of stakeholders through a bottom-up approach (Juerges and Hansjürgens, 2018; Kontogianni et al., 2012). Such approach was targeted in this paper through cognitive mapping of scientists' and managers' knowledge of soil biodiversity which can guide the development of information campaigns. We identified differences in understanding between scientists and managers, and Flanders and Romania, on which communication and conservation campaigns are recommended to rely, as tailoring messages to the target audience has been found to be the most effective (van den Broek, 2018). Specifically, results indicated that managers lack detailed information on the intrinsic value of soils, including specific soil characteristics such as *soil structure*, "ecosystem functions" such as *soil mixing* and *nutrient cycling*, and driving processes such as *eutrophication*. Moreover, managers had limited insights in detailed explanations of the relationships between concepts, in particular between soil biodiversity and management practices. Therefore, administering information on soil biodiversity could potentially increase adoption of forest management that supports soil biodiversity, but such information transfer should go beyond awareness raising and providing general information. The communication strategies should also be tailored towards the social and forestry context of managers, especially concerning "drivers" and "pressures" that influence soil biodiversity. Whereas Flemish managers were largely confronted with the threats of atmospheric deposition, acidification and eutrophication, Romanian managers worried more about erosion and issues with steep slopes. Additionally, the Romanian policy context that regulates forest management decisions more strictly might limit the range of management decisions considered.

While developing such communication strategies requires joint input and effort from scientists, policy makers and managers, there is an important role for policy makers to enhance conditions for knowledge exchange and discussion about soil biodiversity. Past research concluded that forest and soil policies should apply an inclusive approach to be effective, due to their dynamic and complex nature and the trade-offs involved between the diverse functions that forests are requested to fulfil (e.g. wood production, recreation, biodiversity conservation) (Šūmane et al., 2018). Such an approach comprises engagement of all stakeholders and integration of their knowledge to obtain a more inclusive and flexible governing (Adhikari and Baral, 2018; Carnol et al., 2014; Mendoza and Prabhu, 2006; Raymond et al., 2010). Conflicting perceptions and lack of consideration of implication issues may lead to low adoption of policy instruments (Rist et al., 2015). As can be concluded from our study, integrating scientists' in-depth knowledge of ecosystem functioning and managers' local knowledge of drivers, pressures and feasible management practices could result in a more coherent picture of the situation. In addition, the framework and method used in this study facilitate an inclusive and adaptive approach that can better handle uncertainties of management outcomes (Birgé et al., 2016; Šūmane et al., 2018). Specifically, the ESC-DSPIR-Adaptive management cycle framework allows consideration of ecosystem services and functions in parallel with recent developments in adaptive forest management (see figure 1 and section 5.1). In addition, the FCM approach could be used as a communication tool to facilitate integration of stakeholders' knowledge by detecting areas of similarity and dissimilarity in inexplicit mental models as was also concluded in previous studies (Christen et al., 2015; Kontogianni et al., 2012; Prager and Curfs, 2016). While areas of dissimilarity point at knowledge opaqueness and might prevent effective communication and policy design, areas of similarity could be a starting point for discussion and integration (Drescher and Perera, 2010; van den Broek, 2018). An area of dissimilarity could for example be the use of fixed skid trails that scientists consider essential to avoid soil compaction and its related effects on soil biodiversity, while managers often think that entering a forest with heavy machinery only once is not harmful (Ampoorter et al., 2012). Particularly in forest planning, such methodology was found to be little applied (Khadka et al., 2013), which highlights the potential of our approach to improve forest planning processes.

6. Conclusion

Our study contributes to an emerging research field that aims to combine ecological and social constructs and methodologies in order to increase insights in social perspectives of ecological systems, specifically focusing on forest soil biodiversity through an exploratory analysis. Despite a general awareness of soil biodiversity, differences in understanding of soil biodiversity between scientists and forest managers were found, as well as between contrasting regions. Managers seem 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. Forest managers state that they take soil biodiversity indirectly into account, considering soil as a black box for the delivery of aboveground services. As adaptive forest management is currently moving towards management for ecosystem functions and services, improved knowledge on functions delivered by soil biodiversity might result in better soil biodiversity conservation efforts. 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. This approach could improve adoption of sustainable management practices and could contribute to a flexible and adaptive management process.

7. Acknowledgements

We would like to thank the respondents for their contribution and effort. We would also like to thank Jan Goris, of the Flemish 'bosgroep Houtland' for bringing us into contact with the Flemish private forest managers, and Cosmin Cosofret for translating during the Romanian interviews. This research was part of the SoilForEUROPE project funded through the 2015-2016 BiodivERsA COFUND call for research proposals, with the national funders Agence Nationale de la Recherche (ANR, France), Belgian Science Policy Office (BELSPO, Belgium), Deutsche Forschungsgemeinschaft (DFG, Germany), Research Foundation Flanders (FWO, Belgium), and the Swedish Research Council (FORMAS, Sweden).

8. References

Addison, S.L., Smaill, S.J., Garrett, L.G., Wakelin, S.A., 2019. Effects of forest harvest and fertiliser amendment on soil biodiversity and function can persist for decades. Soil Biol. Biochem. 135, 194–205. https://doi.org/10.1016/j.soilbio.2019.05.006

Adhikari, K., Hartemink, A.E., 2016. Linking soils to ecosystem services - A global review. Geoderma 262, 101–111. https://doi.org/10.1016/j.geoderma.2015.08.009

Adhikari, S., Baral, H., 2018. Governing Forest Ecosystem Services for Sustainable Environmental Governance: A Review. Environments 5, 53. https://doi.org/10.3390/environments5050053

Agentia de Protectia Mediului (APM) Suceava, 2020. Proces verbal al Conferintei a II-a de amenajare pentru fondul forestier proprietate publica a statului administrat de Ocolul Silvic Rasca, din cadrul Directiei Silvice Suceava. http://www.anpm.ro/documents/27459/46773638/PV+Conferinta+II+OS+Rasca.PDF/035cb2c2-2f77-4097-92e5-eeca6fca4fe0. Posted 23.01.2020

Ampoorter, E., De Schrijver, A., Van Nevel, L., Hermy, M., Verheyen, K., 2012. Impact of mechanized harvesting on compaction of sandy and clayey forest soils: Results of a meta-analysis. Ann. For. Sci. 69, 533-542. https://doi.org/10.1007/s13595-012-0199-y

Baeten, L., Verheyen, K., Wirth, C., Bruelheide, H., Bussotti, F., Finér, L., Jaroszewicz, B., Selvi, F., Valladares, F., Allan, E., Ampoorter, E., Auge, H., Avăcăriei, D., Barbaro, L., Bărnoaiea, I., Bastias, C.C., Bauhus, J., Beinhoff, C., Benavides, R., Benneter, A., Berger, S., Berthold, F., Boberg, J., Bonal, D., Brüggemann, W., Carnol, M., Castagneyrol, B., Charbonnier, Y., Chećko, E., Coomes, D., Coppi, A., Dalmaris, E., Dănilă, G., Dawud, S.M., de Vries, W., De Wandeler, H., Deconchat, M., Domisch, T., Duduman, G., Fischer, M., Fotelli, M., Gessler, A., Gimeno, T.E., Granier, A., Grossiord, C., Guyot, V., Hantsch, L., Hättenschwiler, S., Hector, A., Hermy, M., Holland, V., Jactel, H., Joly, F.-X., Jucker, T., Kolb, S., Koricheva, J., Lexer, M.J., Liebergesell, M., Milligan, H., Müller, S., Muys, B., Nguyen, D., Nichiforel, L., Pollastrini, M., Proulx, R., Rabasa, S., Radoglou, K., Ratcliffe, S., Raulund-Rasmussen, K., Seiferling, I., Stenlid, J., Vesterdal, L., von Wilpert, K., Zavala, M.A., Zielinski, D., Scherer-Lorenzen, M., 2013. A novel comparative research platform designed to determine the functional significance of tree species diversity in European forests. Perspect. Plant Ecol. Evol. Syst. 15, 281–291. https://doi.org/10.1016/J.PPEES.2013.07.002

Baldwin, C., Lewison, R.L., Lieske, S.N., Beger, M., Hines, E., Dearden, P., Rudd, M.A., Jones, C., Satumanatpan, S., Junchompoo, C., 2016. Using the DPSIR framework for transdisciplinary training and knowledge elicitation in the Gulf of Thailand. Ocean Coast. Manag. 134, 163–172. https://doi.org/10.1016/j.ocecoaman.2016.09.005

Bardgett, R.D., Van Der Putten, W.H., 2014. Belowground biodiversity and ecosystem functioning. Nature 515, 505–511. https://doi.org/10.1038/nature13855

Baveye, P.C., Baveye, J., Gowdy, J., 2016. Soil "Ecosystem" Services and Natural Capital: Critical Appraisal of Research on Uncertain Ground. Front. Environ. Sci. 4:41. https://doi.org/10.3389/fenvs.2016.00041

Bell, S., 2012. DPSIR = A Problem Structuring Method? An exploration from the "imagine" approach. Eur. J. Oper. Res. 222, 350–360. https://doi.org/10.1016/j.ejor.2012.04.029

Berkes, F., Colding, J., Folke, C., 2008. Navigating social-ecological systems : building resilience for complexity and change. Cambridge University Press.

Birgé, H.E., Bevans, R.A., Allen, C.R., Angeler, D.G., Baer, S.G., Wall, D.H., 2016. Adaptive management for

soil ecosystem services. J. Environ. Manage. 183, 371–378. https://doi.org/10.1016/j.jenvman.2016.06.024
Blujdea, V., 2005. Studiu privind perceptia asupra impactului schimbarii climatice asupra pădurilor. Analele ICAS, 48, 151-160.
Borcard, D., Gillet, F., Legendre, P., 2011. Numerical Ecology with R, Springer International Publishing AG. https://doi.org/10.1007/978-3-319-71404-2
Bosma, C., Glenk, K., Novo, P., 2017. How do individuals and groups perceive wetland functioning? Fuzzy cognitive mapping of wetland perceptions in Uganda. Land use policy 60, 181–196. https://doi.org/10.1016/J.LANDUSEPOL.2016.10.010
Brockerhoff, E.G., Barbaro, L., Castagneyrol, B., Forrester, D.I., Gardiner, B., González-Olabarria, J.R., O'B. Lyver, P., Meurisse, N., Oxbrough, A., Taki, H., Thompson, I.D., Van Der Plas, F., Jactel, H., 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv 26, 3005–3035. https://doi.org/10.1007/s10531-017-1453-2
Cambi, M., Certini, G., Neri, F., Marchi, E., 2015. The impact of heavy traffic on forest soils: A review. For. Ecol. Manage. 338, 124–138. https://doi.org/10.1016/J.FORECO.2014.11.022
Campioli, M., Vincke, C., Jonard, M., Kint, V., Demarée, G., Ponette, Q., 2012. Current status and predicted impact of climate change on forest production and biogeochemistry in the temperate oceanic European zone: review and prospects for Belgium as a case study. J. For. Res. 17, 1–18. https://doi.org/10.1007/s10310-011-0255-8
Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486, 59–67. https://doi.org/10.1038/nature11148
Carnol, M., Baeten, L., Branquart, E., Grégoire, J.C., Heughebaert, A., Muys, B., Ponette, Q., Verheyen, K., 2014. Ecosystem services of mixed species forest stands and monocultures: Comparing practitioners and scientists perceptions with formal scientific knowledge. Forestry 87, 639–653. https://doi.org/10.1093/forestry/cpu024
Castellacci, F., Archibugi, D., 2008. The technology clubs: The distribution of knowledge across nations. Res. Policy 37, 1659–1673. https://doi.org/10.1016/j.respol.2008.08.006
Christen, B., Kjeldsen, C., Dalgaard, T., Martin-Ortega, J., 2015. Can fuzzy cognitive mapping help in agricultural policy design and communication? Land use policy 45, 64–75. https://doi.org/10.1016/J.LANDUSEPOL.2015.01.001
Commission of the European Communities, 2006. Thematic strategy for soil protection (COM 2006.231). European Commission Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of Regions. Brussels. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006DC0231&from=EN
Cunha, A.A.R., Silva Filho, J.L., Morais, D.C., 2016. Aggregation cognitive maps procedure for group decision analysis. Kybernetes 45, 589–603. https://doi.org/10.1108/K-04-2015-0092
Drescher, M., Perera, A.H., 2010. Comparing two sets of forest cover change knowledge used in forest landscape management planning. J. Environ. Plan. Manag. 53(5), 591-613. https://doi.org/10.1080/09640561003727110
Duckles, B., Scholler, D., Waring, E., Draper, J., Laderas, T., 2007. qcoder – lightweight package to conduct qualitative coding. Available at https://github.com/ropenscilabs/qcoder.
Dumitrascu, M., Stefanescu, S.L., 2018. Stakeholders' Perceptions on Soil Quality Relevance and on the Impact of Soil Protection Policies in Romania. 18th Int. Multidiscip. Sci. GeoConference SGEM2018, Ecol. Econ. Educ. Legis. 18. https://doi.org/10.5593/sgem2018/5.3/s28.096
ElSawah, S., Mclucas, A., Mazanov, J., 2013. Using a Cognitive Mapping Approach to Frame the Perceptions of Water Users About Managing Water Resources: A Case Study in the Australian Capital Territory. Water Resour. Manag. 27, 3441–3456. https://doi.org/10.1007/s11269-013-0357-5
Eurostat, 2015. Land cover statistics. [Data statistics]. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Land_cover_statistics#Land_cover_in_the_EU
Feliciano, D., Bouriaud, L., Brahic, E., Deuffic, P., Dobsinska, Z., Jarsky, V., Lawrence, A., Nybakk, E., Quiroga, S., Suarez, C., Ficko, A., 2017. Understanding private forest owners' conceptualisation of forest management: Evidence from a survey in seven European countries. J. Rural Stud. 54, 162–176. https://doi.org/10.1016/J.JRURSTUD.2017.06.016
Gari, S.R., Newton, A., Icely, J.D., 2015. A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean Coast. Manag. 103, 63–77. https://doi.org/10.1016/J.OCECOAMAN.2014.11.013
Goldmann, K., Schöning, I., Buscot, F., Wubet, T., 2015. Forest management type influences diversity and community composition of soil fungi across temperate forest ecosystems. Front. Microbiol.

https://doi.org/10.3389/fmicb.2015.01300
Gray, S., Chan, A., Clark, D., Jordan, R., 2012. Modeling the integration of stakeholder knowledge in social–ecological decision-making: Benefits and limitations to knowledge diversity. Ecol. Modell. 229, 88–96. https://doi.org/10.1016/j.ecolmodel.2011.09.011
Gray, Steven, Zanre, E., Gray, Stefan, 2014. Fuzzy Cognitive Maps as Representations of Mental Models and Group Beliefs, in: Papageorgiou, E. (Ed.), Fuzzy Cognitive Maps for Applied Sciences and Engineering. Springer Berlin Heidelberg, Berlin, pp. 29–48. https://doi.org/10.1007/978-3-642-39739-4_2
Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being, in: Raffaelli, D.G., Frid, C.L.J. (Eds.), Ecosystem Ecology: A New Synthesis. Cambridge University Press, pp. 110–139.
Hartmann, M., Niklaus, P.A., Zimmermann, S., Schmutz, S., Kremer, J., Abarenkov, K., Lüscher, P., Widmer, F., Frey, B., 2014. Resistance and resilience of the forest soil microbiome to logging-associated compaction. ISME J. 8, 226–244. https://doi.org/10.1038/ismej.2013.141
Ingram, J., Fry, P., Mathieu, A., 2010. Revealing different understandings of soil held by scientists and farmers in the context of soil protection and management. Land use policy 27, 51–60. https://doi.org/10.1016/J.LANDUSEPOL.2008.07.005
Jabbour, R., Zwickle, S., Gallandt, E.R., McPhee, K.E., Wilson, R.S., Doohan, D., 2014. Mental models of organic weed management: Comparison of New England US farmer and expert models. Renew. Agric. Food Syst. 29(4), 319-333. https://doi.org/10.1017/s1742170513000185
Jetter, A.J., Kok, K., 2014. Fuzzy Cognitive Maps for futures studies-A methodological assessment of concepts and methods. Futures 61, 45–57. https://doi.org/10.1016/j.futures.2014.05.002
Jones, N. a., Ross, H., Lynam, T., Perez, P., Leitch, A., 2011. Mental Model an Interdisciplinary Synthesis of Theory and Methods. Ecol. Soc. 16, 46–46. https://doi.org/46
Jones, N.A., Ross, H., Lynam, T., Perez, P., 2014. Eliciting Mental Models: a Comparison of Interview Procedures in the Context of Natural Resource Management. Ecology and Society 19(1): 13. http://dx.doi.org/10.5751/ES-06248-190113
Jucker, T., Bouriaud, O., Coomes, D.A., 2015. Crown plasticity enables trees to optimize canopy packing in mixed-species forests. Funct. Ecol. 29, 1078–1086. https://doi.org/10.1111/1365-2435.12428
Juerges, N., Hansjürgens, B., 2018. Soil governance in the transition towards a sustainable bioeconomy – A review. J. Clean. Prod. 170, 1628–1639. https://doi.org/10.1016/j.jclepro.2016.10.143
Khadka, C., Hujala, T., Wolfslehner, B., Vacik, H., 2013. Problem structuring in participatory forest planning. For. Policy Econ. 26, 1–11. https://doi.org/10.1016/J.FORPOL.2012.09.008
Knorn, J., Kuemmerle, T., Radeloff, V.C., Szabo, A., Mindrescu, M., Keeton, W.S., Abrudan, I., Griffiths, P., Gancz, V., Hostert, P., 2012. Forest restitution and protected area effectiveness in post-socialist Romania. Biol. Conserv. 146, 204-212. https://doi.org/10.1016/j.biocon.2011.12.020
Kontogianni, A.D., Papageorgiou, E.I., Tourkolias, C., 2012. How do you perceive environmental change? Fuzzy Cognitive Mapping informing stakeholder analysis for environmental policy making and non-market valuation. Appl. Soft Comput. 12, 3725–3735. https://doi.org/10.1016/J.ASOC.2012.05.003
Korboulewsky, N., Perez, G., Chauvat, M., 2016. How tree diversity affects soil fauna diversity: A review. Soil Biol. Biochem. 94, 94–106. https://doi.org/10.1016/j.soilbio.2015.11.024
Lähtinen, K., Toppinen, A., Suojanen, H., Stern, T., Ranacher, L., Burnard, M., Kitek Kuzman, M., 2017. Forest Sector Sustainability Communication in Europe: a Systematic Literature Review on the Contents and Gaps. Curr. For. Reports. 3, 173-187. https://doi.org/10.1007/s40725-017-0063-2
Lamarque, P., Meyfroidt, P., Nettier, B., Lavorel, S., 2014. How ecosystem services knowledge and values influence farmers' decision-making. PLoS One 9(9). https://doi.org/10.1371/journal.pone.0107572
Lamarque, P., Tappeiner, U., Turner, C., Steinbacher, M., Bardgett, R.D., Szukics, U., Schermer, M., Lavorel, S., 2011. Stakeholder perceptions of grassland ecosystem services in relation to knowledge on soil fertility and biodiversity. Reg. Environ. Chang. 11, 791–804. https://doi.org/10.1007/s10113-011-0214-0
Lawrence, A. and Gillett, S. 2011. Human Dimensions of Adaptive Forest Management and Climate Change: A Review Of International Experience. Forestry Commission Research Report. Forestry Commission, Edinburgh. i-iv + 1-44 pp.
Lemanceau, P., Maron, P.-A., Mazurier, S., Mougel, C., Pivato, B., Plassart, P., Ranjard, L., Revellin, C., Tardy, V., Wipf, D., 2015. Understanding and managing soil biodiversity: a major challenge in agroecology. Agron. Sustain. Dev. 35, 67–81. https://doi.org/10.1007/s13593-014-0247-0
Lewison, R.L., Rudd, M.A., Al-Hayek, W., Baldwin, C., Beger, M., Lieske, S.N., Jones, C., Satumanatpan, S., Junchompoo, C., Hines, E., 2016. How the DPSIR framework can be used for structuring problems and facilitating empirical research in coastal systems. Environ. Sci. Policy 56, 110–119. https://doi.org/10.1016/J.ENVSCI.2015.11.001
Lukac, M., 2017. Soil biodiversity and environmental change in European forests. Cent. Eur. For. J. 63, 59–65. https://doi.org/10.1515/forj-2017-0010

McAlister, A.M., Lee, D.M., Ehlert, K.M., Kajfez, R.L., Faber, C.J., Kennedy, M.S., 2017. Qualitative coding: An approach to assess inter-rater reliability. ASEE Annu. Conf. Expo. Conf. Proc. 2017-June. https://doi.org/10.18260/1-2--28777

MEA, 2005. Ecosystems and Human Well-Being. Island Press, Washington DC.

Mehryar, S., Sliuzas, R., Sharifi, A., Reckien, D., van Maarseveen, M., 2017. A structured participatory method to support policy option analysis in a social-ecological system. J. Environ. Manage. 197, 360–372. https://doi.org/10.1016/j.jenvman.2017.04.017

Mendoza, G.A., Prabhu, R., 2006. Participatory modeling and analysis for sustainable forest management: Overview of soft system dynamics models and applications. For. Policy Econ. 9, 179–196. https://doi.org/10.1016/J.FORPOL.2005.06.006

Meyfroidt, P., 2013. Environmental cognitions, land change, and social-ecological feedbacks: an overview. J. Land Use Sci. 8, 341–367. https://doi.org/10.1080/1747423X.2012.667452

Montanarella, L., Lobos Alva, I., 2015. Putting soils on the agenda: the three Rio Conventions and the post-2015 development agenda. Curr. Opin. Environ. Sustain. 15, 41–48. https://doi.org/10.1016/j.cosust.2015.07.008

Müller, F., Burkhard, B., 2012. The indicator side of ecosystem services. Ecosyst. Serv. 1, 26–30. https://doi.org/10.1016/J.ECOSER.2012.06.001

Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Jellesmark Thorsen, B., Winkel, G., Avdibegović, M., Dobšinská, Z., Feliciano, D., Gatto, P., Gorriz Mifsud, E., Hoogstra-Klein, M., Hrib, M., Hujala, T., Jager, L., Jarský, V., Jodłowski, K., Lawrence, A., Lukmine, D., Pezdevšek Malovrh, Š., Nedeljković, J., Nonić, D., Krajter Ostoić, S., Pukall, K., Rondeux, J., Samara, T., Sarvašová, Z.A., Elena Scriban, R., Šilingienė, R., Sinko, M., Stojanovska, M.B., Stojanovski, V.B., Stoyanov, N.C., Teder, M.D., Vennesland, B.E., Vilkriste, L.F., Wilhelmsson, E.G., Wilkes-Allemann, J.H., Bouriaud, L., 2018. How private are Europe's private forests? A comparative property rights analysis. Land use policy 76, 535–552. https://doi.org/10.3929/ethz-b-000250212

Nielsen, U., Wall, D.H., Six, J., 2015. Soil Biodiversity and the Environment. Annu. Rev. Environ. Resour. 40, 63–90. https://doi.org/10.1146/annurev-environ-102014-021257

Olazabal, M., Chiabai, A., Foudi, S., Neumann, M.B., 2018a. Emergence of new knowledge for climate change adaptation. Environ. Sci. Policy 83, 46–53. https://doi.org/10.1016/j.envsci.2018.01.017

Olazabal, M., Neumann, M.B., Foudi, S., Chiabai, A., 2018b. Transparency and Reproducibility in Participatory Systems Modelling: the Case of Fuzzy Cognitive Mapping. Syst. Res. Behav. Sci. 35, 791–810. https://doi.org/10.1002/sres.2519

Orgiazzi, A., Bardgett, R.D., Barrios, E., Behan-Pelletier, V., Briones, M.J.I., Chotte, J.-L., De Deyn, G.B., Eggleton, P., Fierer, N., Fraser, N., Hedlund, K., Jeffery, S., Johnson, N.C., Jones, A., Kandeler, E., Kaneko, N., Lavelle, P., Lemanceau, P., Miko, L., Montanarella, L., Moreira, F.M.S., Ramirez, K.S., Scheu, S., Singh, B.K., Six, J., van der Putten, W.H., Wall, D.H., (Eds.), 2016. Global Soil Biodiversity Atlas. European Commission, Publications Office of the European Union, Luxembourg.

Özesmi, U., Özesmi, S.L., 2004. Ecological models based on people's knowledge: A multi-step fuzzy cognitive mapping approach. Ecol. Modell. 176, 43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Prager, K., Curfs, M., 2016. Using mental models to understand soil management. Soil Use Manag. 32, 36–44. https://doi.org/10.1111/sum.12244

Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., Evely, A.C., 2010. Integrating local and scientific knowledge for environmental management. J. Environ. Manage. 91, 1766–1777. https://doi.org/10.1016/J.JENVMAN.2010.03.023

Rist, L., Shackleton, C., Gadamus, L., Stuart, F., Iii, C., Gowda, C.M., Setty, S., Kannan, R., Uma Shaanker, R., 2015. Ecological Knowledge Among Communities, Managers and Scientists: Bridging Divergent Perspectives to Improve Forest Management Outcomes. Environ. Manage. 57, 798–813. https://doi.org/10.1007/s00267-015-0647-1

Robinson, O.C., 2014. Sampling in Interview-Based Qualitative Research: A Theoretical and Practical Guide. Qual. Res. Psychol. 11, 25–41. https://doi.org/10.1080/14780887.2013.801543

Smeets, E., Weterings, R., 1999. Environmental indicators : Typology and overview. Eur. Environ. Agency 25, 19.

Sousa-Silva, R., Verbist, B., Lomba, Â., Valent, P., Suškevičs, M., Picard, O., Hoogstra-Klein, M.A., Cosofret, V.C., Bouriaud, L., Ponette, Q., Verheyen, K., Muys, B., 2018. Adapting forest management to climate change in Europe: Linking perceptions to adaptive responses. For. Policy Econ. 90, 22–30. https://doi.org/10.1016/j.forpol.2018.01.004

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., Rios, I. des I., Rivera, M., Chebach, T., Ashkenazy, A., 2018. Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. J. Rural Stud. 59, 232–241. https://doi.org/10.1016/J.JRURSTUD.2017.01.020

Thees, O., Olschewski, R., 2017. Physical soil protection in forests - insights from production-, industrial- and institutional economics. For. Policy Econ. 80, 99–106. https://doi.org/10.1016/j.forpol.2017.01.024
van den Broek, K., 2018. Illuminating divergence in perceptions in natural resource management: A case for the investigation of the heterogeneity in mental models. J. Dyn. Decis. Mak. 4, 2. https://doi.org/10.11588/jddm.2018.1.51316
Van Der Sluis, T., Arts, B., Kok, K., Bogers, M., Busck, A.G., Sepp, K., Loupa-Ramos, I., Pavlis, V., Geamana, N., Crouzat, E., 2018. Landscape Research Drivers of European landscape change: stakeholders' perspectives through Fuzzy Cognitive Mapping Drivers of European landscape change: stakeholders' perspectives through Fuzzy Cognitive Mapping. Landsc. Res. 44, 458–476. https://doi.org/10.1080/01426397.2018.1446074
Vanwindekens, F.M., Baret, P. V., Stilmant, D., 2014. A new approach for comparing and categorizing farmers' systems of practice based on cognitive mapping and graph theory indicators. Ecol. Modell. 274, 1–11. https://doi.org/10.1016/J.ECOLMODEL.2013.11.026
Vanwindekens, F.M., Stilmant, D., Baret, P. V., 2013. Development of a broadened cognitive mapping approach for analysing systems of practices in social–ecological systems. Ecol. Modell. 250, 352–362. https://doi.org/10.1016/J.ECOLMODEL.2012.11.023
Vanwindekens, F.M., Stilmant, D., Baret, P.V., 2019. cogmapr: Cognitive Mapping Tools Based on Coding of Textual Sources. R package version 0.9.1. Available from https://CRAN.R-project.org/package=cogmapr
Vasslides, J.M., Jensen, O.P., 2016. Fuzzy cognitive mapping in support of integrated ecosystem assessments: Developing a shared conceptual model among stakeholders. J. Environ. Manage. 166, 348–356. https://doi.org/10.1016/j.jenvman.2015.10.038
Verheyen, K., Ceunen, K., Ampoorter, E., Baeten, L., Bosman, B., Branquart, E., Carnol, M., De Wandeler, H., Grégoire, J.-C., Lhoir, P., Muys, B., Setiawan, N.N., Vanhellemont, M., Ponette, Q., 2013. Assessment of the functional role of tree diversity: the multi-site FORBIO experiment. Plant Ecol. Evol. 146, 26–35. https://doi.org/10.5091/plecevo.2013.803
VMM, 2018. Environmental Outlook 2018. Solution for a sustainable future. https://doi.org/10.1016/S0026-0576(96)94124-0
Vuillot, C., Coron, N., Calatayud, F., Sirami, C., Mathevet, R., Gibon, A., 2016. Ways of farming and ways of thinking: do farmers' mental models of the landscape relate to their land management practices? Ecol. Soc. 21, 35. https://doi.org/10.5751/ES-08281-210135
Wagner, K., 2007. Mental Models of Flash Floods and Landslides. Risk Anal. 27, 671–682. https://doi.org/10.1111/j.1539-6924.2007.00916.x
World Bank, 2009. Measuring Knowledge in the World's Economies, Knowledge for Development Program. Washington DC.
Yoon, B.S., Jetter, A.J., 2016. Comparative analysis for Fuzzy Cognitive Mapping. Eng. Technol. Manag. Fac. Publ. Present. 112, 1897–1908. https://doi.org/10.1109/PICMET.2016.7806755
Yousefpour, R., Temperli, C., Jacobsen, J.B., Thorsen, B.J., Meilby, H., Lexer, M.J., Lindner, M., Bugmann, H., Borges, J.G., Palma, J.H.N., Ray, D., Zimmermann, N.E., Delzon, S., Kremer, A., Kramer, K., Reyer, C.P.O., Lasch-Born, P., Garcia-Gonzalo, J., Hanewinkel, M., 2017. A framework for modeling adaptive forest management and decision making under climate change. Ecol. Soc. 22(4), 40. https://doi.org/10.5751/ES-09614-220440

Appendices

Appendix A

Outline of questions from the interview guide:

Knowledge of forest experts on the role of forest soil biodiversity in forests

[INTRODUCTION]

1. STATE / SOIL BIODIVERSITY

S State of forest soil	**1.** What does soil biodiversity mean to you? **2.** Which physical factors or processes do you think determine soil quality? **3.** Which chemical factors or processes do you think determine soil quality? **4.** Which biological factors or components do you think determine soil quality? **5.** Do you think that some or all of these soil components interact? What is the nature of their relation in your opinion? How do they interact with soil biodiversity? Which groups of soil fauna do you think are responsible for these relations?

2. Impact / Ecosystem services

I Impact	**6.** Where can soil biodiversity be useful for in your opinion? **7.** What are the most relevant ecosystem services, or goods and services that are useful for humans, that forests deliver in your opinion? **8.** Which of these ecosystem services do you think are supported by soil biodiversity? **9.** Which aspect of soil biodiversity is, in your opinion, most important for this provisioning of ecosystem services? **10.** Which mechanisms and processes (performed by soil fauna) are leading to these ecosystem services, in your opinion?

3. Pressure and Driving factors

P Pressure	**11.** Which processes do you think exert a pressure on the forest soil, and specifically on soil biodiversity in forests?
D Driving forces	**12.** Which driving factors (forces) cause pressures on forest soil and its biodiversity, in your opinion?

4. Response / Management

R Response	**13.** How can you best describe the state of soil biodiversity in [country/region] forest? And compared to the European situation? Do you think that there is a need to intervene? **14.** Which interventions or measures can be taken to obtain an optimal soil biodiversity in forests? **15.** Does forest management influence soil biodiversity in your opinion? **16.** Which management interventions do you think affect soil biodiversity? In which direction do they influence soil biodiversity (improve, deteriorate, no idea)? **17.** Do you feel that you are able to execute some of these management interventions <u>in practice</u> in your forest? Why (not)? Which interventions? **18.** Do you feel that these management interventions can be executed <u>in practice</u> in [country/region] forests? Why (not)? Which interventions? **19.** Is soil biodiversity in your opinion sufficiently accounted for in current forest management? (Why not?)

5. Link with aboveground/tree biodiversity

Link with tree biodiversity	**20.** Do you think that soil biodiversity and aboveground tree biodiversity are connected? **21.** How would you describe this relation? (positive, negative, etc.) In which direction does it flow? (which one is the cause and which one is the consequence?) **22.** In your opinion, is it an effect solely caused by the number of trees, irrespectively of which species are combined, or is the specific species combination important? **23.** Which mechanisms and processes do you think cause this relationship between both?

24. Do you still want to add something? Do you have further questions or remarks?

Appendix B

Table B.1: List of concepts and definitions developed by reconstructing the integrated framework based on literature and thorough reading of the interview transcripts. This list was established before transcript coding. For the definitions, experts were consulted and online encyclopedia were used. DPSIR refers to the Driver-Pressure-State-Impact-Response framework (Smeets and Weterings, 1999).

No.	Concept	Definition	Category DPSIR
1	Atmospheric deposition	Phenomenon through which pollutants, including gases and particles, are deposited from the atmosphere on the earth's surface, in the form of dust or precipitation.	Driver
2	Acidification	Change in natural chemical balance caused by an increase in the concentration of acidic elements.	Pressure
3	Eutrophication	Process by which pollution causes a water body to become overrich in organic and mineral nutrients so that excessive growth of plants and algae cause oxygen supply depletion.	Pressure
4	Soil compaction	Process in which a stress applied to the soil increases the density of soil.	Pressure
5	Climate change	Change in global or regional climate patterns, attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels.	Driver
6	Climatological conditions	The composite weather conditions of a region, as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds.	Pressure
7	Forest fire	A large destructive fire that spreads over a forest.	Driver
8	Species dominance	Degree to which a taxon is more numerous than its competitors in an ecologcial community, or makes up more of the biomass.	Driver
9	Forest fragmentation	Breaking of large, contiguous forested areas into smaller pieces of forest.	Driver
10	Land use history	Past uses of a plot of land.	Driver
11	Land use	Series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources.	Driver
12	Population increase	An increase in the number of people that reside in a country, state, county, or city.	Driver
13	Policy regulations	Governamental rule or mechanisms that limits, steers or controls social behaviour.	Driver
14	Transport	System of vehicles for getting from one place to another.	Driver
15	Agriculture	Practice of farming, including cultivation of the soil for the growing crops and the rearing of animals to provide food, wool and other products.	Driver
16	Nutrient imbalance	Excess or deficiency of nutrients in the soil. Difference between the nutrient inputs and the nutrient outputs.	Pressure
17	Soil profile disturbance	Process that redistributes the original layering of the soil.	Pressure
18	Texture	Soil property that indicates the relative content of particles of various sizes, such as sand, silt and clay.	Soil characteristic
19	Soil structure	Soil property that describes the arrangement of the solid parts of the soil and of the pore space located between them.	Soil characteristic
20	Soil profile	A vertical section of the soil from the ground surface downwards to where the soil meets the underlying rock.	Soil characteristic
21	pH	Chemical property expressing the acidity or alkalinity of the soil on a logarithmic scale.	Soil characteristic
22	Nutrient content	Amount of subtances that provide nourishment to plants and animals, present in the soil.	Soil characteristic
23	Base saturation	Extent to which the exchange sites of the soil's adsorption complex are occupied by exchangeable basic cations.	Soil characteristic

24	Pollutant content	Amount of substances in the soil that contaminates the environment.	Soil characteristic
25	Soil biodiversity	(Diversity of) living organisms present in soil such as bacteria, fungi, a wide variety of larger soil fauna and larger organisms.	Soil characteristic
26	Dead wood	Part of a tree or entire tree that is dead, standing or falling.	Soil characteristic
27	Plant and tree roots	Part of trees or plants that typically lies below the surface of the soil.	Soil characteristic
28	Humus	Dark organic material in the soil, formed by the decomposition of leaves and other plant material.	Soil characteristic
29	Nutrient cycling	Process that describes the use, movement and recycling of nutrients in the environment.	Ecosystem function
30	Water filtration	Process through which particles and pollutants are removed from the water while passing through the soil.	Ecosystem function
31	Flow mediation	Process through which the water flow is directed through the soil.	Ecosystem function
32	Trophic interactions	Feeding interactions between trophic levels which correspond with the position that an organisms occupies in a food chain.	Ecosystem function
33	Soil forming processes	Processes through which soil layers are formed.	Ecosystem function
34	Soil mixing	Process that restructures soil, by human or soil organism activity.	Ecosystem function
35	Root exchange	Process through which particles, gases and other substances are exchanged between roots and their environment.	Ecosystem function
36	Gas exchange	Diffusion of gases from an area of higher concentration to an area of lower concentration.	Ecosystem function
37	Biodiversity conservation	Conserving live on earth in all its forms and keeping natural ecosystems functioning and healthy.	Ecosystem service
38	Heritage appreciation	Appreciation for the inheritance value for artifacts present in the soil.	Ecosystem service
39	Water regulation	Process through which the amount and content of water is regulated in soil such as water filtration or water storage.	Ecosystem service
40	Carbon sequestration	Process through which greenhouse gasses are stored in the soil.	Ecosystem service
41	Timber production	Production of timber through growing trees.	Ecosystem service
42	Production of non-wood forest products	Production of products delivered by the forest, other than timber, such as mushrooms or berries.	Ecosystem service
43	Biological control	Activities of predators and parasites in ecosystems that act to control populations of potential pest and disease vectors.	Ecosystem service
44	Local climate regulation	Ability of an ecosystem to influence local climate and air quality by for example providing shade.	Ecosystem service
45	Soil conservation	Ability of an ecosystem to prevent soil erosion and ensure soil fertility.	Ecosystem service
46	Liming & fertilizing	Action of adding and spreading lime or fertilisers through a plot of land.	Management practice
47	Dead wood removal	Action of removing dead branches and standing or felled trees from a forest.	Management practice
48	Integrated soil recovery	Action encompassing multiple practices to improve soil before planting, including inoculation and local/precise fertilizer application.	Management practice
49	Rules and restrictions on recreation	Policy measures to restrict (open) access to forest for citizens to recreate.	Management practice
50	Forest structure diversification	Varying layering in the forest canopy through specific management actions such as thinning.	Management practice
51	Tree species choice	The choice of tree species to plant and/or favor as part of forest management.	Management practice
52	Harvesting	The process of felling trees and preparing them for transport.	Management practice

53	Thinning	The process of removing the smaller, weaker trees in order to favor good quality quality trees to grow.	Management practice
54	Litter removal	The process of taking away litter to use it for example in botanic applications.	Management practice
55	Soil restoration	The process of enhancing compacted soils to improve soil porosity.	Management practice
56	Biocide use	The application of a substance to destroy or inhibit the growth of (harmful) living organisms.	Management practice
57	Clear-cutting	The process of removing all trees in an area of forest.	Management practice
58	Water level regulation	All management practices that regulate the level of the ground water table such as the installation and maintenace of dikes.	Management practice
59	Recreation	Activity done for enjoyment, outside of work, in the forest.	Ecosystem service
60	Pollution	The presence in or introduction into the environment of a substance which has harmful or poisonous effects.	Driver
61	Vegetation	The plant cover in a forest.	Driver
62	Topography	The physical shape of a particular area, including its hills, valleys and rivers.	Driver

Appendix C

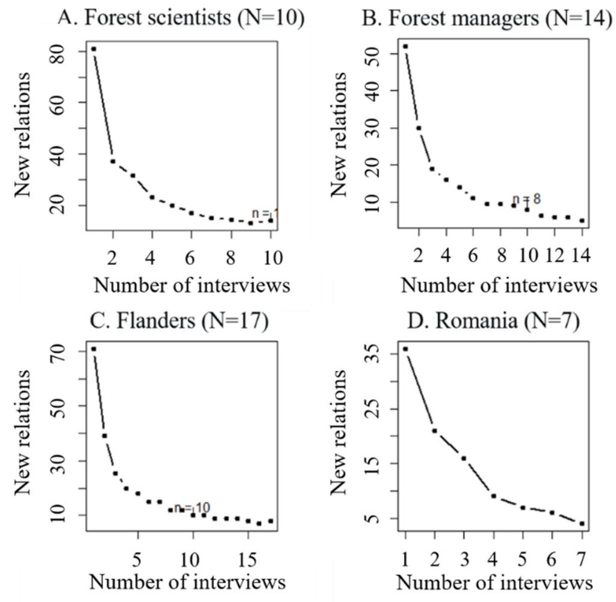


Figure C.1: Accumulation curves generated following the approach of Vanwindekens et al. (2013) to assess sample size requirements based on the number of new relationships for the four groups assessed in this study: forest scientists (A), forest managers (B), Flemish forest stakeholders (C) and Romanian forest stakeholders (D).

Appendix D

Table D.1 shows the reconstruction of the integrated ESC-DPSIR-Adaptive management cycle framework based on the individual interview transcripts. Specifically, all concepts that were mentioned by at least 50% of all respondents within a group are listed. Per group (Flemish forest scientists – N_I=7, Flemish forest managers – N_I=10, Romanian forest scientists – N_I=3, Romanian forest managers – N_I=4) concepts that were quoted by at least 75% of respondents are indicated by a cross (**X**), while concepts stated by 50-74% of respondents are shown using a circle (O).

Firstly, Flemish scientists shared the highest number of concepts among at least 50% of their sample and most of these concepts even among more than 75%. Overall, the categories "drivers" and "pressures" comprised the highest share of concepts with *harvesting* and *climatological conditions* being mentioned by at least 75% of respondents in all groups. In addition, *species dominance* and *climate change* were also shared among groups, albeit to a lower extent, and *soil compaction* and *acidification* were shared by at least 50% of respondents for three out of four groups. *Topography* was only present for at least 50% of Romanian respondents and also *soil profile disturbance* was more frequently mentioned by Romanian respondents. On the contrary, solely Flemish respondents shared *atmospheric deposition*, *agriculture* and *recreation* between at least half of their sample, whereas *land use history*, *forest fragmentation*, *nutrient imbalance* and *eutrophication* were only revealed by at least half of Flemish scientists. In general, the description of "physical soil quality", "chemical soil quality" and "biological soil quality" was comparable across groups mainly referred to by *texture* and *soil structure*, *nutrient content* and *pH*, and *soil biodiversity* for these three quality indicators respectively. Nevertheless, *base saturation* was only included by at least 50% of Flemish forest scientists and *pollutant content* only for Flemish respondents. *Nutrient cycling* and *trophic interactions* were two ecosystem functions shared by at least half of respondents in all groups, whereas *soil mixing* and *water filtration* were solely mentioned by at least 50% of Flemish scientists. In all groups at least half of the respondents included *timber production*, *water regulation* and *carbon sequestration* as ecosystem services in their frameworks. Lastly, *tree species choice* and *harvesting* were highly present as a "response" for all groups, whereas *dead wood removal* was only lacking for Romanian forest managers. *Liming & fertilizing*, *integrated soil recovery*, *restrictions on recreation* and *soil restoration* were solely mentioned by at least half of Flemish scientists while *water level management* was only included by at least 50% of Flemish forest managers. *Harvesting*, *tree species choice* and *water level regulation* were referred to as both a "pressure" and "response", suggesting a crucial role of forest management in maintaining soil biodiversity.

Table D.1: Comparison of the most frequently mentioned concepts related to the integrated ESC-DPSIR-Adaptive management cycle framework between four groups: Flemish forest scientists (N_I=7), Flemish forest managers (N_I=10), Romanian forest scientists (N_I=3) and Romanian forest managers (N_I=4). Concepts that were mentioned by at least 75% of respondents are indicated by a cross (X), while concepts that were quoted by 50-74% of respondents are indicated by a circle (O).

		Flemish scientists (N_I=7)	Flemish managers (N_I=10)	Romanian scientists (N_I=3)	Romanian managers (N_I=4)
1	Harvesting	**X**	**X**	**X**	**X**
2	Tree species choice	**X**		O	
3	Atmospheric deposition	**X**	O		
4	Agriculture	**X**	**X**		
5	Climate change	**X**	**X**	O	O
6	Species dominance	**X**	O	O	O
7	Land use history	**X**			
8	Clear-cutting	**X**		O	
9	Topography			**X**	O
10	Water level regulation		O		
11	Recreation	O	O		
12	Land use		O	O	O
13	Forest fragmentation	O			
14	Forest fires				O
15	Climatological conditions	**X**	**X**	**X**	**X**
16	Acidification	**X**	O		O
17	Soil compaction	**X**	**X**	O	
18	Nutrient imbalance	**X**			
19	Eutrophication	**X**			
20	Soil profile disturbance	O		O	**X**
21	Texture	**X**	**X**	**X**	O
22	Soil structure	**X**	**X**	**X**	O
23	Soil profile	O		O	O
24	Nutrient content	**X**	**X**	O	**X**
25	pH	**X**	**X**	**X**	**X**
26	Base saturation	**X**			
27	Pollutant content	O	O		
28	Soil biodiversity	**X**	**X**	**X**	**X**
29	Plant and tree roots	O	O	O	
30	Humus	O		O	O
31	Dead wood				O
32	Nutrient cycling	**X**	O	**X**	**X**
33	Soil mixing	**X**			
34	Trophic interactions	**X**	O	O	O
35	Water filtration	**X**			O
36	Timber production	**X**	**X**	**X**	**X**
37	Production of non-wood forest products	O		O	
38	Water regulation	**X**	O	O	O
39	Carbon sequestration	**X**	O	O	O
40	Local climate regulation		O		
41	Biological control	O			
42	Tree species choice	**X**	**X**	O	O
43	Liming and fertilising	**X**			
44	Harvesting	**X**	**X**	**X**	**X**
45	Dead wood removal	**X**	**X**	**X**	
46	Water level regulation		O		
47	Integrated soil recovery	O			
48	Restrictions on recreation	O			
49	Soil restoration	O			

Appendix E

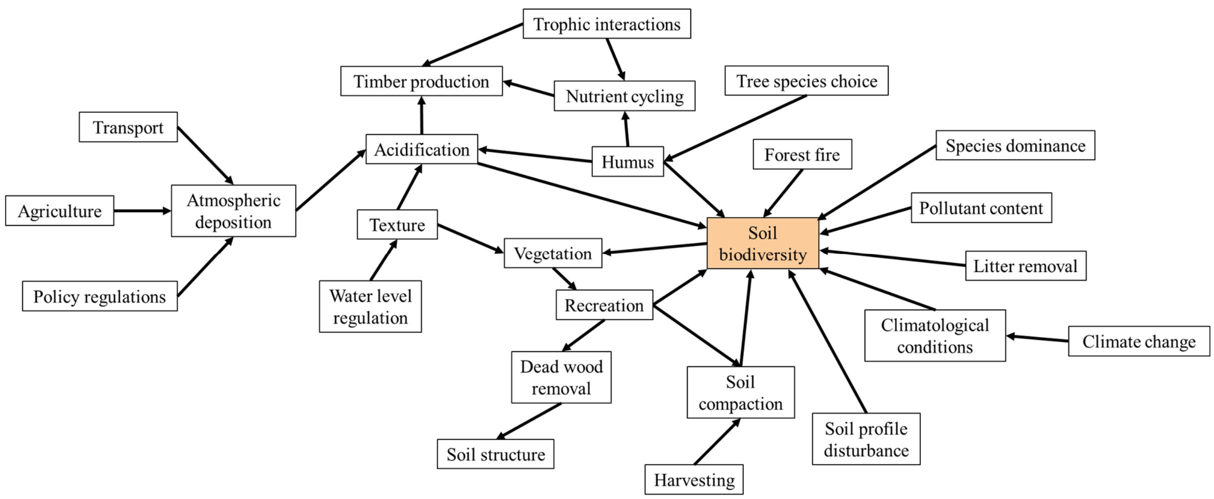


Figure E.1: Example of an Individual Cognitive Map (ICM) (Public forest manager, Flanders). The central concept *Soil biodiversity* is highlighted.

Table E.1: Example of the coding process in qcoder, showing part of the relationships linked to the ICM in Figure E.1 of this appendix.

Relationship			Interviewee's quotation
Nr	**From concept …**	**To concept …**	
1	Soil biodiversity	Soil structure	"Because it is the soil life that brings air and structure in the soil."
2	Soil biodiversity	Soil structure	"Soil life specifically improves the pore volume of your soil and thus the water storage capacity. And thanks to this, trees will grow better and if trees grow better, more CO_2 will be captured and so on."
	Soil biodiversity	Soil mixing	
	Soil mixing	Water regulation	
	Water regulation	Timber production	
	Timber production	Carbon sequestration	
3	Water level regulation	Soil biodiversity	"Also a big pressure [on soil biodiversity], I think, and it is a dangerous one because you can't see it, drought, general drought because of lowering ground water levels etc. And increasing water levels at other places … due to dikes that are no longer managed."
4	Recreation	Soil biodiversity	"Recreation is, at some places, also a pressure on soil biodiversity."
5	Harvesting	Nutrient cycling	"And I also won't do things such as forest milling and shredding, because that is a very unnatural speed of recycling food in the ecosystem and that is not very good."
6	Harvesting	Vegetation	"… that trees are stripped on the logging roads and that machines drive on these. Because, you drive on a sort of mattress of those branches. That brings a lot of resilience, literally, that makes that the soil pressure is largely distributed. And also, the system's nutrient balance evolves in the good direction."
	Harvesting	Nutrient imbalance	
	Harvesting	Soil compaction	
7	Harvesting	Soil compaction	" … that you are obliged to take out trees with horses. Or with a winch, if those trees don't allow for heavy machinery."

8	Tree species choice	Humus	"Planting the right trees, to ameliorate the humus quality."
9	pH	Soil biodiversity	"I also think if your pH is much higher and also you humus content, that you will have a much more active soil life that can recover quicker."
	Humus	Soil biodiversity	
10	Soil biodiversity	Soil mixing	"Especially bioturbation, from insects to miles, rabbits, I don't know, but everything that causes bioturbation, mixing of soils, is important."
11	Climate change	Climatological conditions	"… temperate climate but it is so disturbed that there are long periods of drought, heavy rainfall, …, I think that this will change soil biodiversity a lot."
	Climatological conditions	Soil biodiversity	

Appendix F

Table F.1: Centrality values of the concepts with highest centrality, selected over all groups. Scientists and managers are compared in the left hand side of the table, while Flemish and Romanian interviewees are compared in the right hand side. The value reflects the centrality, divided by the number of interviews in a group to normalize for sample size. In bold, the five concepts with highest centrality are shown for each group. Between brackets, the nature of the concept is shown relative to receiver and transmitter type, respectively, on a scale from 0 to 1 (see table 3 for definitions of receiver and transmitter).

	Scientists (N_I=10)	**Managers (N_I=14)**	**Flanders (N_I=17)**	**Romania (N_I=7)**
Soil biodiversity	27.8 (0.67-0.33)	21.6 (0.71-0.29)	26.6 (0.69-0.31)	18.3 (0.69-0.31)
Vegetation	**4.6 (0.57-0.43)**	**4.1 (0.68-0.32)**	**4.4 (0.64-0.36)**	**4.0 (0.69-0.31)**
Soil compaction	**3.9 (0.54-0.46)**	**2.6 (0.53-0.47)**	**3.6 (0.53-0.47)**	1.9 (0.54-0.46)
Tree species choice	**3.8 (0.13-0.87)**	**2.9 (0.20-0.80)**	**3.8 (0.18-0.82)**	1.9 (0.08-0.92)
Nutrient cycling	**5.6 (0.43-0.57)**	**3.7 (0.63-0.37)**	**4.6 (0.51-0.49)**	**4.1 (0.59-0.41)**
Harvesting	1.9 (0.11-0.89)	**2.4 (0.27-0.73)**	2.4 (0.22-0.78)	1.7 (0.17-0.83)
Atmospheric deposition	2.8 (0.36-0.64)	1.8 (0.40-0.60)	3.1 (0.38-0.62)	-
Soil structure	3.6 (0.64-0.36)	1.9 (0.59-0.41)	**3.4 (0.63-0.37)**	0.9 (0.50-0.50)
Timber production	2.5 (0.92-0.08)	2.2 (0.90-0.10)	2.5 (0.88-0.12)	1.9 (1.0-0.0)
Recreation	1.7 (0.53-0.47)	1.9 (0.42-0.58)	2.4 (0.45-0.55)	0.4 (0.67-0.33)
Acidification	3.2 (0.62-0.38)	1.7 (0.46-0.54)	3.1 (0.58-0.42)	0.6 (0.25-0.75)
Humus	3.6 (0.47-0.53)	1.9 (0.44-0.56)	2.9 (0.48-0.52)	1.9 (0.38-0.62)
Trophic interactions	**3.8 (0.39-0.61)**	1.7 (0.42-0.58)	2.6 (0.36-0.64)	**2.6 (0.5-0.5)**
Soil profile disturbance	1.8 (0.61-0.39)	1.3 (0.39-0.61)	1.1 (0.42-0.58)	**2.4 (0.59-0.41)**
Climatological conditions	2.9 (0.31-0.69)	2.0 (0.29-0.71)	2.2 (0.35-0.65)	**2.9 (0.20-0.80)**

Appendix G

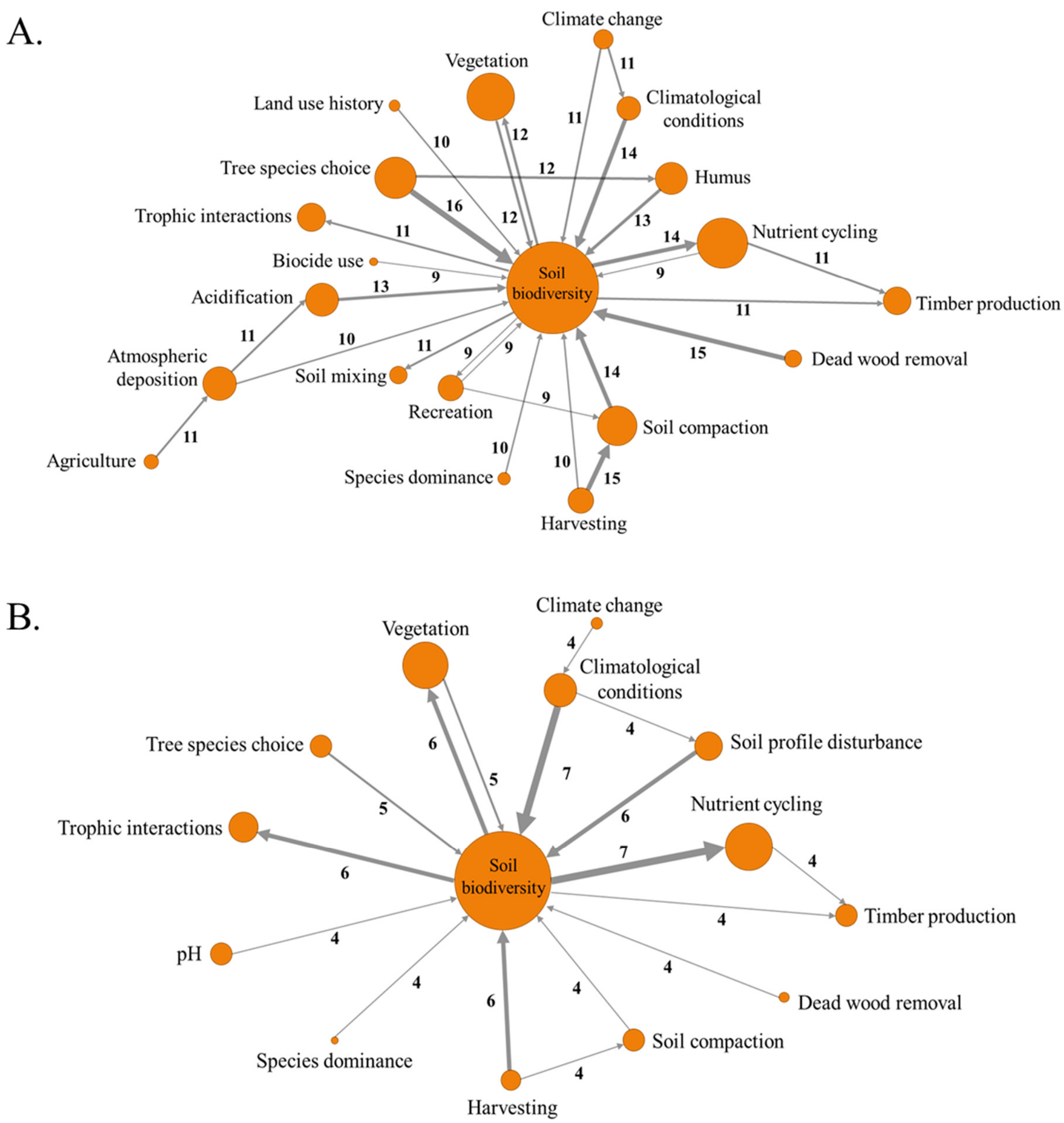


Figure G.1: Condensed social cognitive maps (SCM) related to forest soil biodiversity of Flemish respondents (A) (N_I=17) and Romanian respondents (B) (N_I=7). Only relationships being mentioned by at least half of the sample are shown, corresponding with a minimal weight of 9 and 4 respectively. Node size reflects concepts' centrality, normalized for sample size, and arrow size reflects relationship weight. Nodes present in both SCM are placed at more or less the same location to facilitate comparison.

Table G.1: Graph theory indicators of social cognitive map for Flemish and Romanian respondents.

	Flanders	Romania
No of individual maps	17	7
No of concepts	62	47
No of transmitter concepts	14	14
No of receiver concepts	7	8
No of ordinary concepts	41	25
No of relationships	293	114
Link-node ratio	4.73	2.43

Table G.2: Significantly different relationships between Flemish and Romanian respondents based on relationship weight, taking different sample sizes into account (Fisher Exact test, α=0.05, ranked by p-value). N_I represents the number of interviews or maps per group.

	Flemish respondents $N_I = 17$	**Romanian respondents** $N_I = 7$	**p-value**	**Significance**
Atmospheric deposition → Acidification	11	0	0.0059	B>R
Agriculture → Atmospheric deposition	11	0	0.0059	B>R
Humus → Soil biodiversity	13	1	0.0088	B>R
Atmospheric deposition → Soil biodiversity	10	0	0.019	B>R
Soil biodiversity → Recreation	9	0	0.022	B>R
Recreation → Soil biodiversity	9	0	0.022	B>R
Climatological conditions → Soil profile disturbance	1	4	0.014	B<R

Appendix H

Table H.1: Mean ± standard deviation of the graph theory indicators for each group (scientists, managers, Flanders and Romania), calculated based on the Individual Cognitive Maps (ICM). Number of concepts and relationships is highest for scientists, followed by Flemish respondents, managers and Romanian respondents.

	Forest scientists $N_I = 10$	**Forest managers** $N_I = 14$	**Flanders** $N_I = 17$	**Romania** $N_I = 7$
No of concepts	35.40 ±8.59	27.07 ± 6.43	33.59 ± 7.43	23.14 ± 5.49
No of transmitter concepts	12.80 ± 2.44	11.86 ± 2.88	13.24 ± 1.99	9.86 ± 2.79
No of receiver concepts	6.80 ± 3.19	4.64 ± 1.28	5.88 ± 2.80	4.71 ± 1.11
No of ordinary concepts	15.80 ± 5.92	10.57 ± 4.54	14.47 ± 5.35	8.57 ± 4.31
No of relationships	56.4 ± 20.37	38.36 ± 14.72	51.65 ± 18.36	31.86 ± 13.64
Link-node ratio	1.55 ± 0.24	1.38 ± 0.25	1.50 ± 0.24	1.34 ± 0.26

A. Forest scientists

	1	2	3	4	5	6	7	8	9	10
1										
2	0.53									
3	0.43	0.51								
4	0.58	0.45	0.46							
5	0.58	0.40	0.54	0.41						
6	0.62	0.25	0.51	0.40	0.41					
7	0.53	0.29	0.48	0.34	0.41	0.34				
8	0.55	0.35	0.49	0.43	0.48	0.42	0.43			
9	0.58	0.56	0.50	0.60	0.57	0.59	0.61	0.58		
10	0.59	0.41	0.52	0.36	0.40	0.39	0.42	0.52	0.62	

C. Flanders

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1																	
2	0.46																
3	0.46	0.50															
4	0.38	0.43	0.57														
5	0.52	0.44	0.54	0.49													
6	0.38	0.50	0.53	0.51	0.50												
7	0.45	0.26	0.45	0.45	0.53	0.55											
8	0.44	0.42	0.48	0.40	0.56	0.44	0.41										
9	0.42	0.40	0.62	0.25	0.58	0.51	0.40	0.41									
10	0.64	0.58	0.57	0.58	0.50	0.64	0.49	0.55	0.63								
11	0.46	0.44	0.38	0.46	0.51	0.50	0.40	0.49	0.49	0.58							
12	0.49	0.35	0.50	0.49	0.56	0.54	0.43	0.53	0.52	0.63	0.47						
13	0.30	0.37	0.45	0.29	0.52	0.42	0.34	0.41	0.34	0.57	0.40	0.52					
14	0.45	0.43	0.52	0.35	0.46	0.52	0.43	0.48	0.42	0.56	0.47	0.50	0.43				
15	0.52	0.48	0.54	0.52	0.47	0.58	0.50	0.53	0.61	0.59	0.51	0.47	0.52	0.53			
16	0.50	0.45	0.55	0.57	0.49	0.47	0.51	0.50	0.53	0.56	0.45	0.53	0.50	0.58	0.53		
17	0.42	0.40	0.56	0.41	0.54	0.52	0.36	0.40	0.39	0.53	0.60	0.50	0.42	0.52	0.54	0.58	

B. Forest managers

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2	0.46													
3	0.44	0.50												
4	0.52	0.44	0.54											
5	0.38	0.50	0.53	0.50										
6	0.48	0.57	0.64	0.62	0.56									
7	0.58	0.58	0.68	0.63	0.64	0.48								
8	0.64	0.58	0.57	0.50	0.64	0.69	0.71							
9	0.63	0.67	0.75	0.57	0.63	0.65	0.70	0.74						
10	0.46	0.44	0.38	0.51	0.50	0.61	0.65	0.59	0.72					
11	0.49	0.35	0.50	0.56	0.54	0.58	0.50	0.63	0.66	0.47				
12	0.65	0.66	0.74	0.61	0.66	0.50	0.65	0.69	0.63	0.79	0.65			
13	0.52	0.48	0.54	0.47	0.58	0.58	0.63	0.59	0.61	0.51	0.47	0.69		
14	0.50	0.45	0.55	0.49	0.47	0.67	0.64	0.56	0.71	0.45	0.53	0.76	0.53	

D. Romania

	1	2	3	4	5	6	7
1							
2	0.43						
3	0.52	0.53					
4	0.56	0.49	0.48				
5	0.54	0.54	0.65	0.70			
6	0.67	0.65	0.50	0.65	0.63		
7	0.58	0.50	0.55	0.44	0.52	0.67	

Figure H. 1: Dissimilarity matrices for included concepts between each pair of ICM within each group (scientists, managers, Flemish respondents and Romanian respondents). The matrix is calculated based on the Jaccard similarity index as explained in the manuscript. Darker colors indicate higher dissimilarity between ICM. Dissimilarity is lowest for Flemish respondents and scientists, followed by Romanian respondents and lastly managers.

APPENDIX H: DRAFT SCIENTIFIC PAPER 2: The effect of information transfer related to soil biodiversity on Flemish citizens' preferences for forest management

The effect of information transfer related to soil biodiversity on Flemish citizens' preferences for forest management

Authors: Iris Vanermen[1], Roselinde Kessels[2], Kris Verheyen[3], Bart Muys[4], Liesbet Vranken[1]

Affiliations:

[1] Division of Bioeconomics, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200 E – Box 2411, 3001 Leuven, Belgium.

[2] Faculty of Applied Economics and StatUa Center for Statistics, Universiteit Antwerpen, Prinsstraat 13, 2000 Antwerp, Belgium

[3] Forest & Nature Lab, Department of Environment, UGent, Geraadsbergsesteenweg 267, 9090 Gontrode, Belgium.

[4] Division of Forest, Nature and landscape, Department of Earth and Environmental Sciences, KU Leuven, Celestijnenlaan 200 E – Box 2411, 3001 Leuven, Belgium.

*Correspondence to: iris.vanermen@kuleuven.be

Abstract

Despite its essential role in the delivery of ecosystem services, soil biodiversity is mostly overlooked in forest management, partly due to a conflicting public opinion. Nevertheless, this public opinion is mostly ignorant of soil biodiversity. To foster adoption of soil biodiversity friendly management practices, this study investigates the effect of information transfer related to soil biodiversity on public preferences for forest management. We used a two-stage discrete choice experiment with a representative sample of 299 Flemish citizens. Results showed that the information transfer significantly increased preferences for higher shares of old trees and dead wood and strengthened preferences for soil biodiversity friendly levels of biodiversity and practices related management attributes. A latent class analysis revealed preference heterogeneity before and after the information transfer with one class outperforming in terms of desired behavior for both stages. In addition, information transfer decreased the differences between classes. Lastly, individuals that attached higher value to the ecological role of forests and were more knowledgeable of soil biodiversity, reacted in the most desired way to the information transfer.

1. Introduction

During the last decades, the insight has grown that ecosystems are inherently linked with social systems. This gave rise to the definition of 'social-ecological systems' that regards humans as an integral part of nature (Berkes, Folke, & Colding, 1998; Meyfroidt, 2013). Forests are such social-ecological system that take up circa 40% the European Union's land area (Eurostat, 2015). Forests are crucial for human well-being because of their essential role in carbon, nutrient and water balances, and the variety of ecosystem services that they deliver, including provisioning, regulating and cultural services (Brockerhoff et al., 2017; Mori, Lertzman, &

Gustafsson, 2017). Conversely, humans affect forests directly, through forest management, and indirectly, through for example greenhouse gas emissions causing atmospheric deposition of pollutants (Hartmann et al., 2014).

Soils are being increasingly recognized for their essential role in the delivery of forest ecosystem services (Bardgett & Van Der Putten, 2014; Lukac, 2017). This role occurs largely through the ecosystem functions that are executed by the diversity of organisms present in soils. These soil organisms interact in a complex soil food web in which each species fulfills a particular function and participate in global biogeochemical cycles (Nielsen, Wall, & Six, 2015). Despite their crucial role, soil biodiversity and soil biological functioning are generally under pressure, especially in agricultural areas (Orgiazzi et al., 2016). While forest soil biodiversity experiences mostly moderate risks, it is crucial to maintain and optimize the current forest soil biodiversity level as forests are believed to play an essential role in climate change mitigation and future delivery of ecosystem services, that are needed for human existence (Gardi, Jeffery, & Saltelli, 2013; Lukac, 2017). In addition, past research discovered that management practices have the potential to damage or support soil biodiversity, depending on the management decisions taken (Lukac, 2017). In order to prevent loss of soil organisms due to management activity, forest managers should thus consider soil biodiversity in their management decisions. Close-to-Nature forest management regimes have received increasing attention during the last decades (Puettmann et al., 2015). These regimes are oriented towards conservation and sustainable provisioning of multiple ecosystem services, and take aboveground diversity into account, but mostly overlook specific soil characteristics and lack wide adoption. Similarly, Lukac et al. (2017) pointed out that forest management currently treats soil as a black box, overlooking the importance of soil biodiversity.

Forest management is complicated due to the relatively long rotation lengths and the high number of factors and objectives to consider (de Bruin, Hoogstra-Klein, Mohren, & Arts, 2015; Lukac, 2017; Smith, Siderelis, Moore, & Anderson, 2012). De Bruin et al. (2015) studied forest managers' perception of the complexity of forest management in the Netherlands and found that 'public opinion' was amongst the most relevant factors influencing decision making. Moreover, 'public opinion' was considered to be uncertain, which means that it is little predictable and hence contributes to the complexity of forest management. Preferences for forest management of the general public often differ from those of forest managers which can generate conflicts among stakeholders (Kearney, Tilt, & Bradley, 2010; Nordén, Coria, Jönsson, Lagergren, & Lehsten, 2017; Referowska-Chodak, 2019). In order to prevent such conflicts to occur, it is crucial to integrate perceptions and preferences of the wider public into the forest management decision making process (Paletto, De Meo, Cantiani, & Maino, 2013; Referowska-Chodak, 2019). Previous research mainly used structured questionnaires and stated preference techniques to elicit public preferences for forest management related to recreation, aesthetics and forest attractiveness, including aboveground biodiversity and structural characteristics (Ciesielski & Stereńczak, 2018; Mikołaj Czajkowski, Bartczak, Giergiczny, Navrud, & Żylicz, 2014; Edwards et al., 2012; Giergiczny, Czajkowski, Zylicz, & Angelstam, 2015; Juutinen, Kosenius, Ovaskainen, Tolvanen, & Tyrväinen, 2017). More recently, the insight has grown that forests need to be valued for the multiple ecosystem services that they deliver and that might trade-off against each other (Mori et al., 2017; Sing, Metzger, Paterson, & Ray, 2018). While the wider public was believed to be primarily interested in recreation and aesthetics, recent studies found that public interest and preferences for other ecosystem services (such as carbon sequestration, water regulation and air quality regulation) and the ecological-environmental forest function are gaining importance (Grilli, Jonkisz, Ciolli, & Lesinski, 2016; Vegard Gundersen & Helge Frivold, 2011; Smith et al., 2012). Nevertheless, few studies elicited preferences for forest management by integrating a wide range of specific forest management characteristics and ecosystem services in a stated preference method (e.g. Varela, Jacobsen, & Mavsar, 2017; Varela et al., 2018). Such approach allows to better cover multiple ecosystem services forest management and to investigate the relative importance of both types of characteristics. Moreover, public preferences for forest management have not yet been studied from a soil biodiversity perspective, despite its crucial role in delivering the forest ecosystem services that are highly valued by the wider public.

In addition, insights in how to steer public opinion and preferences are of high value to policy makers and forest managers. This allows to better match public preferences and optimal management decisions from an ecological and environmental forest perspective. Previous research found that information significantly changed willingness-to-pay for environmental goods when respondents were unfamiliar with the good, while no significant effect was found on willingness-to-pay for respondents that were familiar with the good (Brahic & Rambonilaza, 2015; Hasselström & Håkansson, 2014; Needham, Czajkowski, Hanley, & LaRiviere, 2018). Hence, soil biodiversity might benefit from preference guiding through information transfer due to limited knowledge and low public awareness of soil biodiversity which is in contrast with its crucial role in the delivery of ecosystem services to society (Keesstra et al., 2016; Turbé et al., 2010; Xylander & Zumkowski-xylander, 2018). Moreover, by making the general public aware of soil biodiversity, public opinion could reinforce adoption of soil biodiversity friendly management practices by forest managers. The impact of information transfer on public preferences related to forest management has been studied previously in a number of publications that generally found positive or insignificant individual-specific effects. For example, Gundersen et al. (2017) investigated the effect of different types of information on visual preferences for dead wood in Norway and found that, overall, information about the ecological role of dead wood increased public support for dead wood in forests. Rambonilaza and Brahic (2016) encountered that part of their sample valued biodiversity in public forests in France higher after information was provided on the ecological processes behind forest management. Nevertheless, this effect was heterogeneous with no significant difference for part of the sample.

In this paper, we want to contribute to this literature by focusing on two aspects that have received limited attention in literature. Firstly, we aim to investigate public preferences for a diverse set of forest management characteristics oriented towards multiple ecosystem services delivery from a soil biodiversity perspective through a choice experiment approach. Secondly, we aim to study the effect of information transfer related to soil biodiversity and forest management on these preferences, which is of particular interest to policy making. Based on previous research, such information is expected to increase preferences for soil biodiversity friendly management practices, at least for part of the sample. To address these objectives, we use Flanders (Belgium) as a case study.

2. Methods

2.1 Case study

Flanders is a densely populated area with high urbanization rates, a high pressure on land and a low forest cover of about 13% (De Valck et al., 2014). Due to fragmentation, forest patches are small and scattered and experience negative effects of neighboring land uses such as atmospheric deposition and agricultural management (Decocq et al., 2016). These developments have put pressure on soil biodiversity and ecosystem services delivery, but at the same time have led to an increase in societal demand for forests and a diversity of ecosystem services that they deliver. Therefore, Flanders is an interesting case study to assess public preferences for multiple ecosystem services forest management.

2.2 Choice experiment method: Theory

The choice experiment method is a widely applied stated preference method that combines the characteristics theory of value (Lancaster, 1966) and the random utility theory of McFadden (1974). Lancaster's characteristics theory articulates that individuals derive utility from a service based on the characteristics that describe that service, rather than from the service as such. McFadden's random utility theory considers individuals to be rational and to maximize their utility when choosing from a set of alternative specifications of a service. By integrating these two theories, the utility that individual i derives from choosing an alternative specification j of a good or service out of a total set of J alternative specifications can be expressed by following equation:

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \sum_{k=1}^{K} \beta_{ik} \, x_{ijk} + \varepsilon_{ij} \quad (1)$$

Specifically, this utility consists of a deterministic component (V_{ij}) and an unobserved random error term that is assumed to be an independently and identically distributed extreme value (ε_{ij}) (Hauber et al., 2016; Hole, 2007). The deterministic component includes a vector of K observed alternative-specific variables (x_{ijk}) that are the characteristics, or attributes, describing the service. A vector of parameters (β_{ik}) expresses individual preferences for each of these characteristics. In this study, we apply the choice experiment method to assess public preferences for forest management. Section 2.2 describes the study design and data collection, while section 2.3 outlines the econometric approach for the data analysis.

2.3 Study design and data collection

Figure X displays the methodological approach that was used for designing this study and collecting data. Specifically, four stages were completed starting with the selection of attributes, that were used in the design of the choice experiment. Then, the survey was developed and responses were collected. Following sections explain each of these four stages in more detail.

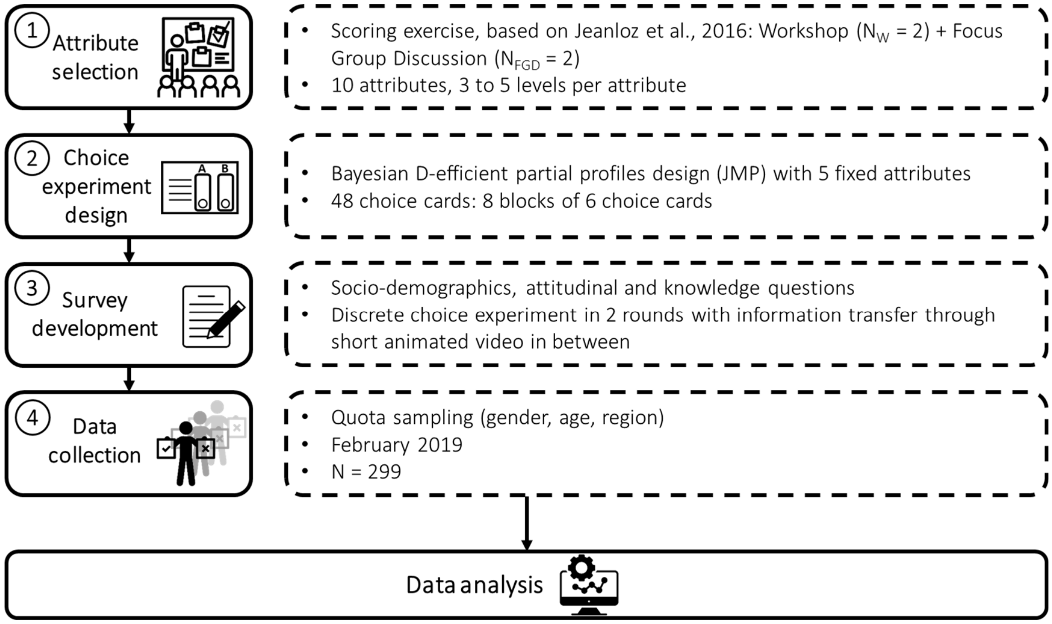


Figure 5: Methodological approach for the design and data collection

2.3.1 Attribute selection

The first step in the study design was to select characteristics or attributes that describe forest management oriented towards multiple ecosystem services. For this purpose, we used an attribute selection process adapted from Jeanloz et al. (2016). Specifically, a list of 38 forest management related characteristics was developed based on literature screening. Then, a scoring exercise was generated, that contained two tables in which participants had to score the 38 attributes according to their relevance for a multiple ecosystem services forest management and for soil biodiversity. This scoring exercise was used in two workshops with academic experts in bio-economics (N=7) and forest and nature management (N=10), respectively. After a short introduction and explanation of the exercise, participants were asked to fill in the scoring exercise. During a short break, the 15 attributes with highest average score were extracted based on the individual exercises for further discussion. Next, participants were asked to collectively select a final set of six or seven attributes, including one cost attribute, by merging and eliminating attributes from the top-15 list. Based on these two workshops, a set of ten attributes was selected. For each of these attributes, levels where set through internal discussion between the scientists conducting this study. Lastly, the set of ten attributes and levels was reviewed for clarity and interpretative problems by citizens in two focus group discussions amongst technical staff and friends and family (N_1=N_2=8). The final set of attributes and levels, is shown in table 1 and includes nine categorical variables and one continuous variable related to the cost attribute. The categorical variables were dummy coded with the base level set equal to the least preferred level from a soil biodiversity perspective.

Table 1: Overview of the attributes and their levels that are used in the choice experiment. Categorical variables are dummy coded. Base levels are set equal to the least preferred levels from a soil biodiversity perspective.

Attribute	Description to respondents	Levels	Merged attribute	Levels
Forestry system [a]	Method used to replace old trees with new trees. In clear-cutting the entire forest stand is replaced at one moment on 100% of its stand area. In group cutting groups of trees are replaced consecutively. In selective cutting individual trees are regularly replaced.	1. Clear-cutting 2. Group cutting 2. Selective cutting	**Forestry system – Understory & shrub layer**	1. Clear-cutting – Even aged without understory *[base level]* 3. Clear-cutting – Even aged with understory 3. Group cutting – Uneven aged without understory 4. Group cutting – Uneven aged with understory 5. Selective cutting – Uneven aged without understory 6. Selective cutting – Uneven aged with understory
Understory & shrub layer [a]	Extent to which smaller trees and a shrub layer are present. In an even-aged forest stand, all trees belong to the same age class, whereas in an uneven aged forest stand, trees belong to different age classes and hence are of different height.	1. Even aged without understory 2. Even aged with understory 3. Uneven aged without understory 4. Uneven aged with understory		
Old trees and dead wood	Share of old trees (=remarkably old for its species) and dead wood (=dead and dying (parts of) trees), expressed relative to the total timber stock.	1. No old trees and dead wood (<1% of total timber stock) *[base level]* 2. Few old trees and dead wood (2-5% of the total timber stock) 3. Many old trees and dead wood (≥10% of the total timber stock)		
Tree species diversity	Extent to which tree species are mixed. In a slightly mixed stand one of the species is dominant, while in an intensively mixed stand all species are present in comparable numbers	1. Monoculture (1 tree species) *[base level]* 2. Slightly mixed (2 to 3 tree species) 3. Intensively mixed (minimum 4 tree species)		
Tree logging	Method used for logging of the wood. Specialized machines are used for logging and skidding the trails in which the use of fixed roads restricts machines to only ride on these marked strips and protection can be used to limit soil compaction.	1. Mechanical logging without fixed logging roads *[base level]* 2. Mechanical logging with fixed logging roads 3. Mechanical logging with fixed logging roads and additional protection (such as steel plates or a bed of branches)		
Carbon storage	Amount of CO_2 stored per 100 ha of forest, translated into yearly CO_2 emissions of a number of citizens. This process can mitigate climate change.	1. Low carbon storage (equivalent to yearly emissions of 250 citizens) *[base level]* 2. Moderate carbon storage equivalent to yearly emissions of 350 citizens) 3. High carbon storage (equivalent to yearly emissions of 450 citizens)		
Water retention	Rate at which (rain)water flows through the forest ecosystem, affecting water quality and storage through purifications and buffering. The slower the water flows, the higher the water quality and storage.	1. Rapid water flow (low water quality and storage) *[base level]* 2. Moderate water flow (moderate water quality and storage) 3. Slow water flow (high water quality and storage)		
Recreation	Possibility to recreate, expressed by the number of paths, the extent to which different user groups are allowed to access the paths and the extent to which motorized traffic is allowed.	1. Many paths, open to all user groups and motorized traffic *[base level]* 2. Many paths, open to all user groups 3. Many paths, user group specific 4. Few paths, open to all user groups 5. Few paths, user group specific		
Mushroom and berry picking	Availability of mushrooms and berries.	1. No mushrooms and berries available for picking *[base level]* 2. Moderate availability of mushrooms and berries for picking 3. Many mushrooms and berries available for picking		
Contribution to a fund	Compulsory yearly contribution per household to a forest fund specifically oriented towards forest maintenance.	€5, €20, €50, €100, €150		

[a] *The attributes "Forestry system" and "Understory and shrub layer" were merged into one new attribute with 6 levels for the design and analysis because of restrictions on the combinations of the levels of these attributes.*

2.3.2 Choice experiment design

After selecting the attributes, the choice experiment was designed using a Bayesian D-efficient design in the JMP 14 Pro software. Because of strong restrictions on the combination between the attributes 'forestry system' and 'understory and shrub layer', these attributes were merged into one attribute with 6 levels for the design and analysis of the choice experiment. Nevertheless, both attributes were presented separately in the choice cards for clarity and ease of understanding. Specifically, an even-aged forest structure can only appear with clear-cutting, whereas an uneven-aged forest structure cannot appear with clear-cutting. Hence, the design and analysis of the DCE uses 9 attributes: the combined attribute forestry system – understory and shrub layer, old trees and dead wood, tree species diversity, tree logging, carbon storage, water retention, recreation, mushroom and berry picking, and contribution to a fund. In total, 48 choice cards were created, that were blocked in 8 blocks of 6 choice cards. Each choice card presented two alternative forest management scenarios, that were characterized by the nine attributes representing management choices. In order to reduce the cognitive burden on respondents that would result from varying all attributes simultaneously, a partial profiles design was adopted, keeping five out of nine attributes fixed per choice card (Kessels, Jones, & Goos, 2015). This set of fixed attributes varied between choice cards in order to maximize the information that could be extracted from the total set of choice cards. The Bayesian design relied on prior estimates of the mean and standard deviation for each parameter, that were set by internal discussion between the experts conducting this study. Each of these experts individually reported the expected sign of each parameter (-,0,+), the expected relative importance of the attributes (-- to ++) and the expected level of preference heterogeneity (-- to ++). After integration of the individual perspectives and internal discussion, a final set of prior estimates for mean and standard deviation was agreed upon and translated into numbers which were added in the choice experiment design. An example of a choice card in Dutch is shown in Figure 2.

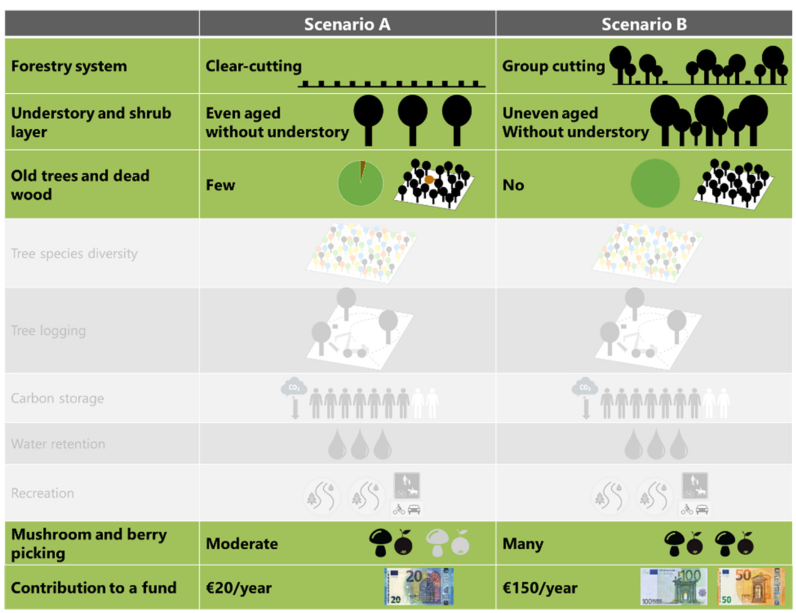


Figure 6: Example of a choice card with the varying attributes of the partial profiles design highlighted in green (translated to English).

2.3.3 Survey development

In order to assess the effect of information transfer related to soil biodiversity on individual preferences, the choice experiment was organized in two rounds. In each round respondents answered six choice cards and a short self-made informative animated video related to soil biodiversity was shown in between. The video included a short description of soil biodiversity, its relevance for society through ecosystem functions and services and its relationship with forest management. The survey consisted of six sections and lasted about 30 minutes in total. First, after an introduction and informed consent, socio-demographic and attitudinal questions related to nature and forests were asked. Next, the choice experiment was introduced and attributes and levels were explained in detail (included in Appendix A). This was followed by the first round of the choice experiment in which each respondent answered one random block of six choice cards whose order was randomized. After the choice cards, follow-up questions were included on relative attribute importance. The third section questioned respondent's knowledge of soil biodiversity and encompassed questions related to the Protection Motivation Theory and subjective norms. This section was included to test their relationship with preference heterogeneity. Next, information on soil biodiversity and forest management was transferred through the short animated video. In order to control for the effect of the informative video on knowledge of soil biodiversity, section three and four were inverted for half of the sample. This was followed by the second round of the choice experiment, analogous to the first round. Lastly, the survey was concluded by thanking the respondent for their participation and offering them the possibility to provide feedback and comments upon request. Ethical approval for this survey was obtained at the Social and Societal Ethics Committee (SMEC) of the KU Leuven.

2.3.4 Data collection

Respondents were sampled through a market research agency (iVOX) using a quota sampling approach (Rambonilaza & Brahic, 2016). A representative sample of 300 Flemish citizens was obtained using age, gender and place of residence as criteria, and taking education level and income into account. The survey was coded using the online tool Socratos and responses were gathered in February 2019. Based on data cleaning, one respondent was omitted from the sample because of uninformative responses that followed a clear pattern over the entire survey. Hence, the sample that was maintained for analysis counted 299 respondents.

2.4 Data analysis

2.4.1 Econometric framework

Based on the observed choices, preferences can be studied by expressing the probability of an alternative forest management scenario to be chosen through a logistic distribution. Several models exist that differ in their assumptions and the extent to which they account for preference heterogeneity. The basic model is a conditional logit model that assumes preferences across individuals to be homogeneous (Hauber et al., 2016). Nevertheless, preferences mostly differ among individuals and assuming homogeneity can lead to biased estimates (Hauber et al., 2016). Preference heterogeneity can be taken into account through the mixed logit model which assumes that preference weights across the sample can be represented by a (normal) distribution with density defined as $f(\beta|\theta)$ and θ the parameters of the distribution (Hauber et al., 2016; Hole, 2007). The probability that respondent i chooses alternative j in choice card t is then given by following expression, conditional on knowing β_i:

$$P_{ijt}(\beta_i) = \frac{e^{V_{ijt}(\beta_i, X_{ijt})}}{\sum_{h=1}^{J} e^{V_{iht}(\beta_i, X_{iht})}} \qquad (2)$$

Through this formula, we can see that the probability of choosing alternative j is a function of the attribute levels of alternative j, as well as the attribute levels of all other alternatives within the choice card. Based on this expression, the probability of the sequence of choices over all choice cards for individual i can be calculated, again conditional on knowing β_i, using following formula:

$$S_i(\beta_i) = \prod_{t=1}^{T} P_{ij(i,t)t}(\beta_n) \quad (3)$$

with $j(i,t)$ the alternative that has been chosen by individual i in choice card t. Lastly, the unconditional probability for the observed sequence of choices can be obtained by integrating the conditional probability over the distribution of β, using the density function $f(\beta|\theta)$:
$P_n(\theta) = \int S_n(\beta)\, f(\beta|\theta) d\beta$

Alternatively, the latent class finite-mixture model assumes that individuals can be grouped into a finite number of classes (Greene & Hensher, 2003; Hauber et al., 2016; Pacifico & Yoo, 2013). While preferences are expected to differ between classes, they are assumed to be homogenous within each class. Therefore, the latent class model estimates preference weights within each class through a conditional logit model, based on following expression for the probability that individual i chooses alternative j in choice card t, conditional on being a member of class q:

$$P_{ijt|q} = \frac{e^{V_{ijt|q}(\beta_q, X_{ijt|q})}}{\sum_{h=1}^{J} e^{V_{iht|q}(\beta_q, X_{iht|q})}} \quad (4)$$

where $V_{ijt|q}(\beta_q, X_{ijt|q})$ is the deterministic component for alternative j in choice card t, conditional on being member of class q, j is the alternative chosen out of a set of J alternatives and the denominator takes into account the deterministic component over all alternatives J within a choice card. Similar to the mixed logit model, the probability for the observed sequence of choices over all choice cards can then be calculated through following formula, again conditional on being a member of class q:

$$S_{i|q} = \prod_{t=1}^{T} P_{ij(i,t)t|q} \quad (5)$$

However, the class assignment and hence class probability are unknown up front. Therefore, the prior probability for individual i to be in class q (class assignment probability) can be calculated using this expression following a fractional multinomial logit:

$$H_{iq} = \frac{e^{z_i \theta_q}}{1 + \sum_{l=1}^{Q-1} e^{z_i \theta_l}} \quad (6)$$

With z_i a set of observable socio-demographic characteristics of the individual that can be included through the class membership option, θ_q the class membership model parameter for class q and θ_Q normalized to 0 to allow identification. In this paper, we did not include individual specific covariates which means that the only element in z_i is the constant term. By consequence, the prior class probabilities are constants that sum to one and thus the same for all agents. This class assignment probability (H_{iq}) is then used to calculate the choice probability that individual i chooses alternative j in choice card t by taking the sum over all classes of the product of H_{iq} and expression 4.

2.4.2 Model estimation

The analysis was performed using Stata16. Firstly, a mixed logit model (mixlogit) allowing for preference heterogeneity was ran on the entire dataset, including observations before and after the information transfer. To assess the effect of information transfer, interaction effects were added between the attribute parameters and an information transfer dummy, that equals one for observations after the information transfer and zero for observations before the information transfer. Stata16 allows a maximum of 20 random parameters in the mixed logit model, while our model included 22 (main effects) parameters. Hence, different specifications were tested and compared, and results of these different models were found to be very similar. The model with the highest (or least negative) log likelihood was therefore selected. This model keeps the monetary attribute fixed (contribution to a fund), as well as the variable linked to the attribute level 'even aged with understory – clearcut'. Moreover, all interaction effects between the main effects and the dummy for the information transfer were kept fixed.

Next, preference heterogeneity and its relationship with socio-demographic and attitudinal characteristics was further investigated through a latent class model (lclogit). This model was run on the data before and after the information transfer separately to identify classes in preferences for both rounds separately after which switching patterns between rounds before versus after the information transfer were investigated. In order to choose the optimal number of classes, goodness-of-fit-measures were compared between a limited number of model specifications that differed in the number of classes specified (AIC, CAIC, BIC) (Pacifico & Yoo, 2013). Moreover, different seed values were tested to investigate the effect of starting values on the results. The best model was then chosen based on the log likelihood and meaningful interpretation of the latent classes. After the estimation, individuals were assigned to classes by calculating individual class probability for each class based on an individuals' sequence of choices (see Pacifico & Yoo, 2013). Then, switching patterns between classes before and after the information transfer were investigated as both rounds of choice cards were answered by the same individuals. Based on these patterns, the most desired switching behavior with respect to soil biodiversity and forest management was detected. Lastly, we investigated to what extent socioeconomic and attitudinal characteristics differed between individuals that reacted more and less desirably to the information transfer, using two-sided t-tests.

3. Results

3.1 The effect of information transfer on preferences through interaction effects

Table 2 contains the results of the mixed logit model, that was run on the entire dataset and included interaction effects between the attribute levels and an information transfer dummy. In general, all parameter estimates were significantly different from zero, with soil biodiversity friendly levels being positively preferred over levels that are least favorable for soil biodiversity. Except for the attribute 'old trees and dead wood', for which no significant effect was found for its highest share. Nevertheless, a significant positive effect was found for the interaction effect between the information transfer and this level, which indicates a significant increase in preferences for higher shares of old trees and dead wood compared to no old trees and dead wood after the information transfer. In addition, significant positive interaction effects were found for both levels of tree species diversity, both levels of tree logging and the presence of few recreation paths that are user group specific. These significant interaction effects do not involve a change in the sign of the main effect but point at a significant increase in relative importance of these attribute levels to explain choice behavior. In this way, they comprise more extreme preferences for these attribute levels after the information transfer, especially for the attributes 'tree species diversity' and 'tree logging'. Furthermore, a positive significant interaction effect with the information dummy was present for the monetary attribute. This suggests that respondents were significantly less averse for higher prices of forest management scenarios after the information transfer.

By comparing the relative magnitude of the parameters coefficients of categorical attributes, the relative attribute importance in explaining choices was derived. Before the information transfer, the attribute 'forestry system – understory and shrub layer' was the most important attribute, followed by the attributes 'recreation' and 'tree species diversity'. After the information transfer, the attributes 'tree species diversity', 'old trees and dead wood' and 'tree logging' increased most in relative importance, at the expense of 'forestry system – understory and shrub layer', 'recreation' and 'mushroom and berry picking'. Nevertheless, the attribute 'forestry system – understory and shrub layer' remained the most important in explaining choices, also after the information transfer.

Table 6: Estimation results of mixed logit model, combining data before and after the information transfer with a fixed interaction effect for each parameter and an information dummy (equaling 1 for observations after the information transfer).

Attribute	Level	Main effect		Interaction effect [a]
		β	**SD**	***β***
Forestry – Understory & shrub layer	Clear-cutting - Even-aged without understory	[base level]		[base level]
	Clear-cutting – Even-aged with understory	0.188	fixed	-0.054
	Group cutting – Uneven-aged without understory	2.021****	-0.359	-0.471
	Group cutting – Uneven-aged with understory	2.219****	0.287	0.296
	Selective cutting – Uneven-aged without understory	3.000****	-0.686*	-0.331
	Selective cutting – Uneven-aged with understory	3.334****	1.808****	-0.115
Tree species diversity	Monoculture	[base level]		[base level]
	Slightly mixed	0.805****	-0.354*	0.471**
	Intensively mixed	1.107****	0.257	0.847***
Old trees and dead wood	None	[base level]		[base level]
	Few	0.446***	0.027	0.062
	Many	0.015	0.598***	0.569***
Tree logging	Without fixed logging roads	[base level]		[base level]
	With fixed logging roads	0.295**	0.066	0.481**
	With fixed logging roads and additional protection	0.611****	0.509***	0.445*
Carbon storage	Equivalent to yearly emissions of 250 citizens	[base level]		[base level]
	Equivalent to yearly emissions of 350 citizens	0.051	0.006	0.264
	Equivalent to yearly emissions of 450 citizens	0.631****	0.676***	-0.166
Water retention	Rapid water flow	[base level]		[base level]
	Moderate water flow	0.420***	-0.078	0.179
	Slow water flow	0.684****	-0.001	0.083
Mushroom & berry picking	Few	[base level]		[base level]
	Moderate	0.344**	0.019	-0.258
	Many	0.580****	0.517**	-0.248
Recreation	Many paths, open to all user groups and motorized traffic	[base level]		[base level]
	Many paths, open to all user groups except motorized traffic	1.293****	0.840***	-0.495
	Many paths, user group specific except motorized traffic	1.287****	0.450	0.066
	Few paths, open to all user groups except motorized traffic	1.561****	-0.807**	0.102
	Few paths, user group specific except motorized traffic	1.505****	1.378****	0.700**
Contribution to forest fund		-0.012****	(fixed)	0.005**
n (observations)			7176	
Log likelihood			-2027.222	

Note: Significant coefficient estimates are indicated with * p<0.1, ** p<0.05, *** p<0.01 or **** p<0.001

[a] Interaction effects of each variable with an information dummy that equals 1 for observations after the information transfer and 0 for observations before the information transfer

In addition to these general findings on average values for the parameter estimates, the mixed logit model suggested heterogeneity in preferences across respondents. This presence of heterogeneity can be seen from the significant subject standard deviations for about half of the main effects parameters, distributed over seven attributes. Only for the attribute 'water retention' no heterogeneity in preferences was found for none of both levels, while the monetary attribute was set fixed. An alternative specification of the mixed logit model in which the interaction effects with the information transfer dummy were allowed to vary across respondents, also suggested heterogeneity in the effect of information transfer on preferences across respondents (results not included). In order to gain insights in this heterogeneity, a latent class logit model was estimated, of which the results are discussed in section 3.2.

3.2 Studying preference heterogeneity by detecting segments before and after the information transfer

First, a latent class model was run on the choice data before the information transfer to detect segments in the sample that include respondents with similar preferences. Then, the change in preferences was studied for these segments by running separate conditional logit models on each segment using the choice data after the information transfer. Lastly, a latent class model was estimated on the choice data after the information transfer to detect the optimal distribution of respondents in segments. By studying the switching patterns of respondents between segments before and after the information transfer, those respondents that react in the most desired way to the information transfer can be detected and characterized.

3.2.1 Model estimation results

The results of the latent class estimation ran on the choice data before the information transfer are shown in column 1 and 2 of Table 3. A model with two latent classes, or segments, outperformed a model with three classes based on the Bayesian Information Criterion (BIC) and the Consistent Akaike Information Criterion (CAIC). The data did not support a model with more than three latent classes as the estimated variance matrix failed to converge. Moreover, different starting values for the algorithm were tried, yielding results that were slightly different in class shares and significance of parameter estimates. Finally, the best model was selected based on the information criteria, log likelihood and meaningful interpretation of the latent classes or segments.

Table 3 : Parameter estimates and significance for latent class model on data before the information transfer (column 1 and 2), conditional logit models on the data after the information transfer using the two classes found before the information transfer (column 3 and 4), and latent class model on data after the information transfer (column 5 and 6).

Attribute	Level	Before information transfer		After information transfer		After information transfer	
		Latent class logit		Conditional logit		Latent class logit	
		Class 1_before	Class 2_before	Class1_before	Class2_before	Class 1_after	Class 2_after
Forestry system- Understory & shrub layer	Clear-cutting – Even aged without understory	[base level]		[base level]		[base level]	
	Clear-cutting – Even aged with understory	-3.173*	0.838**	0.569	-0.091	0.410	0.134
	Group cutting – Uneven aged without understory	3.319***	2.059****	1.746****	1.066****	2.774****	0.251
	Group cutting – Uneven-aged with understory	2.963***	2.044****	2.418****	1.888****	4.018****	0.740
	Selective cutting – Uneven-aged without understory	3.482****	2.881****	2.531****	2.068****	4.556****	0.991**
	Selective cutting – Uneven-aged with understory	1.341*	3.069****	2.646****	2.275****	4.468****	1.611***
Tree species diversity	Monoculture	[base level]		[base level]		[base level]	
	Slightly mixed	3.792****	0.272	1.244****	0.976****	1.939****	0.268
	Intensively mixed	6.022***	0.393	1.864****	1.571****	2.649****	0.701*
Old trees and dead wood	None	[base level]		[base level]		[base level]	
	Few	1.640***	0.198	0.419**	0.391***	0.552**	0.137
	Many	0.588	-0.090	0.434*	0.531***	0.710**	0.490*
Tree logging	No fixed logging roads	[base level]		[base level]		[base level]	
	Fixed logging roads	2.723***	-0.192	0.639**	0.652****	1.068****	0.281
	Fixed logging roads and additional protection	1.604***	0.301*	0.917***	0.788****	1.085****	0.737*
Carbon storage	Equivalent to yearly emissions of 250 citizens	[base level]		[base level]		[base level]	
	Equivalent to yearly emissions of 350 citizens	1.309**	-0.035	0.232	0.307**	0.584**	0.212
	Equivalent to yearly emissions of 450 citizens	2.657***	0.402*	0.730***	0.475***	0.753**	0.609**
Water retention	Rapid water flow	[base level]		[base level]		[base level]	
	Moderate water flow	3.261***	-0.125	0.353	0.500****	1.032****	-0.279
	Slow water flow	3.915***	0.246	0.531*	0.547***	1.691****	-0.643
Mushroom & berry picking	Few	[base level]		[base level]		[base level]	
	Moderate	0.046	0.221	-0.052	0.106	0.626	-0.520**
	Many	0.503	0.620***	0.262	0.341*	0.418	0.310
Recreation	Many paths, open to all user groups and motorized traffic	[base level]		[base level]		[base level]	
	Many paths, open to all user groups	5.602**	0.775***	0.963**	0.481**	0.614*	0.896
	Many paths, user group specific	3.035**	1.225****	1.539****	0.845****	0.848***	1.634***
	Few paths, open to all user groups	3.284**	1.510****	1.800****	0.966****	1.394****	1.518**
	Few paths, user group specific	6.612***	0.691***	1.748****	1.416****	2.160****	1.264***
Contribution to forest fund		-0.022***	-0.010****	-0.009****	-0.005***	-0.003	-0.012***
Class probability		33.1%	66.9%	33.1%	66.9%	67.2%	32.8%
Membership function constant		0.895 ***		/	/	-0.597	
n (observations)		3588		1188	2400	3588	
Log likelihood		-1006.3703		-319.2498	-668.1083	-983.5183	
BIC		2269.2605		794.2601	1547.4470	2223.5565	
AIC		2102.7406		682.4995	1420.2170	2057.0365	

Significant coefficient estimates are indicated with * p<0.1, ** p<0.05, *** p<0.01 or **** p<0.001

Before the information transfer (column 1 and 2), differences between both classes seemed to be mainly linked to attributes related to biodiversity ('tree species diversity', 'old trees and dead wood'), one pure management practice ('tree logging'), regulating ecosystem services ('carbon storage', 'water retention') and the cultural ecosystem service 'mushroom and berry picking'. The first class included about 33% of the total sample and had significant preferences for most of the parameters with levels that support soil biodiversity generally preferred over levels that are less favorable from a soil biodiversity perspective, except for the attributes 'old trees and dead wood', for which only the highest level was significant, and 'mushroom and berry picking', for which preferences were insignificant. Therefore, the preferences of this class generally encouraged forest management choices that support soil biodiversity, considering a wide range of characteristics. On the other hand, the second class comprised about 67% of the respondents and seemed to attach more importance to forest aesthetics and cultural ecosystem services, as witnessed by the significant parameter estimates for the attributes 'forestry system – understory and shrub layer', 'recreation' and a high availability of mushrooms and berries. Nevertheless, this class also expressed a significant positive preference for the highest levels of the attributes 'carbon storage' and 'tree logging'. In general, the results suggest that members of class 2 care most about recreation and visual attractiveness through layering and the extent of open patches in the forest, while members of class 1 additionally attach equal importance to biodiversity aspects (except for the highest level of 'old trees and dead wood'), tree logging techniques and regulating ecosystem services. This observation can be deducted from the significance of parameter estimates as well as the relative magnitude of the parameter estimates over attributes within one class. Hence, class 1 seems to align best with management that supports soil biodiversity, while it includes only the minority of respondents. We defined class 1 members as environmentalists, while members of class 2 were described as recreational users.

In order to investigate how the preferences of these two segments (environmentalists and recreational users) changed after the information transfer, conditional logit models were ran of which the estimation results are shown in column 3 and 4 of table 3. By comparing column 1 and 3, it can be seen that the information transfer had limited effects on the preferences of the first segment (environmentalists). Specifically, the environmentalists expressed a significant positive preference for the highest level of old trees and dead wood after the information transfer, while this was insignificant before the information transfer. Moreover, they preferred only the highest levels of the regulating ecosystem services carbon storage and water retention after the information transfer, while they also positively preferred intermediate levels before the information transfer. On the other hand, differences in preferences before versus after the information transfer are more pronounced for the second segment (recreational users). While before the information transfer they had significant preferences for a limited set of attributes mostly related to forest aesthetics and cultural ecosystem services, they expressed significant positive preferences for all attributes after the information transfer. The largest differences are linked to the attributes 'tree species diversity', 'old trees and dead wood' and 'water retention' of which both levels become highly preferred after the information transfer, relative to their base levels. Moreover, preferences increase in significance for the attributes 'tree logging' and 'carbon storage'. Hence, the information transfer seemed to have a large effect on the preferences of the second segment, leading to enlargement of attention to all attributes, including biodiversity related management characteristics, pure management practices and regulating ecosystem services.

Analogous to the procedure described for the latent class analysis before the information transfer, the optimal number of segments after the information transfer was chosen based on the information criteria, log likelihood and interpretation of the segments. A model with two latent classes, or segments, was also found to be optimal after the information transfer (column 5 and 6) with class 1 comprising 67% of the respondents and class 2 including 33% of the respondents. Similar to what was observed before the information transfer, class 1 after the information transfer encompassed significant estimates for most of the parameters, except for even-aged forests with understory and clear-cutting (compared to even-aged forests without understory and clear cutting), both levels of the attribute 'mushroom and berry picking' and the monetary attribute 'contribution to a fund'. The latter indicates that members of class 1 seemed indifferent to the cost of the forest management scenarios. Conversely, members of class 2 expressed preferences that only included the highest levels of nearly all attributes, except for the ecosystem services 'water retention' and 'mushroom and berry picking'. For the latter, a significant negative preference was found for the intermediate level. This indicates that members from class 2 after the information transfer generally only value an increase from the lowest to the highest level with respect to support for soil biodiversity of most attributes. Moreover, class 2 revealed a highly significant negative preference for the monetary attribute, in contrast to class 1. Lastly, the relative magnitude of the parameter estimates between attributes within one class indicates that class 1 attaches highest importance to the attributes 'forestry system – understory & shrub layer', 'tree species diversity' and 'recreation', followed by 'tree logging' and 'water retention'. On the other hand, class 2 seems to value the attributes 'forestry system – understory & shrub layer' and 'recreation' the most, followed by 'tree species diversity', 'tree logging' and 'water retention'. Hence, similar attributes were considered the most important for both classes, but 'tree species diversity' was valued more important for class 1 compared to class 2. However, the relative importance of the monetary attribute in class 2 cannot be directly assessed from the parameter estimate and is hence not taken into account in this ranking. Based on these findings, differences between both classes with respect to soil biodiversity seemed more limited after the information transfer compared to what was found before the information transfer. Nevertheless, class 1 seemed to be most favorable from a practical soil biodiversity perspective as preferences were generally significant at higher levels and mostly included the intermediate levels, which are considered more feasible to forest managers and could hence facilitate adoption. Moreover, the most important attributes in explaining choices remain 'forestry system – understory and shrub layer' and 'reaction' in both classes, while class 1 additionally attaches comparable importance to 'tree species diversity'. Hence, we described members of class 1 as environmentalists, similar to before the information transfer, but with increased preferences for higher shares of old trees and dead wood and insignificance towards the monetary cost. On the other hand, we characterized class 2 members as critical and economic environmentalists that preferred only the highest attribute levels from an environmental and soil biodiversity perspective and that indicated high attention for the cost of forest management, compared to class 1.

3.2.2 Characterization of segments before the information transfer

By running conditional logit models using choice data after the information transfer on the two segments that were detected before the information transfer, the information transfer was found to have the largest desired effect on respondents from class 2, namely recreational users. To study how respondents from this class differed from respondents from class 1 (environmentalists), two-sided t-tests were executed on a wide range of socio-economic, attitudinal, behavioral and knowledge-related characteristics. Table 4 displays the characteristics that were found to differ significantly between both segments. Specifically, respondents that belonged to the segment 'recreational users' attached significantly less importance to the forest function biodiversity and visited forests significantly less for nature observation. Furthermore, a significant smaller share indicated to have considered soil biodiversity while answering the DCE before the information transfer. Members of the segment 'recreational users' also agreed significantly more that science has insufficient knowledge on forest soil biodiversity to take it into account in forest management and significantly less indicated that forests give them a sense of well-being. Moreover, they agreed significantly more that increasing the variation in forest structure decreases forest soil biodiversity, while generally the opposite is true. Lastly, a significantly smaller share of respondents belonging to this segment were members of a nature organization, while a significantly higher share had an educational level of secondary or lower.

Table 4: Comparison of socio-economic, attitudinal, behavioral and knowledge related characteristics using two-sided t-test between class 1 (environmentalists) and class 2 (recreational users) before the information transfer.

	Environmentalists (N = 99)	Recreational users (N = 200)	Significance (p-value)
Forest_function_biodiversity [a]	4.02 (0.099)	3.71 (0.074)	** (0.015)
Activity_nature_observation [a]	2.29 (0.133)	1.89 (0.078)	*** (0.005)
Considered soil biodiversity in DCE (%)	77.8%	58.0%	**** (0.0007)
"Until now, science has insufficient knowledge on forest soil biodiversity in order to be taken into account in forest management." [a]	2.09 (0.143)	2.43 (0.111)	* (0.072)
"Forests provide me with a sense of well-being." [a]	4.38 (0.071)	4.18 (0.060)	** (0.036)
"The higher the variation in forest structure, the lower the forest soil biodiversity." [a]	2.86 (0.259)	3.55 (0.169)	** (0.031)
Member of nature organization	27.3%	14.0%	*** (0.005)
Maximum secondary education	41.4%	54.0%	** (0.041)

Significant coefficient estimates are indicated with * p<0.1, ** p<0.05, *** p<0.01 or **** p<0.001

[a] Mean score (and standard error) based on a 5-point likert scale with 1 item (with 1 = not important at all/disagree to 5 = very important/agree)

3.2.3 Characterization of switching patterns between segments before and after the information transfer

Because the same individuals answered both rounds of the choice experiment (before and after the information transfer), we were able to investigate how individuals reacted on the information transfer. Figure 3 shows the switching patterns of individuals between the latent class before and after the information transfer, expressed by the share of total respondents. As mentioned before, preferences were in general more in favor of soil biodiversity after the information transfer, but class 2 expressed preferences that were more critical as they only valued an increase from a low to a high level and expressed a significantly negative preference for the monetary variable. Therefore, we defined class 1 after the information transfer as the most preferred from a soil biodiversity perspective. Hence, individuals that switched from class 2 before the information transfer to class 1 after the information transfer are considered to react best on the information transfer. This group included about 45% of the total sample which is the highest share of all switching patterns. In addition, respondents that stayed within class 1 after the information transfer

(22%) also responded as desired to the information, but showed only small changes in their preferences, related to 'old trees and dead wood' and the monetary attribute. On the other hand, respondents that were part of class 1 before the information transfer, but switched to class 2 after the information transfer were considered to respond in the least desired way, as they did not significantly value an intermediate increase anymore for most attributes than respondents that stayed within class 1. This group was however the smallest with only 11% of the total sample. Moreover, an alternative explanation for this observation could be that these respondents considered the monetary attribute the most important and hence ended up in class 2 after the information transfer as this attribute was no longer significant in class 1. Lastly, about 22% of the respondents stayed within class 2 after the information transfer. While the most desired pathway would have been to change to class 1, switching to class 2 after the information transfer still encountered an improvement in preferences from a soil biodiversity perspective, by significantly valuing more attributes than aesthetics and recreation and by focusing on the highest levels.

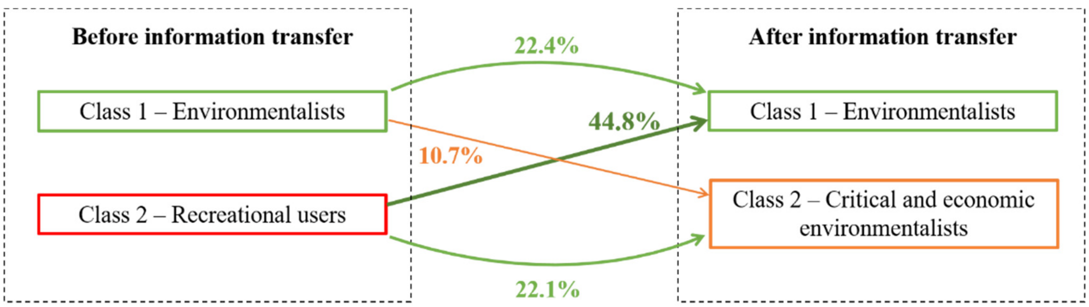


Figure 7: Pattern of switching between latent classes before and after the information transfer, expressed by the share of total respondents (N = 299). The latent classes are based on the latent class analysis that was described in section 3.2.1

Lastly, we investigated to what extent socio-economic, attitudinal and knowledge related characteristics determined the differences in switching patterns. For this purpose, we compared individuals that reacted on the information transfer in the most desired way with those that behaved less desirably. Thus, individuals that ended up in class 1 after the information transfer (environmentalists – 22.4% + 44.8%) were compared with those that ended up in class 2 (critical and economic environmentalists – 10.7% + 22.1%) using t-tests. The results of this comparison are shown in table 5. None of the socio-economic characteristics (age, gender, income, etc.) was found to be significantly different between both groups. Contrarily, respondents that reacted best to the information transfer (environmentalists) valued the forest functions biodiversity, environmental regulation and conservation higher. In addition, they more frequently visited forests for nature observation and mushroom and berry picking, and included a significant higher share of respondents that visited forests more than 19 times in the past year. Moreover, they scored lower on a scale that represented a human-centered attitude towards forests. This attitude specified that forests should mainly serve humans and that human intervention in forests is beneficial for biodiversity and its functioning. Furthermore this group of respondents attached significantly more importance to the available forest area, forest functioning, biodiversity and soil biodiversity which was represented by a single score. Lastly, the respondents in this best behaving group scored significantly higher on the knowledge questions related to soil biodiversity, forest functioning and management.

Table 5: Comparison of socio-economic, attitudinal and knowledge related characteristics using two-sided t-test between the group of respondents that reacts best on the information transfer from a soil biodiversity perspective (= environmentalists (after information transfer): 22.4% + 44.8%) and the group that reacts in a less desirable manner (= critical and economic environmentalists (after information transfer): 10.7% + 22.1%).

	Environmentalists (N = 201)	Critical & economic environmentalists (N = 98)	Significance (p-value)
Function_biodiversity [a]	3.95 (0.072)	3.54 (0.104)	*** (0.002)
Function_environmental regulation [a]	4.20 (0.067)	3.67 (0.119)	**** (0.000)
Function_conservation [a]	4.23 (0.063)	3.90 (0.111)	*** (0.008)
Activity_nature_observation [a]	2.11 (0.088)	1.82 (0.108)	** (0.050)
Activity_picking [a]	1.31 (0.057)	1.12 (0.047)	* (0.081)
Human-centered attitude [b]	2.63 (0.049)	2.89 (0.078)	*** (0.003)
Forest visits [>19 times/past year] (%)	23.9%	15.3%	* (0.086)
Importance [b d]	4.07 (0.054)	3.83 (0.078)	** (0.013)
Knowledge [c d]	8.51 (0.311)	7.48 (0.457)	* (0.061)

Significant coefficient estimates are indicated with * p<0.1, ** p<0.05, *** p<0.01 or **** p<0.001
[a] Mean score (and standard error) based on a 5-point likert scale with 1 item
[b] Mean score (and standard error) based on a 5-point likert scale with multiple items (Homo_centric_attitude (4), Importance (4))
[c] Score (and standard error) on 10 based on 14 knowledge items that were scored on a 5-point likert scale (disagree - agree)
[d] Including only respondents that answered the knowledge questions before watching the informative video (N = 104 and N = 52, for group 1 and group 2 respectively)
The item(s) for each of these variables is (are) lined out in the questionnaire that is available upon request.

4. Discussion

In general, we found that Flemish citizens preferred environmentally and soil biodiversity friendly levels of forest management related characteristics already before information transfer on soil biodiversity. Except for the attribute 'old trees and dead wood' of which lower shares were preferred. A limited amount of dead wood in forests was also found to be preferred in a review study that combined 109 publications of European studies on public forest preferences (Ciesielski & Stereńczak, 2018). Nevertheless, the information transfer in our study significantly increased preferences for the highest shares of old trees and dead wood. Similarly, Gundersen and Frivold (2011) found that Norwegian citizens preferred photographs of forests with no or little dead wood, but that including a short text on the ecological benefits of dead wood, significantly increased the probability of a photo to be preferred. In a follow-up study that extended the information treatment by including different types of information, Gundersen et al. (2017) found that ecological information had the highest effect and that this effect continued to exist even when the information was left out in consequent pictures. The topic of dead wood has received increasing attention in the Flemish forestry planning during the last decades. Maintaining dead wood has been included in the management goals which has resulted in increasing shares of dead wood in forests (Govaere, 2020). This has come along with changes in forest aesthetics, that could potentially have led to societal conflicts with recreational users and citizens. Our results highlight the potential of short simple informative videos to counteract these conflicts and ensure societal harmony between recreational users and forest managers. Moreover, our study indicated that recreation and the aesthetic value of forests through layering and open patches following tree logging are still considered the most important forest management attributes for citizens, both before and after the information transfer. Nevertheless, biodiversity related aspects and pure management practices significantly increased in importance, while this was not found for regulating ecosystem services.

Looking further into preference heterogeneity, we found two latent classes both before and after the information transfer. While these latent class models revealed some interesting findings, the results presented here do not represent the global optimum, but a local optimum, selected based on the log likelihood value and a meaningful interpretation. Nevertheless, it does represent a way to divide the sample of 299 respondents into classes that have homogeneous preferences within a class, but heterogeneous preferences between classes. Differences between classes were more pronounced before the information transfer with the largest class focusing on aesthetics and recreation, at the expense of regulating ecosystem services, biodiversity components and the pure management practice tree logging. This complies with the focus in forest valuation literature on public preferences for recreation, aesthetics and structure related forest characteristics (e.g. Ciesielski and Stereńczak, 2018; Edwards et al., 2012; Giergiczny et al., 2015). In addition, similar to our results, these studies mostly encountered preferences for layered, uneven-aged forests and opposition against large areas of clear-cuts.

Furthermore, we found that the group of respondents that reacted best on the information transfer from a soil biodiversity perspective, mostly included individuals that valued environmental aspects of forests higher, had higher soil biodiversity knowledge and were more often regular forest visitors. On the other hand, they adhered less to a human-oriented vision on forests. These findings match the conclusions of previous studies on public forest preferences in several European regions. For example, Brahic and Rambonilaza (2015) and Rambonilaza and Brahic (2016) investigated the effect of information on public preferences for preservation of forest biodiversity in France. They found that mainly environmental sensitiveness and forest use explained higher willingness-to-pay values for forest biodiversity and that only individuals that were knowledgeable about biodiversity and regularly use forests expressed higher preferences for less known aspects of biodiversity such as dead wood. In addition, Grilli et al. (2016) found that valuing non-productive ecosystem services of forests resulted in a higher probability of preferring mixed forests over monocultures in a Polish context, while no effect was found of socio-economic characteristics. Lastly, Czajkowski et al. (2014) identified effects of recreational forest use on preferences for forest attributes amongst Polish citizens with frequent visitors having higher preferences for ecological attributes and levels such as the highest increase in area of protection of ecologically valuable forests.

Lastly, our results indicate that information transfer on soil biodiversity has the potential to strengthen preferences of Flemish citizens towards biodiversity friendly management practices on the short term. Nevertheless, we acknowledge that our approach does not allow to derive strong conclusions on the long-term effect of information transfer. However, the presence of a short-term effect should encourage researchers to investigate the long-term effect of information transfer by retaking the questionnaire at a subsequent point in time, as was done for example by Czajkowski et al. (2016) to investigate stability of willingness-to-pay and preferences for forest management over time.

5. Conclusion and policy recommendation

In this study, we investigated the effect of information transfer related to soil biodiversity on preferences of Flemish citizens for forest management. We found significant effects for some management characteristics, mainly technical and biodiversity related, that revealed strengthening support for the highest levels after the information transfer, that support soil biodiversity most. In general, the information transfer was found the have the largest effect on preferences for higher shares of old trees and dead wood. Furthermore, this level was significantly preferred by both preference classes after the information transfer, while no significance for this level was found for the two classes before the information transfer. While the information transfer was found to have largest effect on citizens that attach higher value to ecological forest functions and are knowledgeable on soil biodiversity, both classes after the information transfer expressed preferences that support soil biodiversity at least to some extent. Based on our study, we encourage policy makers in Flanders to use short informational videos related to the importance of soil biodiversity in forests, with a focus on old trees and dead wood. By increasing public support for soil biodiversity friendly management practices, forest managers could be encouraged to take soil biodiversity into account in their decision making. Nevertheless, policy makers should be aware that environmentally-oriented citizens are expected to alter preferences in the most desired way.

6. Acknowledgements

This research was part of the SoilForEUROPE project funded through the 2015-2016 BiodivERsA COFUND call for research proposals, with the national funders Agence Nationale de la Recherche (ANR, France), Belgian Science Policy Office (BELSPO, Belgium), Deutsche Forschungsgemeinschaft (DFG, Germany), Research Foundation Flanders (FWO, Belgium), and the Swedish Research Council (FORMAS, Sweden).

7. References

Bardgett, R. D., & Van Der Putten, W. H. (2014). Belowground biodiversity and ecosystem functioning. Nature, 515(7528), 505–511. https://doi.org/10.1038/nature13855

Berkes, F., Folke, C., & Colding, J. (1998). Linking social and ecological systems : management practices and social mechanisms for building resilience. Cambridge University Press. Retrieved from https://www.cambridge.org/vi/academic/subjects/life-sciences/ecology-and-conservation/linking-social-and-ecological-systems-management-practices-and-social-mechanisms-building-resilience?format=PB

Brahic, E., & Rambonilaza, T. (2015). The impact of information on public preferences for forest biodiversity preservation: A split-Sample test with choice experiment method. Revue d'Economie Politique, 125(2), 253–275. https://doi.org/10.3917/redp.252.0253

Brockerhoff, E. G., Barbaro, L., Castagneyrol, B., Forrester, D. I., Gardiner, B., González-Olabarria, J. R., … Jactel, H. (2017). Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodivers Conserv, 26, 3005–3035. https://doi.org/10.1007/s10531-017-1453-2

Ciesielski, M., & Stereńczak, K. (2018). What do we expect from forests? The European view of public demands. Journal of Environmental Management, 209, 139–151. https://doi.org/10.1016/J.JENVMAN.2017.12.032

Czajkowski, Mikolaj, Barczak, A., Budzinski, W., Giergiczny, M., & Hanley, N. (2016). Preference and WTP stability for public forest management. Forest Policy and Economics. https://doi.org/10.1016/j.forpol.2016.06.027

Czajkowski, Mikołaj, Bartczak, A., Giergiczny, M., Navrud, S., & Żylicz, T. (2014). Providing preference-based support for forest ecosystem service management. Forest Policy and Economics, 39, 1–12. https://doi.org/10.1016/j.forpol.2013.11.002

de Bruin, J. O., Hoogstra-Klein, M. A., Mohren, G. M. J., & Arts, B. J. M. (2015). Complexity of forest management: Exploring perceptions of Dutch forest managers. Forests, 6(9), 3237–3255. https://doi.org/10.3390/f6093237

De Valck, J., Vlaeminck, P., Broekx, S., Liekens, I., Aertsens, J., Chen, W., & Vranken, L. (2014). Benefits of clearing forest plantations to restore nature? Evidence from a discrete choice experiment in Flanders, Belgium. Landscape and Urban Planning, 125, 65–75. https://doi.org/10.1016/j.landurbplan.2014.02.006

Decocq, G., Andrieu, E., Brunet, J., Chabrerie, O., De Frenne, P., De Smedt, P., … Wulf, M. (2016). Ecosystem Services from Small Forest Patches in Agricultural Landscapes. Current Forestry Reports, 2(1), 30–44. https://doi.org/10.1007/s40725-016-0028-x

Edwards, D., Jay, M., Jensen, F. S., Lucas, B., Marzano, M., Montagné, C., … Weiss, G. (2012). Public preferences for structural attributes of forests: Towards a pan-European perspective. Forest Policy and Economics, 19, 12–19. https://doi.org/10.1016/j.forpol.2011.07.006

Gardi, C., Jeffery, S., & Saltelli, A. (2013). An estimate of potential threats levels to soil biodiversity in EU. Global Change Biology, 19(5), 1538–1548. https://doi.org/10.1111/gcb.12159

Giergiczny, M., Czajkowski, M., Zylicz, T., & Angelstam, P. (2015). Choice experiment assessment of public preferences for forest structural attributes. Ecological Economics. https://doi.org/10.1016/j.ecolecon.2015.07.032

Greene, W. H., & Hensher, D. A. (2003). A latent class model for discrete choice analysis: contrasts with mixed logit. Transportation Research Part B: Methodological, 37(8), 681–698. https://doi.org/10.1016/S0191-2615(02)00046-2

Grilli, G., Jonkisz, J., Ciolli, M., & Lesinski, J. (2016). Mixed forests and ecosystem services: Investigating stakeholders' perceptions in a case study in the Polish Carpathians. Forest Policy and Economics, 66, 11–17. https://doi.org/10.1016/j.forpol.2016.02.003

Gundersen, V., Stange, E. E., Kaltenborn, B. P., & Vistad, O. I. (2017). Public visual preferences for dead wood in natural boreal forests: The effects of added information. Landscape and Urban Planning, 158, 12–24. https://doi.org/10.1016/J.LANDURBPLAN.2016.09.020

Gundersen, Vegard, & Helge Frivold, L. (2011). Naturally dead and downed wood in Norwegian boreal forests: public preferences and the effect of information. Scandinavian Journal of Forest Research, 26(2), 110–119. https://doi.org/10.1080/02827581.2010.536567

Hartmann, M., Niklaus, P. A., Zimmermann, S., Schmutz, S., Kremer, J., Abarenkov, K., … Frey, B. (2014). Resistance and resilience of the forest soil microbiome to logging-associated compaction. The ISME Journal, 8(1), 226–244. https://doi.org/10.1038/ismej.2013.141

Hasselström, L., & Håkansson, C. (2014). Detailed vs. fuzzy information in non-market valuation studies: the role of familiarity. Journal of Environmental Planning and Management, 57(1), 123–143. https://doi.org/10.1080/09640568.2012.736370

Hauber, A. B., González, J. M., Groothuis-Oudshoorn, C. G. M., Prior, T., Marshall, D. A., Cunningham, C., … Bridges, J. F. P. (2016). Statistical Methods for the Analysis of Discrete Choice Experiments: A Report of the ISPOR Conjoint Analysis Good Research Practices Task Force. Value in Health, 19(4), 300–315. https://doi.org/10.1016/J.JVAL.2016.04.004

Hole, A. R. (2007). Fitting mixed logit models by using maximum simulated likelihood. The Stata Journal (Vol. 7).

Jeanloz, S., Lizin, S., Beenaerts, N., Brouwer, R., Van Passel, S., & Witters, N. (2016). Towards a more structured selection process for attributes and levels in choice experiments: A study in a Belgian protected area. Ecosystem Services, 18, 45–57. https://doi.org/10.1016/j.ecoser.2016.01.006

Juutinen, A., Kosenius, A.-K., Ovaskainen, V., Tolvanen, A., & Tyrväinen, L. (2017). Heterogeneous preferences for recreation-oriented management in commercial forests: the role of citizens' socioeconomic characteristics and recreational profiles. Journal of Environmental Planning and Management, 60(3), 399–418. https://doi.org/10.1080/09640568.2016.1159546

Kearney, A. R., Tilt, J. R., & Bradley, G. R. (2010). The effects of forest regeneration on preferences for forest treatments among foresters, environmentalists, and the general public. Journal of Forestry, 108(5), 215–229. https://doi.org/10.1093/jof/108.5.215

Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., … Fresco, L. O. (2016). The significance of soils and soil science towards realization of the United Nations sustainable development goals. Soil, 2(2), 111–128. https://doi.org/10.5194/soil-2-111-2016

Kessels, R., Jones, B., & Goos, P. (2015). An improved two-stage variance balance approach for constructing partial profile designs for discrete choice experiments. Applied Stochastic Models in Business and Industry, 31(5), 626–648. https://doi.org/10.1002/asmb.2065

Lancaster, K. J. (1966). A NEW APPROACH TO CONSUMER THEORY. Journal of Political Economy, 74, 132–157.

Lukac, M. (2017). Soil biodiversity and environmental change in European forests. Central European Forestry Journal, 63(2–3), 59–65. https://doi.org/10.1515/forj-2017-0010

McFadden, D. (1974). Chapter Four - Conditional logit analysis of qualitative choice behavior. In P. Zarembka (Ed.), Frontiers in Econometrics (pp. 105–142). New York: Academic Press. https://doi.org/10.1080/07373937.2014.997882

Meyfroidt, P. (2013). Environmental cognitions, land change, and social-ecological feedbacks: an overview. Journal of Land Use Science, 8(3), 341–367. https://doi.org/10.1080/1747423X.2012.667452

Mori, A. S., Lertzman, K. P., & Gustafsson, L. (2017). Biodiversity and ecosystem services in forest ecosystems: a research agenda for applied forest ecology. Journal of Applied Ecology, 54(1), 12–27. https://doi.org/10.1111/1365-2664.12669

Needham, K., Czajkowski, M., Hanley, N., & LaRiviere, J. (2018). What is the causal impact of information and knowledge in stated preference studies? Resource and Energy Economics, 54, 69–89. https://doi.org/10.1016/J.RESENEECO.2018.09.001

Nielsen, U., Wall, D. H., & Six, J. (2015). Soil Biodiversity and the Environment. Annu. Rev. Environ. Resour., 40, 63–90. https://doi.org/10.1146/annurev-environ-102014-021257

Nordén, A., Coria, J., Jönsson, A. M., Lagergren, F., & Lehsten, V. (2017). Divergence in stakeholders’ preferences: Evidence from a choice experiment on forest landscapes preferences in Sweden. Ecological Economics, 132, 179–195. https://doi.org/10.1016/J.ECOLECON.2016.09.032

Orgiazzi, A., Panagos, P., Yigini, Y., Dunbar, M. B., Gardi, C., Montanarella, L., & Ballabio, C. (2016). A knowledge-based approach to estimating the magnitude and spatial patterns of potential threats to soil biodiversity. Science of the Total Environment, 545–546(January), 11–20. https://doi.org/10.1016/j.scitotenv.2015.12.092

Pacifico, D., & Yoo, H. Il. (2013). Lclogit: A stata command for fitting latent-class conditional logit models via the expectation-maximization algorithm. Stata Journal, 13(3), 625–639. https://doi.org/10.1177/1536867x1301300312

Paletto, A., De Meo, I., Cantiani, M. G., & Maino, F. (2013). Social Perceptions and Forest Management Strategies in an Italian Alpine Community. Mountain Research and Development, 33(2), 152–160. https://doi.org/10.1659/mrd-journal-d-12-00115.1

Puettmann, K. J., Wilson, S. M. G., Baker, S. C., Donoso, P. J., Drössler, L., Amente, G., … Bauhus, J. (2015). Silvicultural alternatives to conventional even-aged forest management - What limits global adoption? Forest Ecosystems, 2(8), 1–16. https://doi.org/10.1186/s40663-015-0031-x

Rambonilaza, T., & Brahic, E. (2016). Non-market values of forest biodiversity and the impact of informing the general public: Insights from generalized multinomial logit estimations. Environmental Science and Policy, 64, 93–100. https://doi.org/10.1016/j.envsci.2016.06.008

Referowska-Chodak, E. (2019). Management and Social Problems Linked to the Human Use of European Urban and Suburban Forests. Forests, 10, 964. https://doi.org/10.3390/f10110964

Sing, L., Metzger, M. J., Paterson, J. S., & Ray, D. (2018). A review of the effects of forest management intensity on ecosystem services for northern European temperate forests with a focus on the UK. Forestry, 91(2), 151–164. https://doi.org/10.1093/forestry/cpx042

Smith, J. W., Siderelis, C., Moore, R. L., & Anderson, D. H. (2012). The effects of place meanings and social capital on desired forest management outcomes: A stated preference experiment. Landscape and Urban Planning, 106(2), 207–218. https://doi.org/10.1016/J.LANDURBPLAN.2012.03.009

Turbé, A., Toni, A. De, Benito, P., Lavelle, P., Lavelle, P., Ruiz, N., … Mudgal, S. (2010). Soil biodiversity: functions, threaths and tools for policy makers. Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment). https://doi.org/10.2779/14571

Varela, E., Jacobsen, J. B., & Mavsar, R. (2017). Social demand for multiple benefits provided by Aleppo pine forest management in Catalonia, Spain. Regional Environmental Change. https://doi.org/10.1007/s10113-016-1038-8

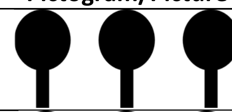
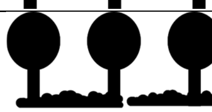
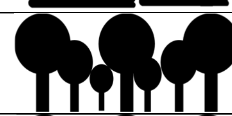
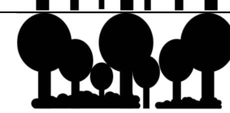
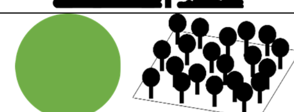
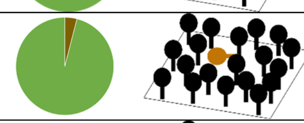
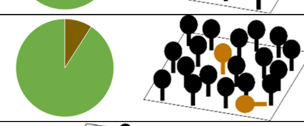
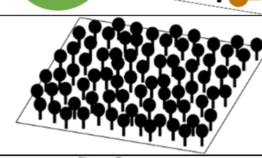
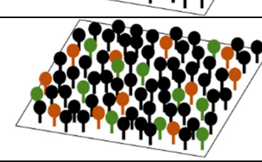
Varela, E., Verheyen, K., Valdés, A., Soliño, M., Jacobsen, J. B., De Smedt, P., … Decocq, G. (2018). Promoting biodiversity values of small forest patches in agricultural landscapes: Ecological drivers and social demand. Science of the Total Environment, 619–620, 1319–1329. https://doi.org/10.1016/j.scitotenv.2017.11.190

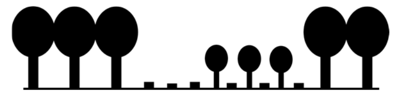
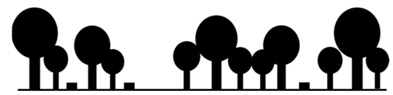
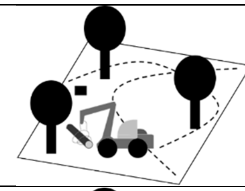
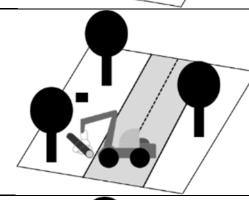
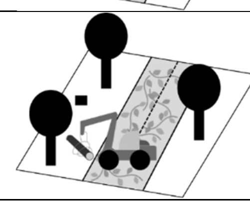
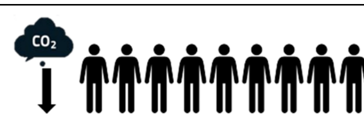
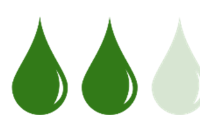
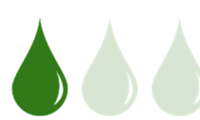
Xylander, W. E. R., & Zumkowski-xylander, H. (2018). Increasing awareness for soil biodiversity and protection The international touring exhibition ‘ The Thin Skin of the Earth .’ Soil Organisms, 90(2), 79–94. https://doi.org/10.25674/KKY5-A011

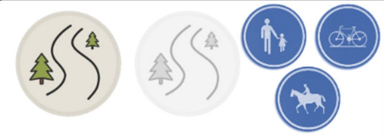
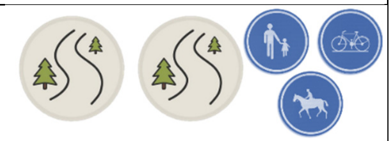
8. Appendices

Appendix A: Information on attributes and levels provided to respondents before the discrete choice experiment

The third part of the questionnaire contains a choice-experiment in which a number of visual choice cards are presented to you. Each card contains two options between which you will have to choose. The two options each depict a forest management scenario, defined by ten management choices shown in the table below. The first column of the table contains the name of the management choice including a short definition. The second column provides additional explanation. In the third column, the levels that define the management choice are presented. These levels will be depicted in the choice cards using the pictograms in column 4. Please read the table below carefully.

Management choice	Explanation	Levels	**Pictogram/Picture**
Understory and shrub layer *= Extent to which smaller trees and a shrub layer are present.*	**Even-aged** forest stand = all trees belong to the same age class. **Uneven-aged** forest stand = trees belong to different age classes and hence are of different height within one stand.	Even-aged without shrub layer	
		Even-aged with shrub layer	
		Uneven-aged without shrub layer	
		Uneven-aged with shrub layer	
Old trees and dead wood *= Share of old trees and dead wood, relatively to the total timber stock.*	**Old tree =** remarkably old for its species. **Dead wood =** dead and dying trees, or parts of trees.	None (<1% of the total timber stock)	
		Few (2-5% of the total timber stock)	
		Many (≥ 10% v of the total timber stock)	
Tree species diversity *= Extent to which tree species are mixed.*	**Monoculture** = only one tree species. **Slightly mixed** = mixture of 2 to 3 tree species of which one species is dominant. **Intensively mixed** = mixture of minimum 4 species. All species are present in comparable numbers.	Monoculture (1 species)	
		Slightly mixed (2 to 3 species)	
		Intensively mixed (minimum 4 species)	

Forestry system *= Replacing old trees with new trees*	**Clear-cutting =** entire forest stand is replaced at one moment on 100% of the total stand area. **Group cutting** = groups of trees are replaced consecutively, step by step. **Selective cutting** = individual trees are regularly replaced.	Clear-cutting	
		Group cutting	
		Selective cutting	
Tree logging *= Way in which wood is logged.*	**Mechanical** = use of specialized machines for logging and skidding the timber. **Fixed logging roads** = during logging, the machines are only allowed to ride on these marked strips. **Additional protection** = the use of methods to limit soil compactation (by driving only on steel plates or over a bed of branches)	Mechanical without fixed logging roads	
		Mechanical with fixed logging roads	
		Mechanical with fixed logging roads and additional protection (by steel plates or a bed of branches)	
Carbon storage *= Storage of carbon in the forest soil.*	This process can mitigate climate change and is expressed as the amount of CO_2 that is stored per 100 ha of forest, translated into **yearly CO_2 emissions of a number of citizens.**	Equivalent to the yearly emissions of 250 citizens	
		Equivalent to the yearly emission of 350 citizens	
		Equivalent to the yearly emissions of 450 citizens	
Water retention *= Rate at which (rain)water flows through the forest ecosystem.*	Forests contribute to water quality and water storage through purification and buffering. The slower the water flows, the higher the **water quality** and the higher the **water storage**.	Slow water flow; high water quality and storage	
		Moderate water flow; moderate water quality and storage	
		Rapid water flow; low water quality and storage	

Recreation *= The possibility to recreate.*	Distinction in the number of paths (**few – many**), the extent to which different user groups (walker, horse rider, etc.) are allowed to access the paths (**whether or not user group specific**) and the extent to which **motorized traffic** is permitted on the forest paths.	Few paths, user group specific except motorized traffic	
		Few paths, open to all user groups except motorized traffic	
		Many paths, user group specific except motorized traffic	
		Many paths, open to all user groups except motorized traffic	
		Many paths, open to all user groups and motorized traffic	
Mushroom and berries picking *= Availability of mushrooms and berries.*		Many	
		Moderate	
		Few	
Yearly contribution to a fund *= Compulsory yearly contribution per household to a forest fund specifically oriented towards forest maintenance.*	A **household** is defined as a group of people living together under one roof and jointly organizing their household.	€5 per family per year	
		€20 per family per year	
		€50 per family per year	
		€100 per family per year	
		€150 per family per year	

APPENDIX I: STICKER WITH QR CODE THAT LEADS TO THE PROJECT WEBSITE (Dutch version)

APPENDIX J: PROVISIONAL DRAFT VERSION OF THE LEAFLET WHICH CONTAINS MAIN PROJECT RESULTS (English version)

Outer face:

Take home messages

- Mixing tree species enhances the diversity of soil organisms. This effect usually remains fairly small but was strong for some groups, such as mycorhizal fungi.
- Mixing tree species leads to a more homogeneous vertical distribution of fine roots as well as changes in root morphology and associations.
- Mixture effects are predicted to become stronger in the future by mitigating the effects of drought on soil biodiversity.

Contacts by Country

BE	B. Muys	bart.muys@kuleuven.be
BE	K. Verheyen	kris.verheyen@ugent.be
FI	T. Domisch	timo.domisch@luke.fi
FR	S. Hättenschwiler	stephan.hattenschwiler@cefe.cnrs.fr
FR	H. Jactel	herve.jactel@pierroton.inra.fr
DE	J. Bauhus	juergen.bauhus@waldbau.uni-freiburg.de
IT	F. Bussotti	filippo.bussotti@unifi.it
NL	M. Berg	m.p.berg@vu.nl
PL	B. Jaroszewicz	b.jaroszewicz@uw.edu.pl
RO	O. Bouriaud	bouriaudfundiv@gmail.com
SE	P. Kardol	paul.kardol@slu.se

Project funding

biodiversa

ANR DFG fwo

belspo formas

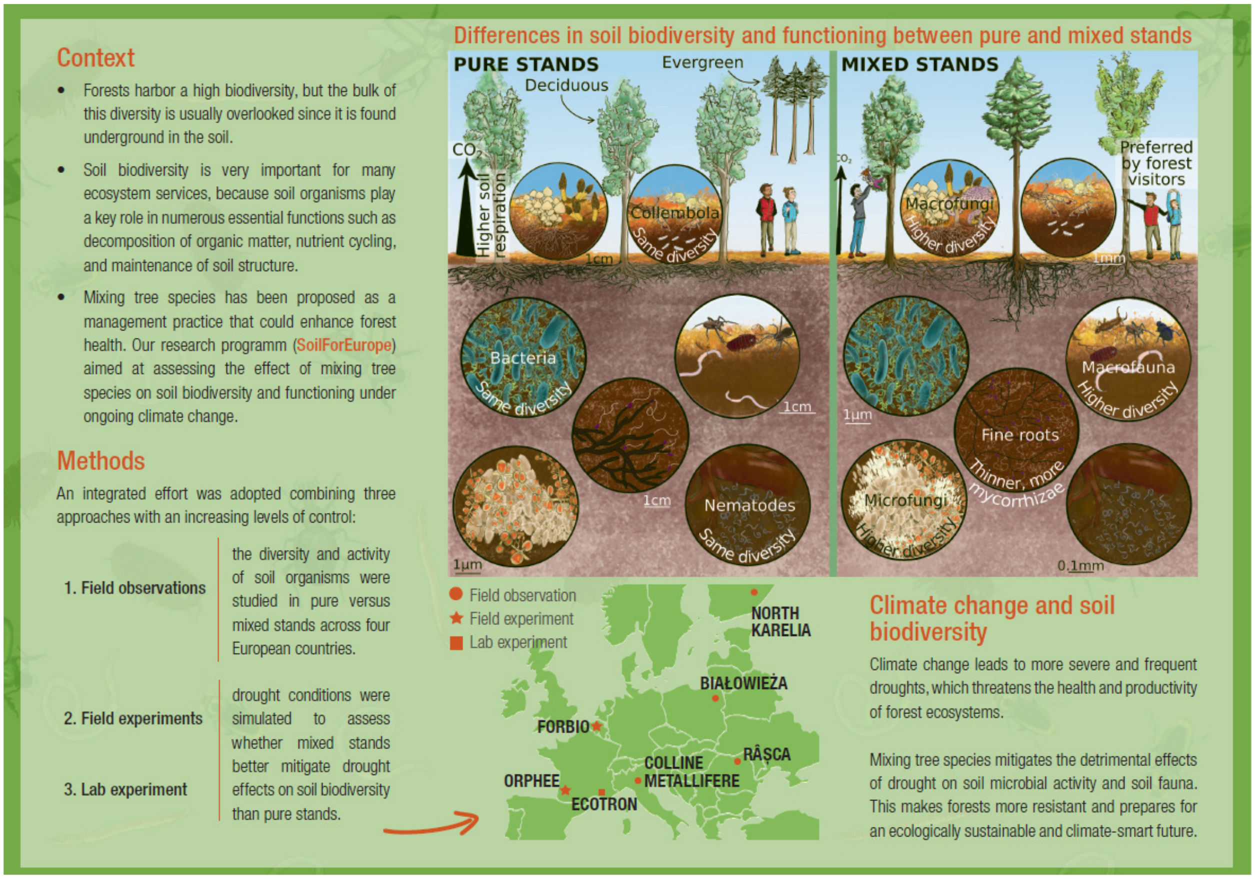
Lay-out: www.graag-design.be
Illustrations: www.lesbullesdemo.fr
Photos soil profiles: Stefaan Dondeyne

https://websie.cefe.cnrs.fr/soilforeurope

Soil For EUROPE

FOREST SOIL BIODIVERSITY AND CLIMATE CHANGE

Inner face:



Context

- Forests harbor a high biodiversity, but the bulk of this diversity is usually overlooked since it is found underground in the soil.
- Soil biodiversity is very important for many ecosystem services, because soil organisms play a key role in numerous essential functions such as decomposition of organic matter, nutrient cycling, and maintenance of soil structure.
- Mixing tree species has been proposed as a management practice that could enhance forest health. Our research programm (SoilForEurope) aimed at assessing the effect of mixing tree species on soil biodiversity and functioning under ongoing climate change.

Methods

An integrated effort was adopted combining three approaches with an increasing levels of control:

1. Field observations — the diversity and activity of soil organisms were studied in pure versus mixed stands across four European countries.

2. Field experiments
3. Lab experiment — drought conditions were simulated to assess whether mixed stands better mitigate drought effects on soil biodiversity than pure stands.

Differences in soil biodiversity and functioning between pure and mixed stands

Climate change and soil biodiversity

Climate change leads to more severe and frequent droughts, which threatens the health and productivity of forest ecosystems.

Mixing tree species mitigates the detrimental effects of drought on soil microbial activity and soil fauna. This makes forests more resistant and prepares for an ecologically sustainable and climate-smart future.