COST ACTION BOTTOMS-UP

BIODIVERSITY OF TEMPERATE FOREST TAXA ORIENTING MANAGEMENT SUSTAINABILITY BY UNIFYING PERSPECTIVES

CA18207

WORKING GROUP 3

EFFECT OF MANAGEMENT ON BIODIVERSITY BASED ON EXPERIMENTS

DELIVERABLE 1

DESCRIPTION OF THE EXISTING FOREST MANIPULATION EXPERIMENTS

Document assembled by:

Flóra Tinya, Bence Kovács, Péter Ódor

www.cost.eu

Introduction

Forests cover 33% of European land representing determinant natural elements of the European landscape (Forest Europe 2015). European forests have a great importance both for society and economy. Timber is an important industrial raw material and renewable energy source, and forests also provide many other economical utilities (hunting, mushroom and berry picking, etc., Forest Europe 2015). They provide fundamental ecosystem services for human well-being as soil and climate protection, climate change mitigation, healthy water, air, and environment (Mori *et al.* 2017). The role of forests in recreation is increasing in the more and more urbanised European landscape. A major part of European biodiversity is directly connected to forests, whose conservation is an increasing challenge and responsibility (EEA 2016).

Thousands of years of land use by European civilizations resulted in considerable decrease of forest cover and in modification of forest structure (Kaplan *et al.* 2009). Although 12% of European forests are protected (by different level of conservation status, Forest Europe 2015), most of them are managed, and only 0.7% of the European forests are in primary conditions, i.e., without human intervention since the last 80 years (Sabatini *et al.* 2018). It is indisputable that the preservation of these primary (old-growth) forest remnants is essential for the conservation of forest biodiversity (Peterken 1996), but because of their very low proportion, the role of forest restoration and close-to-nature forest management remains crucial in the maintenance of European forest biodiversity (Bauhus *et al.* 2013). For instance in close-to-nature forestry systems, the ecological and economical aspects are integrated into forest management resulting in an ecological sustainable timber production (Kraus and Krumm 2013).

The exploration of the relationships between forest biodiversity and management is indispensable for the maintenance of an ecologically sustainable forest management. In this view, multi-taxon studies (regarding many organism groups) are particularly relevant, since the different groups of organisms respond variously to forestry treatments (Paillet *et al.* 2010, Sabatini *et al.* 2016). The most important indicators for the status of European forests are based on stand structure, management and tree species composition (Forests Europe 2015), only birds and vascular plants are mentioned as taxa-based indicators, although many other organism groups (e.g., saproxylic beetles, fungi, and bats) are better indicators of the natural conditions of forests (Paillet *et al.* 2010). Although most of the studies related to forest biodiversity are focused only one organism group, the number of multi-taxon studies is increasing (Dörfler *et al.* 2018, Elek *et al.* 2018, Schall *et al.* 2020). Forest management influences biodiversity via changes of abiotic conditions (light, temperature, and soil conditions), hence the exploration of management – stand structure – abiotic conditions – biodiversity relationships is very important for the understanding of the main drivers of forest biodiversity (Elek *et al.* 2018).

The aim of the BOTTOMS-UP COST Action is the integration of these local and regional multi-taxon studies on a continental level. The main questions of the Action are:

• Which are the optimal indicators of sustainable forest management to be adopted in Europe?

• What are the effects of different management practices on multi-taxon forest biodiversity?

• What are the thresholds for key structural elements (e.g., deadwood, tree-related habitats) to maintain multi-taxon forest biodiversity?

• Is the biodiversity response to forest structure and management congruent across taxa?

• What are the effects of forest management on the functional diversity of various taxonomic groups and on ecosystem functions?

• What abiotic conditions (e.g., microclimate, and soil chemistry) are influenced by forest management and how do they affect multi-taxon biodiversity?

Working Group 1 and 2 are committed to create a common platform of different observational multi-taxon studies. Within this framework, Working Group 3 collects information about those studies that conducted experiments related to forest management effects on multi-taxon biodiversity. WG3 will take advantage of the fine-scale management information available for sites under manipulation experiments to analyse the effects of innovative management strategies, likely underrepresented across the network of observational sites. WG3 will also focus on sharing knowledge on forest manipulation experiments in order to promote these research activities and coordinate them into a single network. The main manipulations, response variables and factors included into the experiments of the participants will be discussed and detailed. The considerable overlaps among the experiments enable to create common analyses based on specific questions and the comparison of the results of different sites. This meta-data evaluation can also reveal the potential knowledge gaps in the network of experiments that will result from the Action.

The analyses based on experimental studies need approaches differing from those used for observational studies, since experiments usually have complex sampling designs and very peculiar management interventions that cannot be easily standardised. Therefore, WG3 worked in synergy with WG1 and WG2, but through a different pathway.

Firstly, the Working Group 3 contacted several researchers within and outside the Action in order to create a network of scientists that collected data on forest manipulation experiments. Thus WG3 network overlaps partly with WG1 and WG2.

The data custodians within WG3 network where invited to provide: i) detailed descriptions of the ongoing experiments in Europe (including all specificities of the projects), ii) all the data suitable for the template datasets originally created for observational studies by WG1 and WG2. The majority of the experimental data custodians took both opportunities.

Therefore, for forest manipulation experiments, the synergistic work of the three working groups resulted in: plot/stand descriptions and raw data for forest structure and biodiversity harmonized with WG1 and WG2, plus specific fine-scale information on the complex and heterogeneous sampling designs and interventions used in the experimental studies. Also all specificities of the projects from which the experiments stemmed were recorded, in order to have an overview about the past and running projects. In this Report, we give a general overview about the collected experiments, including the followings:

- Geographical and habitat representation;
- The main intervention (treatment) types;
- Representation of different taxonomic groups;
- The studied environmental variables.

The Report explores the main research and knowledge gaps related to experimental studies on forest biodiversity. Besides the general evaluation, we include into this Report the metadata tables of the experimental sites and the individual experiment descriptions as supplementary material.

Methods

We collected experiments that fulfilled the following criteria:

1) Forests had to belong to Pan-European closed forests (i.e. canopy cover ≥40%, before the treatments).
2) There had to be at least one kind of stand structure manipulation, plus control plots. Manipulations could be commercial forestry treatments or conservation-oriented forest management actions (e.g., deadwood manipulation, creation of microhabitats, etc.).
3) At least 3 repetition had to be sampled for each treatment.
4) Data should be collected from minimum three taxonomic groups, representing at least two of the following broad groups of organisms: Plantae, Fungi and Animalia, and Animalia should be included.
5) Data custodians had to give a detailed description of the study design, the treatments, the sampling protocols, and accurate geographical coordinates of the plots.

The search for experiments was performed through several means. Participants of the BOTTOMS-UP COST Action were called to join to the network if they have appropriate experiments. They were also asked to look for experiments in their own country and spread our call among their colleagues. We searched projects on the internet as well. We scanned the list of the LIFE projects (https://ec.europa.eu/environment/life/project/Projects/index.cfm) relating to forests, and searched for relevant publications on the Web of Science. Bernes *et al.* (2015) published a systematic map of studies on the effect of forest management on biodiversity; experiments fitting to our criteria were sorted from their metadatabase. Originally, we focused on the temperate and hemiboreal region of Europe, but experiments performed in the Mediterranean and boreal region were also included. However, the boreal zone has not been explored extensively, thus our list does not offer a representative collection of boreal experiments. As our aim was primarily to create a network among the research groups working on similar experiments, and not only to create and analyse a database from the forest experiment data, projects in the planning stage (yet without any implemented interventions and after-treatment data) were also involved.

Because of the heterogeneity of the involved projects, a textual description was necessary to collect all specific information about the projects Thus, experiment custodians were asked to fill a description form in Word format about their experiment. Before the final establishment of the description form, the preliminary versions were iterated among the participants of the Action, and their suggestions were incorporated. Main parts of the description form were the followings:

1.) General information: name of the experiment, contacts, questions of the experiment, locality, basic data about the experimental design (number of sites/blocks/ treatments/plots and main dates of interventions and data collections);
2.) Site descriptions: geographical and vegetation information about the sites;
3.) Applied treatments: free description of the interventions and the design, with graphical representation;
4.) Investigated organism groups: list of taxa and short description about their sampling methods;
5.) Investigated environmental variables: list of measured environmental variables and a short description of the measurement methods;
6.) Other investigated functions/processes: free explanation of additional functions or processes investigated in the experiment;
7.) References of the publications related to the experiment;
8.) Participating experts in the project.

After collecting the filled forms, we summarized the most important, standardisable information of all experiments in table formats. Separate metadata tables have been created about the experiment-level and site-level metadata. During the construction of the tables, we tried to standardize the highly various descriptions of the custodians.
Concerning the treatments, we defined 7 main intervention categories with subcategories (Table 1). As there are many complex experiments, we allowed to have more than one intervention category and subcategory per project. Experiment designs were so heterogeneous that besides the standardized intervention data, it was necessary to create a column with free text description of the design.

Table 1. The applied treatment categories and subcategories.

Intervention category	Category abbrev.	Intervention subcategory	Subcategory abbrev.
Cutting	CUT	Catalan reference models	CAT
		Clear-cutting	CLE
		Close-to-nature forestry	CLO
		Conservation-oriented management	CON
		Forest–open field mosaic creation	FOR
		Gap-cutting	GAP
		Green tree retention	GRE
		Thinning	THI
		Undergrowth removal	UND
Microhabitat enrichment	MIC	Deadwood enrichment	DEA
		Habitat tree manipulation	HAB
Game exclosure	GAM	Game exclosure	GAM
Prescribed burning	BUR	Prescribed burning	BUR
Forest floor manipulation	FLO	Fertilization	FER
		Litter raking	LIT
		Mechanical damage of ground layer	MEC
Water manipulation	WAT	Ditch-filling	DIT
Tree composition manipulation	TRE	Admixing tree species manipulations	ADM
		Pure and mixture stands of two tree species	PUR

Definition of investigated organism groups was based on the taxonomic categories used by the WG1 and WG2 for observational projects. However, several new groups were mentioned in the descriptions beyond this list, thus we had to extend it. In many projects, only subgroups of a given taxa were sampled, hence we created columns for the enumeration of investigated subgroups. In some cases, these were taxonomic groups, but in many cases these meant functional groups or groups that can be collected by a special kind of sampling method (however, for the sake of simplicity, henceforth we call them "taxa"). Accordingly, complete standardisation was not possible without loss of information. In the case of arthropods, most of the traps collect numerous taxa, among which only some have been identified and analysed in the given project, depending on the competence and capacity of the experts working in the project. However, the other collected taxa have the potential to be identified and used during a future cooperation between experiments with different experts. In order to show these opportunities, we listed also the applied arthropod collecting methods besides the investigated taxa.

Because the experiments were highly various also in their spatial scales, site-level data were hardly standardisable as well, since the accuracy of the data was very different. In many cases, only intervals could be given for some numerical characteristics of the sites (e.g., altitude, stand age, canopy openness), or just the same approximate value was given for all sites. Forest types were defined based on the EEA categories (EEA 2007); in many cases more than one type was assigned to a site.

The first version of the tables was sent to the experiment custodians after highlighting the uncertain points that needed to be checked, corrected or implemented. This ensured the minimisation of mistakes during the standardisation process. However, this process of exchange and checking is still ongoing, thus the presented metadatabase will still be subjected to minor corrections in the near future.

Based on the metadata tables, some descriptive plots were created to present the result. Figures were done using R 3.6.1. (R Core Team 2019) using the package tidyverse (Wickham *et al.* 2019).

The report has been assembled by the authors listed on the title page, with the contribution of all experiment custodians (listed in Annex 1).

Results

General data about the experiments, design

Altogether 26 experiments have been collected from 14 European countries (Fig. 1, Fig. 2). The experiments comprise 284 sites. Metadata of the sites are in the Annex 2, Table S2 and S3. Basic information for each experiment is shown in Table 2; the detailed textual descriptions of each experiments are in the Annex 3. The investigated areas cover not only a broad range of latitude and longitude (from Spain to Finland), but also of altitude: they range from 5 m to 1850 m above sea level.

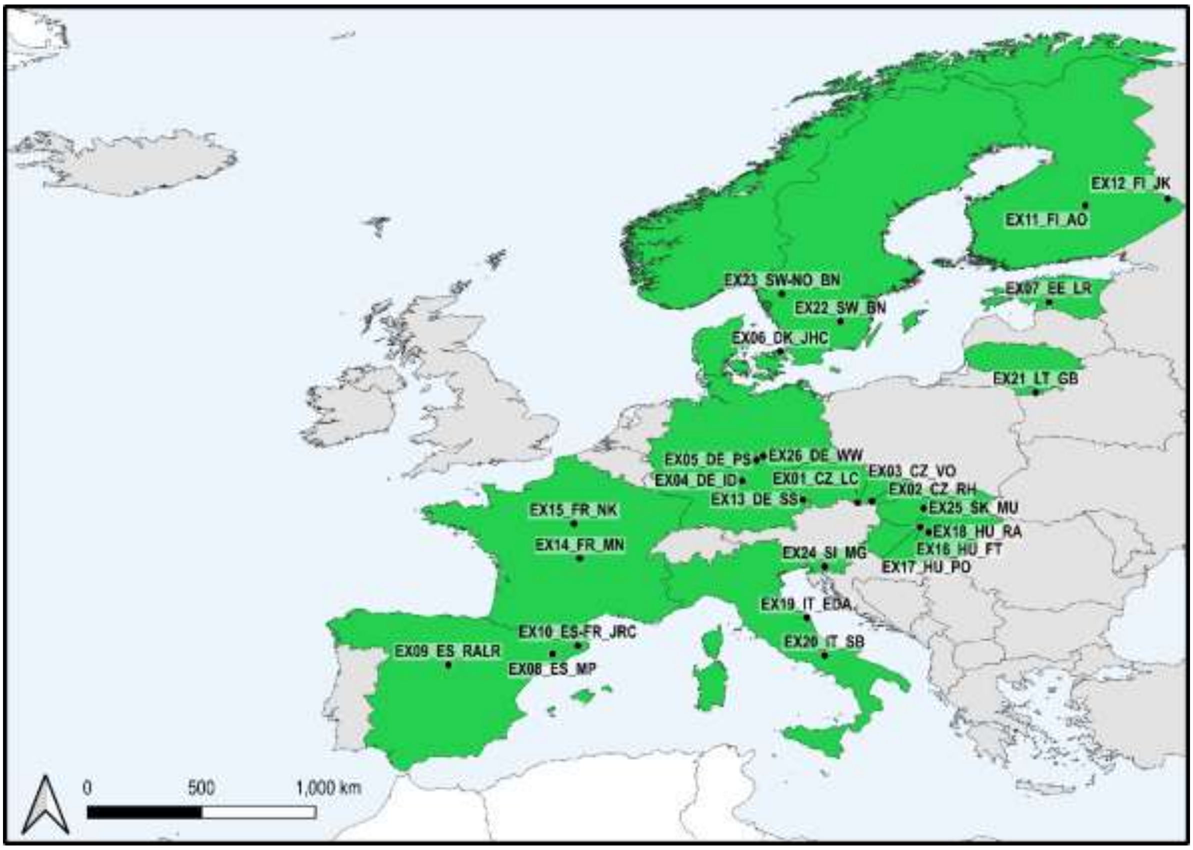

Figure 1. Location of the multi-taxon forest-manipulation experiments in Europe. Countries hosting one or more experiment are green. Experiment codes contain the identification number of the experiment, the code of the country and the initials of the contact person (Table 2).

Sites of the experiments represented 27 forest types from 11 forest categories. More than half of the experiments were located in three forest categories: in Mesophytic deciduous forest (23%, mainly Sessile oak–hornbeam forest), Beech forest (16%), and Mountainous beech forest (16%) (Fig. 3). The proportion of Hemiboreal forests and nemoral coniferous and mixed broadleaved-coniferous forests was 12%.

Design and spatial scale of the experiments was quite various. Number of sites within the projects varied from 1 to 89, while number of plots ranged from 15 to 190. Among 26 experiments, 16 were arranged in blocks. Area of the sites varied between 0.16 and 30 000 ha. All experiments had untreated control plots, and most of them (23 projects) had also before-treatment data. After-treatment data collection was heterogeneous: in some cases, it happened only once, in other cases more times, or even regularly, yearly. In other cases, there was a large difference even within an experiment among the temporal frequency of sampling of different taxa.

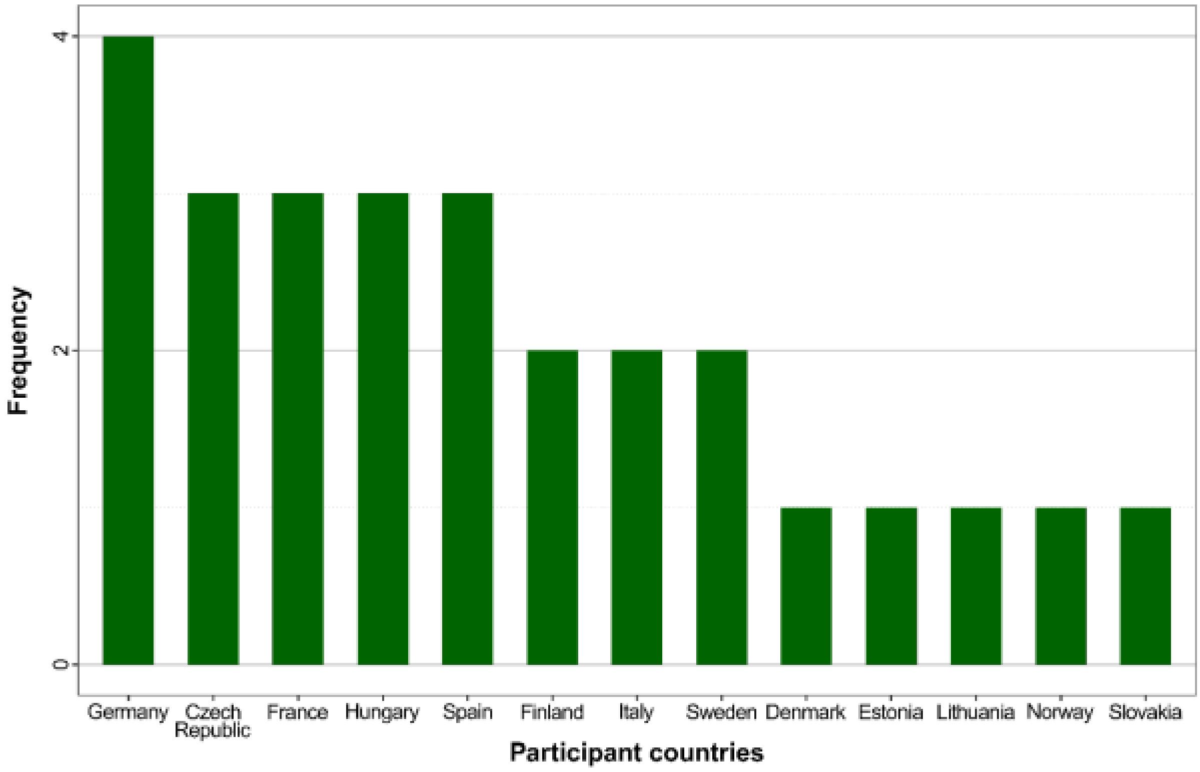

Figure 2. Number of experiments in different countries.

Table 2. General information of the included experiments: forest categories (EEA codes), number of sites and plots, treatment categories and investigated taxa.

Experiment_ID	EEA codes	Site No	Total Plot No	Treatments	Taxa
EX01_CZ_LC	5	6	36	CUT	HER, WOO, COL, CAR, LEP, HYM, REP, AVE
EX02_CZ_RH	5	1	15	CUT	HER, WOO, CAR, HYM, HEI, ARA
EX03_CZ_VO	5	1	45	FLO	HER, WOO, BRY, SOA, ARA
EX04_DE_ID	6	1	69	MIC	HER, WOO, BRY, LIC, FUN, COL, CAR, HEM, AVE, CHI
EX05_DE_PS	2, 5, 6, 7	3	116	CUT, MIC	HER, WOO, BRY, FUN, DEA, COL, CAR, LEP, HYM, HEM, ANN
EX06_DK_JHC	6	5	25	CUT, MIC	HER, WOO, BRY, LIC, FUN, CAR, AVE
EX07_EE_LR	11	2	64	CUT, WAT	HER, WOO, LIC, FUN, AMP, AVE
EX08_ES_MP	10	numerous, within 2 areas	176	CUT, BUR	AVE, BRY, VAS, WOO
EX09_ES_RALR	7	1	24	CUT, GAM	AVE, FUN, LEP, LIC, MAM, VAS, WOO
EX10_ES-FR_JRC	5, 9, 10	6	24	CUT	AVE, BRY, CHI, COL, VAS, WOO
EX11_FI_AO	1	43	43	CUT	BRY, FUN, VAS, WOO
EX12_FI_JK	1	1	24	CUT, BUR, GAM	BRY, CAR, COL, FUN, HEM, LIC, VAS, WOO
EX13_DE_SS	7	1	190	CUT, MIC	ARA, BRY, CAR, COL, DEA, FUN, HEM, MOL, VAS, WOO
EX14_FR_MN	2, 3, 5, 7, 10, 14	89	178	GAM	BRY, FUN, VAS, WOO
EX15_FR_NK	6	12	33	CUT, TRE, GAM	AVE, BRY, CAR, LIC, MAM, SOA, VAS, WOO
EX16_HU_FT	5	1	36	CUT	ANN, ARA, CAR, DIP, VAS, WOO
EX17_HU_PO	5	1	30	CUT, GAM	ANN, ARA, CAR, COL, SOA, VAS, WOO
EX18_HU_RA	5, 8	8	22	CUT, MIC	ARA, AVE, CAR, COL, VAS, WOO
EX19_IT_EDA	3, 6, 7, 8	6	49	CUT	AMP, AVE, CAR, CHI, DIP, SOA, VAS, WOO
EX20_IT_SB	7	6	33	CUT, MIC, TRE, GAM	AVE, COL, FUN, LIC, VAS, WOO
EX21_LT_GB	1, 2	26	70	CUT, FLO, MIC, BUR	AVE, BRY, COL, HYM, LIC, VAS, WOO
EX22_SW_BN	2	25	50	CUT	BRY, COL, DIP, FUN, LIC, MOL, VAS, WOO
EX23_SW-NO_BN	2	26	52	CUT	COL, DIP, FUN, HEM, LEP, VAS, WOO
EX24_SI_MG	7	3	27	CUT	AVE, CAR, COL, DIP, FUN, VAS, WOO
EX25_SK_MU	5	5	40	CUT, FLO	BRY, SOM, VAS, WOO
EX26_DE_WW	2, 3, 6	3	90	MIC	ACA, COL, DEA, FUN

Abbreviations: Experiment codes (Experiment ID) contain the identification number of the experiment, the code of the country and the initials of the contact persons. EEA codes: 1. Boreal forests, 2. Hemiboreal forest and nemoral coniferous and mixed broadleaved-coniferous forest, 3. Alpine coniferous forest, 5. Mesophytic deciduous forest, 6. Mesophytic deciduous forest, 7.

Mountainous beech forest, 8. Thermophilous deciduous forest, 9. Broadleaved evergreen forest, 10. Coniferous forest of the Mediterranean, Anatolian and Macaronesian region, 11. Mire and swamp forests, 14. Plantations and self-sown exotic forest.
Treatments: CUT=cutting, FLO=forest floor manipulation, GAM=game-exclosure, MIC=microhabitat enrichment, TRE=tree composition, WAT=water manipulation.
Taxa: ACA=Acari, AMP=Amphibia, ANN=Annelida, ARA=Araneae, AVE=Aves, BRY=Bryophyta, BUR=prescribed burning, CAR=Carabidae, CHI=chiroptera, COL=Coleoptera, DEA=Deadwood microbiome, DIP=Diptera, FUN=Fungi, HEI=Herbivorous insects, HEM=Hemiptera, HYM=Hymenoptera, LEP=Lepidoptera, LIC=Lichinales, MAM=Mammalia, MOL=Molluscs, REP=Reptilia, SOA=Soil arthropods, SOM=Soil microbiome, VAS=Vascular understory, WOO=Woody regeneration.

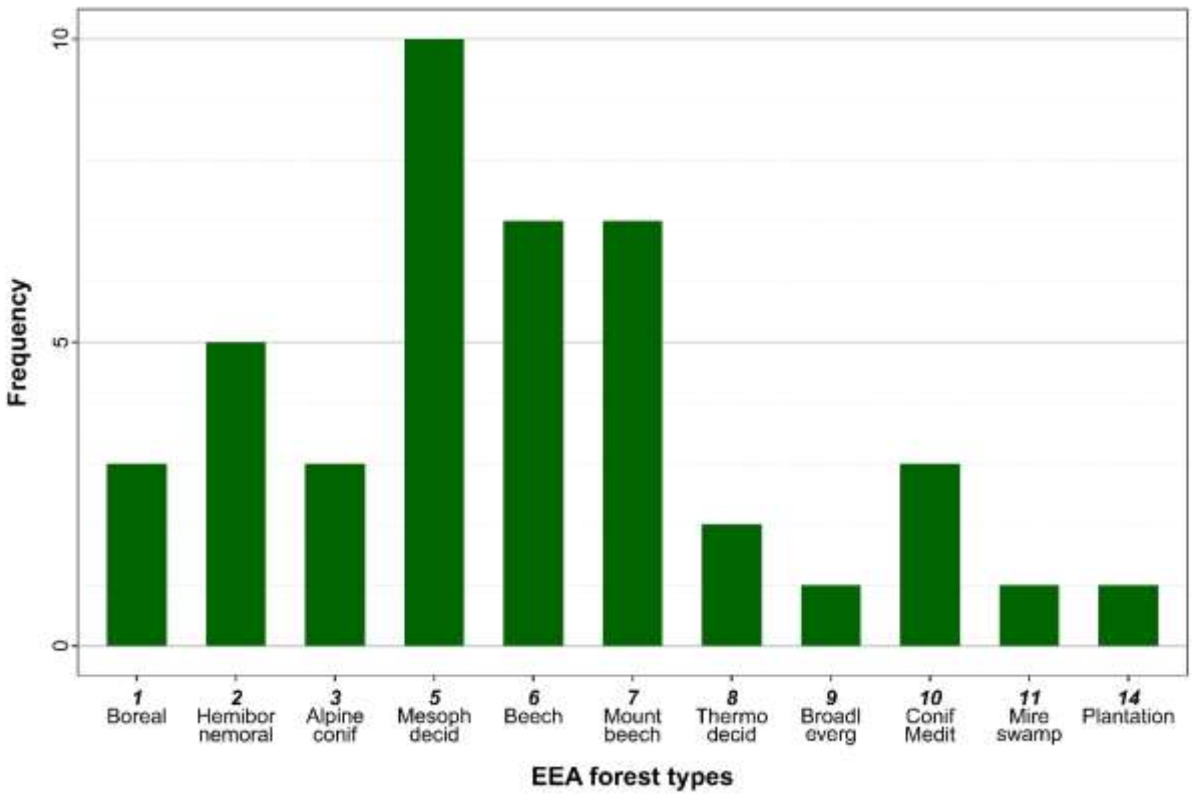

Figure 3. Distribution of experiments according to forest categories. One experiment can belong to more than one category.

Treatments

Most of the treatments were cuttings (56%), but microhabitat enrichment and game exclosure were also done in several projects (18% and 10%, respectively) (Fig. 4). Forest floor manipulation, prescribed burning, and tree species composition manipulations were scarcer, while water manipulation occurred only in one experiment. Within cutting, gap-cutting and thinning were the most common interventions, while the most frequent microhabitat-treatment was deadwood-creation. Mean number of treatment types within an experiment was 2.4, it ranged from 1 to 5. Number of temporal repetitions of the interventions was various: in some cases, interventions happened only once, while other interventions were repeated more times.

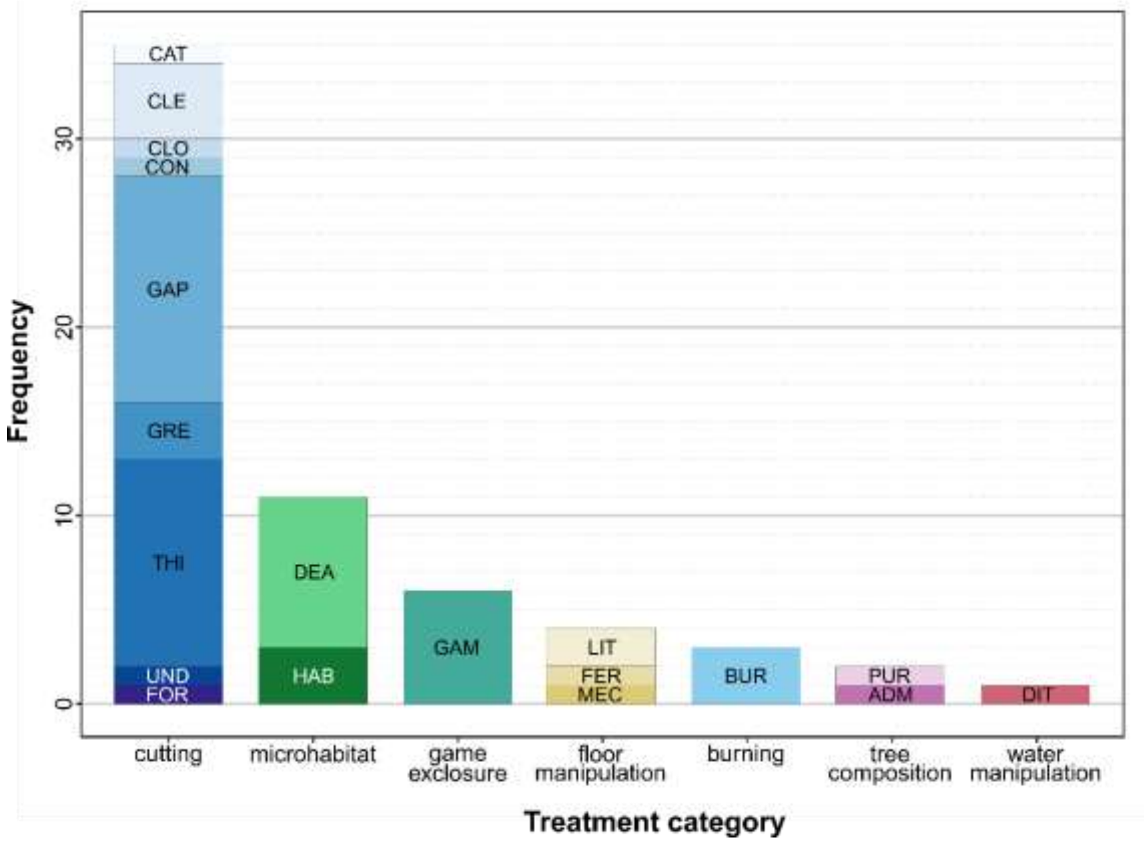

Figure 4. Frequency of the different treatment categories and subcategories in the experiment network.

Abbreviations: Cutting: CLE=clear-cutting, CLO=close-to-nature forestry, CON=conservation-oriented management, CAT=Catalan reference model, FOR=forest–open field mosaic creation, GAP=gap-cutting, GRE=green tree retention, THI=thinning, UND=undergrowth removal. Microhabitat: DEA=deadwood creation, HAB=habitat trees. GAM=game exclosure. Floor manipulation: LIT=litter raking, FER=fertilization, MEC=mechanical damage of ground layer. BUR=prescribed burning. Tree composition: ADM= admixing species, PUR=pure and mixture of two tree species. Water manipulation: DIT=ditch filling.

Investigated taxa

Altogether 24 taxa were studied in the experiment network (Fig. 5). On average, 6.73±1.93 taxa were sampled in an experiment, the minimum value was 4, and the maximum was 11. Vascular understory and woody regeneration were studied in almost all experiments (25 cases). Bryophyta, Fungi and Coleoptera were sampled in 14 experiments, while Carabidae and Aves in 13 projects. In case of Fungi, Coleoptera, Hymenoptera, Diptera, Hemiptera, Soil arthropods, Annelida, and Mammals only various subgroups of the taxon were sampled in most of the experiments. The most common arthropod sampling methods were pitfall trap (10 cases), window trap (6 cases), flight interception trap (5 cases), and Malaise trap (5 cases).

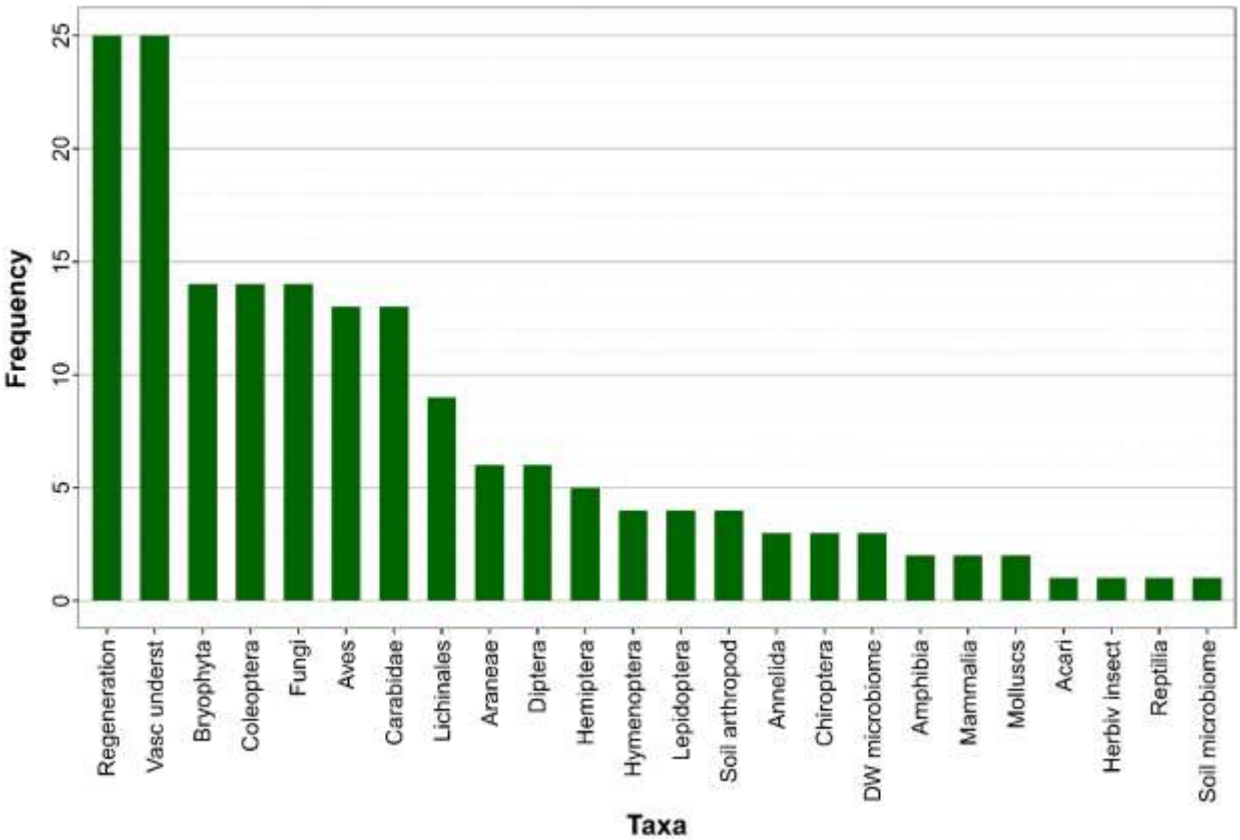

Figure 5. Frequency of studied taxa in the experiment network.

Studied environmental variables

Light was the environmental variable measured most often in the experiments (measured in 18 cases, Fig. 6); the most common approach was through hemispherical photos (10 cases). Soil components, air temperature, soil pH and air humidity were measured also at least in 10 projects. Litter data were collected in much less (2–6) experiments.

In 18 experiments, besides biodiversity, some additional functions or processes were also measured (Table 3). Game browsing was studied in 8 experiments, and decomposition processes were investigated in 6 projects.

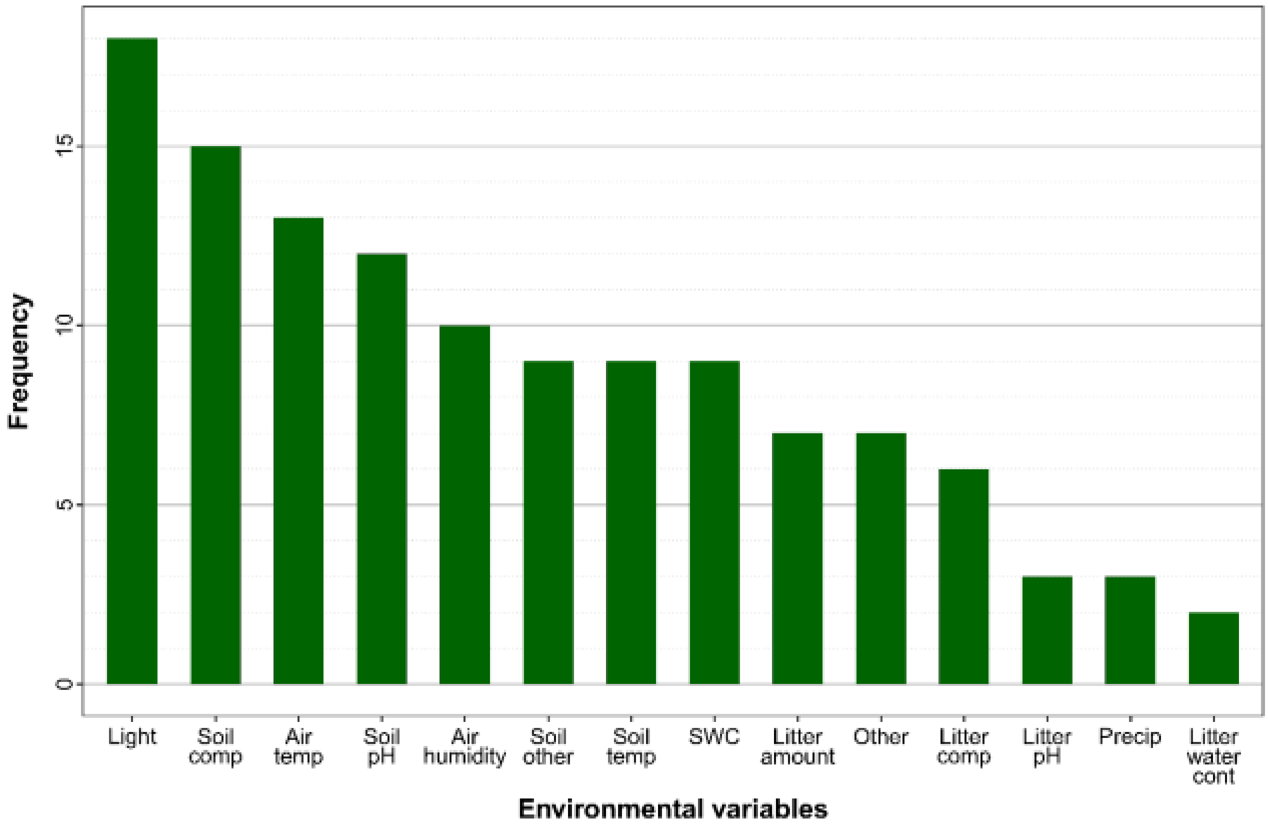

Figure 6. Frequency of measured environmental variables in the experiment network.

Table 3. Other functions and processes measured in the experiments.

Function/process	Frequency
Browsing	8
Decomposition	6
Seed fall	3
Fire prevention	2
Large wild ungulates activity	2
Wild boar activity	2
Biodiversity of small wetlands	1
Bryophyte transplantation	1
Cattle activity	1
Centennial trees	1
CO_2-efflux	1
Incidence of oak mildew and ash dieback	1
Sedge transplantation	1
Seed recruitment of herbs	1
Socio-economic evaluation	1
Tree growth	1
Tree phenology	1
Windthrow	1

Stand structural data

Stand structural data were available for all experiments. Species identity and diameter at breast height were determined in 23 projects, deadwood data, height, basal area, canopy openness, number of stems, and volume were obtainable more in than 15 projects (Fig. 7).

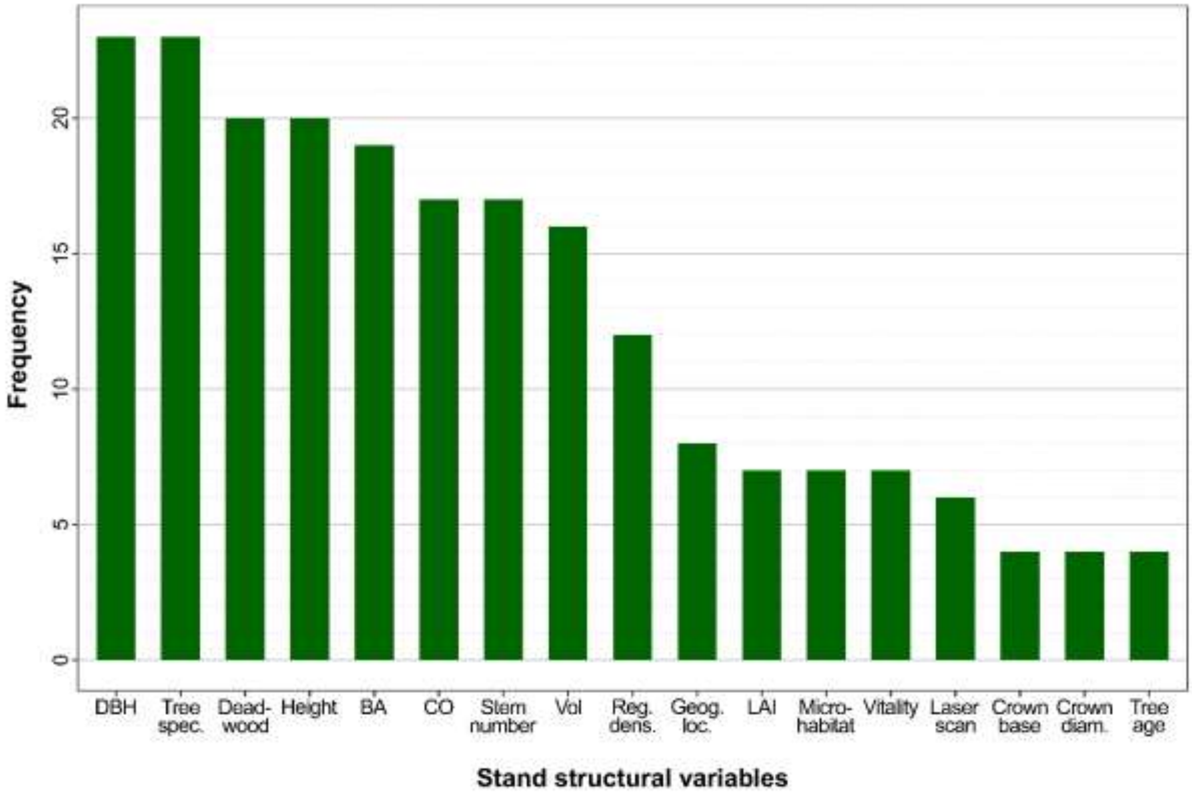

Figure 7. Frequency of measured stand structural variables in the experiment network.

Discussion

Distribution of experiments across forest categories

Similarly to the database of WG1 (Burrascano *et al.* 2020), three forest categories (Mesophytic deciduous forest, Beech forest, Mountainous beech forest) are overrepresented among the experiments. We have intermediate number of experiments from the boreal and hemiboreal region, however, compared to their area in Europe (Barbati *et al.* 2014), and to the number of forestry experiments in the region (http://noltfox.metla.fi), they are underrepresented in the network. Thermophilous deciduous and Coniferous forests of the Mediterranean are more or less well represented with two and three experiments, respectively. Broadleaved evergreen forests, Mire and swamp forests, and Plantations and self-sown exotic forests constitute knowledge gaps with their 1-1 experiments. We do not have any experiments from Acidophilous oak and oak-birch forests, Floodplain forests and Non-riverine alder, birch or aspen forests.

Potential connection point between experiments

The collected experiments are quite heterogeneous in their spatial scale, interventions, and also in their sampling methods. This makes it difficult to merge them in a common database and use them for common calculations on the level of the whole network. However, there are numerous issues that can be jointly analysed across some experiments. We draw up two approaches:

1) Connecting similar treatments: what is the effect of a given treatment type on the forest biodiversity through many experiments carried out in various forest types?
2) Connecting similar taxa: how does one or more taxon respond to various treatments in various forest types? Since the species pool is various in different regions, it would need a functional approach or evaluations on community level.

Hereinafter we highlight those elements of these two variables (treatment, taxon) that proved to be enough frequent in the network to ensure a good basis to create connections between several experiments:

Among treatments, only few types are relevant across a broad range of European forests. The most frequent treatment (with 12 cases) is gap-cutting that is the main element of the continuous cover forestry (CCF, Pommenering and Murphy 2004). Thus, using these experiments enables us to better focus on this innovative, sustainable management system than it would be possible from observational studies (where selection system is only the third one after rotation and clear-cutting forestry systems, Burrascano *et al.* 2020).

However, a fair number of experiments also studied different kind of thinnings (11 cases). Since a large proportion of European forests is managed by rotation forestry (Forest Europe 2015), it is also important to explore those thinning techniques that may benefit biodiversity.

Eight studies investigated the effect of deadwood manipulation on biodiversity. It is a crucial intervention of conservation-oriented management that is applied in an increasing extent across Europe. The aim of conservation-oriented management is not timber production, but primarily the biodiversity conservation (Lacaze 2000). For an effective use of such management strategy, it is necessary to explore its effects on forest biota, both at local and at broader scale. Deadwood manipulation can be used also in commercial forestry to enhance biodiversity of managed forests.

Game browsing is a cardinal issue in numerous forests of Europe, as over-browsing can inhibit the regeneration of the forest, and may influence the understory vegetation as well as other taxa (Bernes *et al.* 2018). Thus, understanding the effect of browsing on woody regeneration and on other components of biodiversity is essential for ecologically and economically sustainable management. Game exclosure is applied in six experiments, and the effect of browsing is studied altogether in eight projects that allows to explore its effect on a larger scale.

Some of the investigated treatments are relevant only in a certain region or forest type, thus we have only a few experiments for them, and their up-scaling to European level is hard. Ditch-filling is relevant only in mire and swamp forests, while litter raking is conducted in temperate sessile oak–hornbeam forests, where it was part of the traditional land-use. Prescribed burning is used in boreal and Mediterranean forests, but this treatment is quite underrepresented in our network.

The four clear-cutting experiments are quite heterogeneous for many aspects, thus a joint analysis is challenging. We have only three examples for green tree retention treatment that is therefore underrepresented, even if studying its effect on biodiversity would be advantageous. As a matter of fact, this forestry system is often considered as an ecologically sustainable method (Gustafsson *et al.* 2010) as compared to simple clearcutting, but its positive effect on biodiversity is taxon specific (Boros *et al.* 2019). Only two experiments studied the effects of tree species composition, therefore the effects of this component on biodiversity can be better investigated through observational studies.

Concerning the studied taxa, vascular understory, and also separately the woody regeneration are the most frequently sampled. As they occur in 25 experiments, they enable common analyses at a wide range of forests. Bryophytes, fungi, beetles, separately the carabid beetles, birds, and lichens have intermediate frequency among the studied taxa. However, in the case of fungi and beetles, it must be considered that in different experiments various subgroups of these taxa are collected. However, in the case of taxa, there is an opportunity to cooperate between projects and help each other to sample additional taxa in order to enhance the overlaps. E.g., in the case of arthropods, many traps collect a wide range of taxa, among which not all have been identified in an experiment, but experts of other research groups may help in this identification work.

Most of the studies are collecting also environmental and stand structural variables that can be used as explanatory variables for biodiversity. Basic stand structural variables (tree species, diameter, height, basal area, volume, and deadwood) are available for most of the projects. However, other structural, microclimatic and soil variables are collected in a very heterogeneous way, only light data were sampled in most of the studies. To increase commonalities, conducting some additional measurements in certain experiments, at least as one-time campaigns can be a possibility for the future.

As the ecological sustainability of a management system means not only the preservation of biodiversity, but also the maintenance of ecological processes (EEA 2016), studying the effects of different treatments on decomposition is also a cardinal issue. The six projects that investigate decomposition processes in our network enables the generalisation of such relationships as well.

Conclusions, way forward

The most important commonalities among studies based on forest manipulation experiments are gap-cutting, thinning, deadwood manipulation and game exclosure among the treatments, and vascular understory, regeneration, beetles, fungi, birds and lichens among the taxa. These commonalities give the opportunity to make the broadest possible generalisations, however, the possible level of the generalisation depends on the given issue. Up-scaling to the level of whole Europe is hard even in these cases, because of the large heterogeneity of the experiments. Besides, numerous other treatments and taxa give opportunity for common analyses on the scale of two or several experiments.

As a next step, after some minor corrections and complement on the meta-database, the experiment custodians will be again involved into the work. They will be asked to find commonalities between their experiment and other projects, based on this report. If the pandemic situation allows, we plan to organize a meeting for experiment custodians in spring 2021, to have a common brainstorming. Our two main tasks will be:

1) to define and undertake additional measurements, where it is possible, to enhance the overlaps between projects;

2) to define those topics, along which common analyses and publications from several experiments will be done.

As this report will be open-access, the description of the network will be available also for other researchers. If any of them owns data based on forest manipulation experiments that fit our criteria, the opportunity is open to join our network. New experiments that are similar to the most frequent ones in the network could strengthen the common analyses, while projects about underrepresented topics could help to fill our knowledge gaps.

References

Barbati, A., Marchetti, M., Chirici, G., Corona, P. (2014): European Forest Types and Forest Europe SFM indicators: Tools for monitoring progress on forest biodiversity conservation. Forest Ecology and Management 321: 145–157. https://doi.org/10.1016/j.foreco.2013.07.004

Bauhus, J., Puettmann, K. J., Kühne, C. (2013): Close-to-nature forest management in Europe: does it support complexity and adaptability of forest ecosystems? In: Messier, C., Puettmann, K. J., Coates, K. D. (eds.): Managing forests as complex adaptive systems: building resilience to the challenge of global change. The Earthscan forest library, Routledge, pp. 187–213. https://doi.org/10.4324/9780203122808

Bernes, C., Jonsson, B. G., Junninen, K., Lõhmus, A., Macdonald, E., Müller, J., Sandström, J. (2015): What is the impact of active management on biodiversity in boreal and temperate forests set aside for conservation or restoration? A systematic map. Environmental Evidence 4: 25. https://doi.org/10.1186/s13750-015-0050-7

Bernes, C., Macura, B., Jonsson, B. G., Junninen, K., Müller, J., Sandström, J., Lõhmus, A., Macdonald, E. (2018): Manipulating ungulate herbivory in temperate and boreal forests: effects on vegetation and invertebrates. A systematic review. Environmental Evidence 7: 13. https://doi.org/10.1186/s13750-018-0125-3

Boros, G., Kovács, B., Ódor, P. (2019): Green tree retention enhances negative short-term effects of clear-cutting on enchytraeid assemblages in a temperate forest. Applied Soil Ecology 136: 106–115. https://doi.org/10.1016/j.apsoil.2018.12.018

Burrascano, S., Chianucci, F., Kepfer Rojas, S., Trentanovi, G. (2020): BOTTOMS-UP: a European platform of multi-taxon forest ecosystem biodiversity and stand structural data. Report, COST Action BOTTOMS-UP (CA18207).

Dörfler, I., Gossner, M. M., Müller, J., Seibold, S., Weisser, W. W. (2018): Deadwood enrichment combining integrative and segregative conservation elements enhances biodiversity of multiple taxa in managed forests. Biological Conservation 228: 70–78. https://doi.org/10.1016/j.biocon.2018.10.013

EEA (2007): European forest types. EEA Technical report No 9/2006. European Environmental Agency, Copenhagen. https://www.eea.europa.eu/publications/technical_report_2006_9

EEA (2016): European forest ecosystems. State and trends. EEA Report No. 5./2016. European Environmental Agency, Luxemburg. https://www.eea.europa.eu/publications/european-forest-ecosystems

Elek, Z., Kovács, B., Aszalós, R., Boros, G., Samu, F., Tinya, F., Ódor, P. (2018): Taxon-specific responses to different forestry treatments in a temperate forest. Scientific Reports 8: 16990. https://doi.org/10.1038/s41598-018-35159-z

Forest Europe (2015): State of Europe's Forests 2015. Ministerial Conference on the Protection of Forests in Europe, Madrid. https://foresteurope.org/state-europes-forests-2015-report/

Gustafsson, L., Kouki, J., Sverdrup-Thygeson, A. (2010): Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scandinavian Journal of Forest Research 25: 295–308. https://doi.org/10.1080/02827581.2010.497495

Hofmeister, J., Hosek, J., Brabec, M., Hermy, M., Dvorak, D., Fellner, R., Malicek, J., Palice, Z., Tencik, A., Hola, E., Novozamska, E., Kuras, T., Trnka, F., Zedek, M., Kasak, J., Gabris, R., Sedlacek, O., Tajovsky, K., Kadlec, T. (2019): Shared affinity of various forest-dwelling taxa point to the continuity of temperate forests. Ecological Indicators 101: 904–912. https://doi.org/10.1016/j.ecolind.2019.01.018

Kaplan, J. O., Krumhardt, K. M., Zimmermann, N. (2009): The prehistoric and preindustrial deforestation of Europe. Quaternary Sciences Reviews 28: 3016–3034. https://doi.org/10.1016/j.quascirev.2009.09.028

Kraus, D., Krumm, F. (eds.) (2013): Integrative approaches as an opportunity for the conservation of forest biodiversity. European Forest Institute, Freiburg.

Lacaze, J. F. (2000): Forest management for recreation and conservation: new challenges. Forestry 73: 137–141. https://doi.org/10.1093/forestry/73.2.137

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: 12–27. https://doi.org/10.1111/1365-2664.12669

Paillet, Y., Berges, L., Hjalten, J., Ódor, P., Avon, C., Bernhardt-Römermann, M., Bijlsma, R-J., De Bruyn, L., Fuhr, M., Grandin, U., Kanka, R., Lundin, L., Luque, S., Magura, T., Matesanz, S., Mészáros, I., Sebastiá, M-T., Schmidt, W., Standovár, T., Tóthmérész, B., Uotila, A., Valladares, F., Vellak, K., Virtanen, R. (2010): Biodiversity differences between managed and unmanaged forests: meta-analysis of species richness in Europe. Conservation Biology 24: 101-112. https://doi.org/10.1111/j.1523-1739.2009.01399.x

Peterken, G. F. (1996): Natural woodland. Ecology and conservation in northern temperate regions. Cambridge University Press, Cambridge.

Pommerening, A., Murphy, S. T. (2004): A review of the history, definitions and methods of continuous cover forestry with special attention to afforestation and restocking. Forestry 77: 27–44. https://doi.org/10.1093/forestry/77.1.27

R Development Core Team (2019). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. https://www.r-project.org/

Sabatini, F. M., Burrascano, S., Azzella, M. M., Barbati, A., De Paulis, S., Di Santo, D., Facioni, L., Giuliarelli, D., Lombardi, F., Maggi, O., Mattioli, W., Parisi, F., Persiani, A., Ravera, S., Blasi, C. (2016): One taxon does not fit all: Herb-layer diversity and stand structural complexity are weak predictors of biodiversity in *Fagus sylvatica* forests. Ecological Indicators 69: 126–137. https://doi.org/10.1016/j.ecolind.2016.04.012

Sabatini, F. M., Burrascano, S., Keeton, W. S., Levers, C., Lindner, M., Potzschner, F., Verkerk, P. J., Bauhus, J., Buchwald, E., Chaskovsky, O., Debaive, N., Horváth, F., Garbarino, M., Grigoriadis, N., Lombardi, F., Duarte, I. M., Meyer, P., Midteng, R., Mikac, S., Mikolas, M., Motta, R., Mozgeris, G., Nunes, L., Panayotov, M., Ódor, P., Ruete, A., Simovski, B., Stillhard, J., Svoboda, M., Szwagrzyk, J., Tikkanen, O. P., Volosyanchuk, R., Vrska, T., Zlatanov, T., Kuemmerle, T. (2018): Where are Europe's last primary forests? Diversity and Distributions 24: 1426–1439. https://doi.org/10.1111/ddi.12778

Schall, P., Heinrichs, S., Ammer, C., Ayasse, M., Boch, S., Buscot, F., Fischer, M., Goldmann, K., Overmann, J., Schulze, E. D., Sikorski, J., Weisser, W. W., Wubet, T., Gossner, M. M. (2020). Can multi-taxa diversity in European beech forest landscapes be increased by combining different management systems? Journal of Applied Ecology 57: 1363-1375.

Wickham, H., Averick, M., Bryan, J., Chang, W., D'Agostino McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., LinPedersen, T., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H. (2019). Welcome to the tidyverse. Journal of Open Source Software, 4: 1686. https://doi.org/10.21105/joss.01686

Annexes

Annex 1. List of experiment custodians (see below)

Annex 2. Metadata of the sites (attached pdf)

Annex 3. Detailed descriptions of the experiments (attached pdf)

ANNEX 1

LIST OF EXPERIMENT CUSTODIANS

Experiment ID	Experiment title	Custodians
EX01_CZ_LC	Partial cutting promotes biodiversity in deciduous lowland forests	Lukáš Čížek
EX02_CZ_RH	Děvín coppicing restoration	Radim Hédl
EX03_CZ_VO	Podyjí litter raking experiment	Vild Ondřej
EX04_DE_ID	Steigerwald experiment	Inken Dörfler
EX05_DE_PS	Biodiversity Exploratories – FOX	Peter Schall
EX06_DK_JHC	The beech forest experiment	Jacob Heilman-Clausen
EX07_EE_LR	DREX (Drained-forest Restoration Experiment)	Liina Remm, Asko Lõhmus
EX08_ES_MP	LIFE Pinassa (Sustainable Management for Conservation of Pinus nigra forests in Catalonia [NE Spain])	Míriam Piqué, Jordi Camprodon
EX09_ES_RALR	Evaluación Natural En Un Antiguo Hayedo Adehesado	Rosa Ana Lopez Rodriguez, Juan Antonio Martín García
EX10_ES-FR_JRC	BIORGEST (Innovative Forest Management Strategies to Enhance Biodiversity in Mediterranean Forests. Incentives & Management Tools, LIFE17 NAT/ES/000568)	Joan Rovira Ciuró
EX11_FI_AO	PuroMonta Buffer Strip Experiment	Anna Oldén, Panu Halme
EX12_FI_JK	FIRE (Fire and retention trees in facilitating biodiversity in boreal forests)	Jari Kouki
EX13_DE_SS	Bavarian Forest Deadwood Experiment	Sebastian Seibold, Jörg Müller
EX14_FR_MN	RENECOFOR	Manuel Nicolas, Lucie Vincenot
EX15_FR_NK	OPTMix (Oak Pine Tree Mixture)	Nathalie Korboulewsky, Anders Mårell
EX16_HU_FT	Pilis Gap Experiment	Flóra Tinya, Péter Ódor
EX17_HU_PO	Pilis Forestry Systems Experiment	Péter Ódor, Flóra Tinya
EX18_HU_RA	LIFE 4 Oak Forests (Conservation management tools for increasing structural and compositional biodiversity in Natura2000 oak forests, LIFE16 NAT/IT/000245)	Réka Aszalós
EX19_IT_EDA	ManFor C.BD. (Managing forests for multiple purposes: carbon, biodiversity and socio-economic wellbeing, LIFE09 ENV/IT/000078)	Ettore D'Andrea, Giorgio Matteucci
EX20_IT_SB	FAGUS (Forests of the Apennines: Good practices to conjugate Use and Sustainability)	Sabina Burrascano, Walter Mattioli
EX21_LT_GB	NATURALIT (Optimizing the management of Natura 2000 network in Lithuania)	Gediminas Brazaitis, Žydrūnas Preikša
EX22_SW_BN	The Swedish Oak Project	Björn Nordén
EX23_SW-NO_BN	TransForest (Transformation of recent forest on abandoned agricultural land for the benefit of biodiversity, ecosystem services and green solutions)	Björn Nordén
EX24_SI_MG	ManFor C.BD. (Managing forests for multiple purposes: carbon, biodiversity and socio-economic wellbeing, LIFE09 ENV/IT/000078)	Maarten de Groot
EX25_SK_MU	Zvolen, Management experiment in oak-hornbeam forests	Mariana Ujházyova, Karol Ujházy, František Máliš
EX26_DE_WW	Biodiversity Exploratories – BELongDead	Wolfgang Weisser, Sebastian Seibold, Martin Gossner