Executive Summary:
Many people perceive biodiversity as enriching and would agree that it has a value by itself. Does biodiversity have, on top of that, an effect on the functions and services of ecosystems, such as productivity or nutrient, carbon and water cycling and the stability of these functions over time? This question has been addressed within the European research project FunDivEUROPE (October 2010 to April 2015), where scientists from 24 institutions spread across 15 countries worked together to deliver evidence-based and relevant information to the scientific community and to stakeholders.

FunDivEUROPE was based on three scientific platforms: First, the European sites of a global network of tree diversity experiments (“Experimental Platform”) were used to establish causal relationships between biodiversity and ecosystem functions. Second, FunDivEUROPE has set up a newly designed network of 209 study plots in existing mature forests (“Exploratory Platform”). The platform covers six focal regions representing important European forest types along the gradient from Boreal to Mediterranean forests. Third, within the “Inventory Platform” existing information from national forest inventories and other forest
monitoring networks has been compiled. The project included measurements on (i) forest biodiversity (i.e. tree species composition, regeneration, functional traits, regional differentiation and adaptation, dead wood, spatio-temporal structural diversity, understorey vegetation, bats and birds, soil animal and microbial communities), on (ii) provisioning and supporting services (i.e. timber quality, tree growth and productivity, root biomass and productivity, leaf area and photosynthesis parameters, nitrogen ecophysiology, soil nutrient stocks, litter production, element fluxes, litter decomposition, water use efficiency, and soil water quality), on (iii) regulating services (i.e. carbon sequestration in woody biomass and soil, herbivory by insects or mammals, resistance to pathogens or invasive species). In addition to these single-function analyses, synthesis activities quantified the effects of tree diversity on stability, multi-functionality and multi-diversity across European forest types. Finally, computer models were used to quantify the potential of tree diversity to mitigate disturbance impacts on the carbon cycle.

The results indicate a variety of responses to changing tree diversity, depending on the functions studied, and often depending on the study region. First, species identity effects were often observed, which means that many functions were influenced by the dominance of particular species. For example, in boreal forests, browsing by moose is higher if preferred species, such as birch and pine, are present, resulting in increased overall damage in species-rich stands containing those species. Second, many effects of tree species richness are evident: diverse forest stands are generally more productive than monocultures, particularly in the case of Mediterranean and Boreal forests. Mechanistically, this can be explained by the ability of mixed-species stands to utilize aboveground space more efficiently compared to monocultures through denser crown packing, thereby allowing them to intercept more light. In addition, tree species diversity contributes to stabilizing productivity over time, meaning that tree diversity can essentially be thought of as an “insurance policy” against hard times. Similarly, we found significant effects of tree species diversity on ecosystem resistance to drought, which however changed with local environmental and climatic conditions. Third, certain functions are not affected by tree diversity. Stem quality, for instance, depends on several tree parameters, but is independent of stand diversity. In sum, it seems obvious that tree diversity has several effects on specific ecological functions and that mixed forests almost never perform worse than pure stands under a multi-functionality perspective. Thus, both functionally diverse forests and functionally important species play a crucial role to adequately preserve and promote key ecosystem functions and services. Future research should now extend these analyses to the landscape scale.

In addition to the three research platforms, FunDivEUROPE has developed and implemented a “Knowledge Transfer Platform” (www.fundiveurope.eu) in order to foster communication, aggregation and synthesis of individual findings and to facilitate communication with stakeholders, policy makers and the wider public. The information gained should thus enable forest owners, managers and policy makers to adapt policies and management for sustainable use of forest ecosystems in a changing environment, capitalizing on the potential effects of biodiversity for ecosystem functioning.

Project Context and Objectives:
1 Project context and main objectives
1.1 Project Context: Forest biodiversity and ecosystem functioning
Does biodiversity matter for the functioning of ecosystems and the delivery of ecosystem services? In other words, does it make any difference to the processes within an ecosystem if there are many or only a few species?
The answer to these questions is not only of pure academic interest, but it becomes more and more relevant for human societies as the loss of biodiversity is dramatic and globally accelerating. The field of ecology dealing with that question has been coined as “Functional Biodiversity Research”, also sometimes called “Biodiversity-Ecosystem Function” (BEF) research. Since the first systematic research projects of the 1990ies, evidence has accumulated, which clearly and consistently showed that decreasing biodiversity is associated with decreasing mean values and increasing variance of many ecosystem functions, such as productivity or nutrient retention. However, the quantification of the biodiversity-ecosystem functioning relationship was heavily biased towards the analysis of small-statured and fast growing model ecosystems, such as grasslands. FunDivEUROPE has shifted functional biodiversity research to the forest realm, applying a study design that explicitly takes into account the diversity and complexity of major European forest types. In addition, early functional biodiversity research mainly focused on production functions and associated services such as carbon sequestration. In contrast, FunDivEUROPE has been implemented around the idea of multifunctionality, i.e. a whole suite of ecosystem functions and associated services has been assessed simultaneously.

The science of forestry in Europe with its long tradition has produced an encyclopaedic knowledge of the ecology of single tree species and of the dynamics of managed forests, mainly focusing on even-aged pure stands, however. Although existent at an empirical level, quantitative information on the development and the management of age-structured multi-species mixtures and how such diverse forests affect ecosystem functioning has been scarce. In silviculture, the question whether a mixture of tree species may perform better or may deliver more desirable products and functions than pure stands has been discussed since the beginning of forest science in the 18th century and remains controversial. However, in forestry, the analysis of mixture effects was largely dominated by studies comparing pure stands with two-species mixtures, focusing on economically important species. Concerns on the ecological sustainability of monocultures and their resistance and resilience against perturbations have raised the interest for mixed tree communities in forestry during the late 20th century. These discussions, further stimulated by policy processes such as the UN-CBD, UN-FCCC, MCPFE, EU-Habitat Directive, etc., initiated a trend in many industrialized nations to convert monocultures into structured mixed stands, hoping that increasing species diversity will enhance functioning and increase stability. FunDivEUROPE has adopted a rigid and statistical sound design to scientifically test this hypothesis, across a large gradient of stand-level tree diversity and in six major European forest types.

Decision making in silviculture and forest management is based on a variety of criteria, with biodiversity mainly taken into account for conservation purposes, thus being considered as a constraint to management. At the same time, in forestry and environmental economics, the prevailing view accepts a trade-off between production-maximation in monocultures on the one hand, and protection of biodiversity for nature conservation purposes in non-productive forests on the other hand. Thus, given the potential benefits of diverse mixed forests, providing information to decision makers about the role of forest diversity for ecosystem functioning and the delivery of ecosystem services, including its role in influencing stability in face of climate change, is crucial. Via its Knowledge Transfer Platform, FunDivEUROPE seeks to provide evidence-based information about using biodiversity as a tool to increase or stabilize multiple ecosystem functions and services in European forests, and how to use that knowledge for the development of silvicultural systems for mixed forests.

1.2 Main objectives
Scientific objectives
Scientific objectives
The overall goal of FunDivEUROPE is to quantify the effects of forest biodiversity on ecosystem function and services in major European forest types.
The scientific objectives of FunDivEUROPE therefore are:

1. to specify the functional significance of biodiversity for each of the main ecosystem service categories, i.e. supporting, provisioning and regulating services; by
   a) developing predictive models of timber and biomass production, including timber quality, aboveground and belowground biomass productivity, leaf area index and photosynthetic parameters;
   b) determining variability in stem wood production in relation to climate change;
   c) quantifying nutrient stocks and cycling, including litter production and element fluxes, nitrogen resorption efficiency, decomposition and mineralization;
   d) assessing hydrological functions and water quality, focusing on water use efficiency, drought stress, and water and element fluxes over various spatial and temporal scales;
   e) estimating the stock of carbon sequestered above and below ground;
   f) quantifying the load of insect pests, mammal herbivores, fungal pathogens and invasive plants;

2. to investigate how the influence of biodiversity on forest ecosystem functioning may vary across different spatial scales (from stand to landscape levels) and different bioclimatic regions of Europe;

3. to combine the strengths of experimental, observational and modelling approaches; by
   a) working in existing tree diversity experiments in Europe, which are part of the global network of tree diversity experiments TreeDivNet (“Experimental Platform”);
   b) by establishing a newly designed network of comparative study plots in six major European forest types, comprising a large gradient of tree species richness ranging from pure stands to highly diverse ones within each region (“Exploratory Platform”);
   c) by compiling forest inventory data, spatial data on soils and climate, and tree functional traits to test whether the patterns and mechanisms identified under (1.) can be extrapolated to larger spatial scales (“Inventory Platform”);
   d) providing a model framework that generates process-based null models against which the empirical findings can be tested;

4. to assess the impact of environmental change by integrating field and modelling data on the performance of pure versus mixed species stands under different disturbance regimes and climate;

5. to develop integrated syntheses on biodiversity effects on multi-functionality and multi-diversity in major European forest types.

Policy relevant objectives
The policy relevant objective of FunDivEUROPE is to strengthen the science-policy interface by delivering timely, relevant and understandable information to policymakers and stakeholders about forest biodiversity and ecosystem services.
The specific policy relevant objectives are:

1. to provide information for stakeholders and decision makers about the functional role of biodiversity in forests, via its “Knowledge Transfer Platform”;
2. to help forest owners and forestry organizations to adapt management strategies for sustainable use of forest ecosystems in a changing environment by formulating adaptation needs and strategies for European forests, and by suggesting silvicultural options for the management of mixed species forests;
3. to support EU policies and international initiatives related to forest ecosystems and environmental change by providing evidence-based knowledge about forest biodiversity, ecosystem functioning,
Change by providing evidence-based knowledge about forest biodiversity-ecosystem functioning relationships;
4. to support climate change mitigation policies by producing a quantitative insight into carbon sequestration and potential climate feedbacks as affected by forest biodiversity;
5. to produce recommendations for a further development of a European Long-Term Ecosystem Research Network that focuses on forest biodiversity and ecosystem functions/services;
6. to contribute to the global science-policy interface, e.g. within the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Project Results:
1 WP 1: Scientific platform design and implementation (WP leader: UGent)
Task 1.1: Implementation of Experimental Platform: Maintenance of TreeDiv_Net
by Michael Scherer-Lorenzen, ALU-FR (RHUL, UFZ, INRA, UGent, UFZ)
Achievement: Similarly to the highly successful application in grassland biodiversity research, the experimental manipulation of tree diversity aims to decouple the effect of the environment from biodiversity effects by establishing experimental communities differing in certain aspects of diversity, but growing in the same environmental conditions. Only by adopting this ‘synthetic community approach’, can within-habitat effects of diversity be detected unequivocally, allowing us to test causal relationships between diversity and function. This approach has been followed within the global network of tree diversity experiments (TreeDivNet).
The Experimental Platform makes use of the existing global network of tree diversity experiments (TreeDivNet, see http://www.treedivnet.ugent.be/ where new forests stands differing in tree species diversity were established during the last fifteen years. These experimental afforestations were established and financed by different and independent groups. At nine locations around the globe (ranging from boreal Finland to tropical Panama), tree communities of differing species diversity have been established since 1999, covering now almost 650 hectares of experimental area composed of almost 5´200 plots. At total of more than 1´000´000 tree individuals have been manually planted in a predefined design. All experiments follow the same basic approach, but differ in some details of their design. For example, at some sites, patch planting has been done to avoid out-competition of slow growing species by fast ones, i.e. to ensure full mixing of species within very long time spans. At other sites, in contrast, individual-based mixing of species has been adopted to allow for early species interactions.
Eleven of such tree diversity experiments are actually located in Europe, covering a latitudinal gradient from Southern Italy to Finland. Some of the experiments are already ten years old, while others have been planted only recently. Thus, mainly processes important during the initial phase of forest establishment can be studied currently, while processes that change with ongoing forest maturation, or that are relevant in mature forests only cannot be addressed in these experiments.
Implementation: At the time of the start of FunDivEUROPE, five experiments were fully established and had already some years of tree growth and basic data acquisition. These include, in decreasing order of age of the experiment, (i) the Satakunta Experiment, Finland, (ii) the BIOTREE experiment, Germany (site Kaltenborn), (iii) the Kreinitz Experiment, Germany, (iv) the ORPHEE Experiment, France, and (v) the FORBIO Experiment, Belgium. Within FunDivEUROPE, these experiments have been successfully maintained and were sampled by several researchers for distinct tasks, although with different intensity (depending on the experimental design and age). The TreeDivNet annual meeting in Helsinki, Finland (19-20 January 2012), as well as the TreeDivNet sDiv Workshop in Leipzig, Germany (20 March 2014), helped to further harmonize maintenance and sampling protocols.
helped to further harmonize maintenance and sampling protocols.

Publications from the project: Verheyen, K. et al. (2015) Contributions of a global network of tree diversity experiments to sustainable forest plantations. AMBIO (accepted with minor revisions).

Task 1.2: Design and establishment of the Exploratory Platform
by Kris Verheyen, UGent (ALU-FR, CSIC, METLA, MLU, UFI, UGent, USV, UWAR)
Achievement: One of the current advances in functional biodiversity research is the move away from short-lived test systems towards the exploration of diversity-ecosystem functioning relationships in structurally more complex ecosystems. In forests, assumptions about the functional significance of tree species diversity have only recently produced a new generation of research on ecosystem processes and services. Novel experimental designs have now replaced traditional forestry trials (see Task 1.1) but these comparatively young experimental plots suffer from specific difficulties that are mainly related to the tree size and longevity. Tree species diversity experiments therefore need to be complemented with comparative observational studies in existing forests. In the scope of FunDivEUROPE, a new network of forest plots along tree species diversity gradients in six major European forest types, the FunDivEUROPE Exploratory Platform, has been established. Key design features of this platform include the extent of the species diversity gradient with mixtures up to five species, strict avoidance of a dilution gradient, special attention to community evenness and minimal covariation with other environmental factors.
Implementation: The Exploratory Platform covers six major forest regions of Europe that extend from Spain and Italy in the south, over Romania, Poland and Germany in central Europe to Finland in the north. Together, the platform hosts most important European broadleaved (e.g. F. sylvatica, Quercus petraea/robur, Quercus ilex, Betula pendula/pubescens) and coniferous tree species (e.g. Pinus sylvestris, Picea abies), with most tree species occurring in several exploratory regions. The diversity gradients range from three to five tree species, depending on the region. Across all regions, 209 30 m x 30 m plots were established. These plots were permanently marked in the field using wooden poles. The position (±0.5 m) and diameter at breast height (dbh, ±0.5 cm) of each tree >7.5 cm dbh was measured in all plots. Based on the tree position data, plot-specific plans were drawn allocating each measurement to particular locations within the plot, including strict no-go areas and preferred walking tracks.
Deliverables D1.1 D1.6

Task 1.3: Implementation of the Inventory Platform
by Sophia Ratcliffe and Christian Wirth, ULEI (ALU-FR, FVA, INRA, USV)
Achievement: National Forest Inventory data was compiled from 8 European forest inventories, including: Spain, France, Germany, Sweden, Finland, Belgium (Walloon and Flanders regions) and Romania. In total we received data from 198,094 inventory plots including 2,606,109 trees of 188 species from 70 genera. Where available the data included estimates of growth, natural mortality, harvesting and regeneration rates, which have been used in several studies to investigate the influence of tree functional biodiversity on forest demographic rates. The exotic status of each species in each inventory was recorded using the DAISIE database (www.europe-aliens.org). Using the plot geographic coordinates the inventory plots were complimented information from climate, species pool, soil and topographic spatial datasets. The plots
Complimented information from climate, species pool, soil and topographic spatial datasets. The plots were classified to the European Forest Type classification in the case where the inventory did not provide the classification and by biome (boreal, temperate or Mediterranean).

Implementation: The harmonised data from the individual National Forest Inventories is stored in a relational database and has been made available to project members in Task 5.4. All publically available data (i.e. data that was not provided to FunDivEUROPE under license) is available to the wider scientific community for use, assuming appropriate acknowledgement of both the NFIs and FunDivEUROPE, thus ensuring continued use of the Inventory Platform. To date we have received three requests for data from scientists outside of FunDivEUROPE.

Publications from the project: Deliverable D1.2

Task 1.4: Data management, data quality assessment and control
by Sophia Ratcliffe and Christian Wirth, ULEI
Achievement: The BEF data portal website was installed on ULEI webservers and customised to meet the design of the FunDivEUROPE website. By the end of the project 282 datasets from the Exploratory and Experimental plots had been uploaded to the data portal. All the datasets have been checked to ensure that: 1) all columns are correctly annotated and invalid values approved; 2) plotcodes and species identities conform to the project’s naming conventions; and 3) sufficient metadata is contained within the datasets to enable other scientist to understand the dataset, especially with regards to data units. Where data is calculated from scripts, such as with the diversity indices, the scripts are also uploaded to the portal, alongside the data. Using the paper proposal mechanism in the data portal, project members have been able to gain access to secured datasets for use in their analyses.

Implementation: We used the BEF data portal, developed within the BEF China (Biodiversity and Ecosystem Functioning, DFG Research Unit 891, http://www.bef-china.de/). The BEF data portal allows for the storage, validation and sharing of data from ecological research groups. In summary, data is uploaded from a formatted MS Excel workbook to the website and submitted through a process of validation and acceptance. An R package (rbefdata) enables data from the portal to be imported directly into R without having to download it first, with appropriate access rights. The R package greatly improved the accessibility of datasets for those scientists working on multiple datasets, in that they don’t have to download the datasets first before importing them into R. The data management team ensured that datasets were uploaded as soon as they were received and requests for access to datasets were processed quickly, to ensure efficient data sharing within the project. The data portal website will continue to be available for project members to access data. A long-term data archiving, including giving each dataset a DOI, is being discussed.

Deliverables D1.3 D1.4. Knowledge Element: The FunDivEUROPE Data portal (http://fundiveuropektp.boku.ac.at/node/246)

Task 1.5: Standardized protocol development and application training
by Michael Scherer-Lorenzen, ALU-FR
Achievement: The functional significance of forest biodiversity can only be quantified with a reasonable noise-to-signal ratio by sampling a high number of plots ensuring high replication per diversity level. This implies that the measurements of specific tasks could not be taken by single PhD students alone, but that the local site technicians and other students had to help in gathering data. To ensure highest level of data
Implementation: ALU-FR has provided a template for protocol writing and ALU-FR has compiled all protocols developed by the task leaders of the different WP’s. In addition, ALU-FR has organized the protocol training workshop in spring 2011, held at the BIOTREE experimental field site in Kaltenborn, Germany, where PhD students and site technicians were instructed to apply the protocols. All sampling protocols are published in deliverable D1.5 and updated sampling protocols can be downloaded from our project web-site: [http://www.fundiveurope.eu/?page_id=1644](http://www.fundiveurope.eu/?page_id=1644).

Publications from the project: Deliverable D1.5

2 WP 2: Forest biodiversity characterization (WP-leader: KUL)
Task T2.1: Tree community composition, diversity and regeneration
by Cristina C. Bastias and Fernando Valladares, CSIC

Question: The functional implications of a low tree species diversity that characterize the most European forests are still poorly understood, as well as its impact on the services and goods provided by these forests. One of the most important regulation services and at the same time less visible is the regeneration of the forest itself. Regeneration provides the link between current and future forests, which is crucial under current rates of environmental changes. The goal of this task was to study how the abundance and diversity of regeneration of dominant tree species in each type of forest changed with the species richness as well as examining the influence of different abiotic and biotic factors (light, depth of soil, % rock, shrub, herb…) on the regeneration of different tree species.

Evidence: At global scale, results showed a positive increase in the abundance of juveniles but contrary to our expectations, a decrease on the diversity of juveniles with increasing species richness in the canopy. An individual analysis for each forest showed that regeneration varied according to species identity and the type of forest. There were no common trends among species to establish and survive neither in the same abiotic and biotic conditions nor under similar levels of canopy diversity. Results are still being explored to increase their potential for guiding forest management under global change scenarios.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D2.1.

Task T2.2: A trait database for functional characterization of stands (Task leader: ULEI)
by Mario Liebergesell and Christian Wirth, ULEI

Achievement: Datasets from 17 databases and >200 monographic sources have been compiled and harmonized in a database containing all species in the exploratory plots as well as economically and ecologically important woody species. In fact, for a set of 142 woody species data for 65 traits have been assembled. Data coverage amounts to ca. 86%. In order to provide rarely measured fine root-data an arboretum with 72 European woody species has been planted in the vicinity of Leipzig/Germany.

Implementation: The database can be accessed via direct contact to the task-leader and the TRY-project. Data from the database are shared for analyses with several partners in FunDivEUROPE (among others: T5.4 T5.3)
Publications from the project: Deliverable D2.2.
Task 2.3: Regional differentiation and adaptation of tree species (phytometer approach)
By Rubén Delgado, Eric Allan and Markus Fischer, UBE
Questions: 1. Are the dominant tree species in Europe adapted to their local conditions? 2. Does species richness affect sapling performance and could it facilitate local adaptation?
Evidence: Question 1: For one dominant tree per country, we planted seedlings from different provenances on all 209 exploratory plots. We found that the local saplings survived better than non-local ones in all countries, on average they had 12.6% higher survival. Adaptation did not seem to be to climate because the climatic origin of the plants was not correlated with performance (only local provenances had higher survival). This might suggest that biotic interactions (perhaps herbivores or pathogens found in the forests) were the main drivers of adaptation. We also planted seedlings in common gardens in each country and here we found no difference in survival between local and non-local seedlings, which might also suggest that it is the biotic interactions present in mature forests that drive local adaptation. We found a remarkably consistent pattern of local adaptation after only 2 growing seasons, which suggests strong local adaptation, at least in the sapling stage. How that advantage accumulates throughout the life of the trees remains an open question. However, our results show the importance of using local provenances in forestry and restoration.
Question 2: In some countries (Germany and Poland) we found that seedlings survived better in diverse forests. However, we found no trend in the other 4 countries, making difficult to draw general conclusions. Furthermore, we found no significant interaction between local adaptation and diversity, which might suggest diversity doesn’t facilitate the expression of the local advantage, at least in the short term. The regions where we detected a positive diversity effect were also the ones with higher sapling survival. In some regions, such as Spain, where survival was very low, we may have lacked power to detect a diversity effect. Additionally, as pointed out by other authors (i.e. Reich et al. 2012), diversity effect accumulates and the time span used in our study may be not long enough to find an effect. Nevertheless survival was never lower in diverse communities, so we do find evidence that diverse communities can facilitate seedling establishment.
Location: Exploratory platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D2.3.

Task 2.4: Quantity and quality of dead woody debris
by Ewa Checko and Bogdan Jaroszewicz, UWAR
Questions: 1. Does variability of coarse woody debris (CWD) stocks and quality (C and N) decrease with increasing species diversity? 2. Does CWD habitat quality (quantified as the diversity of decay stages) and CWD sizes increase with tree species diversity? 3. Do trees with lower decay rates (e.g. pines, oaks) induce a sampling effect of higher CWD stocks with increasing species diversity?
Evidence: Question 1: Tree species diversity (defined as tree species richness or Shannon diversity) did not influence the amount (neither expressed as volume nor biomass) of deadwood accumulated in any of the studied sites, although its quantity at most of the sites (except Spain where on most plots no CWD was present) showed weak tendency to increase along increasing diversity of stands. Similarly, neither relative carbon pools (total C amount at a single plot divided by C amount of the best performing plot in a particular site) nor relative nitrogen pools depended on diversity level.
Question 2: Our second hypothesis was not confirmed in Boreal (Finland) and Mountainous beech (Romania) forest. In lowland forests of Hemiboreal (Poland) and Beech (Germany) forest types diversity levels influenced CWD characteristics, but differences were significant only for comparisons between
levels influenced CWD characteristics, but differences were significant only for comparisons between monocultures and the highest mixture levels. In Italy all diversity levels differed significantly from each other, except for five species mixtures and monocultures. In Mediterranean type of the forest (Spain) the highest diversity level differed significantly from all other diversity levels.

Question 3: Carbon content was relatively constant within tree species during first stages of decay. Only in advanced decomposition classes some increase (by few percent) of C content was observed. Carbon content in CWD was relatively constant also along climatic gradients, however, we found differences in this parameter in wood of some species on different Exploratory Platform sites. For most of sites and species we observed a strong increase of the nitrogen content in dead wood biomass with proceeding decay, and N content tended to be higher in wood of broadleaved compared to coniferous species.

Despite the fact that our results suggest lack of influence of diversity on the amount or variability of logs, we cannot extrapolate this conclusion to all European forests. Recent (last 5-10 years) logging did not take place at any of the study sites but deadwood accumulation due to mortality of tress and decomposition of biomass is a long-term process and past forest management of the previous several decades may influence deadwood quantity and quality in the stand. E.g. most of deadwood was removed whenever plot was accessible in Spain, and the lack of the most advanced decay classes (5; only some logs in 4 were present) in Italy suggest that we observe the results of past management rather than effects of natural deadwood dynamics.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D2.4. Knowledge Element: Dead wood and nitrogen stocks: the older, the richer (http://fundiveuropektp.boku.ac.at/node/227)

Task 2.5: Spatio-temporal forest structural complexity
by Ian Seiferling, Raphael Proulx and Christian Wirth, UQTR/ULEI
Question: What is the role of tree species diversity in determining the seasonal growth patterns of plant communities in temperate forest systems?
Evidence: Through this analysis of the time-lapse imagery we find that tree diversity has important implications for community phenology, seemingly in a top-down or cascading manner, directed by canopy phenology. That is, though no significant linear relationship between tree diversity and overstory phenology is evident (simply a weak one is found), an increase in the mean growing season length, and decrease in variance, for mixtures relative to monocultures is evident. The effect of tree diversity then appears to get amplified, so to speak, down the forest strata as we find that tree diversity is an important predictor of understory phenology, wherein the growing season of understory communities is longer when growing under a diverse canopy.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D2.5. Knowledge Element: Tree species mixtures influencing forest structure and phenology (http://fundiveuropektp.boku.ac.at/node/251)

Task 2.6: Understorey vegetation
by Evy Ampoorter and Kris Verheyen, UGent
Questions: 1. Does overstorey diversity positively affect understorey diversity? 2. Do changes in the overstorey composition affect the understorey biomass?
Evidence: Question 1: At the tree diversity experiment BIOTREE higher tree species richness slightly increased plot-level understorey species richness (i.e. alpha diversity). This contrasted with the tree diversity experiment in Satakunta and the mature forests of the Exploratory Platform, where the plot level
diversity experiment in Satakunta and the mature forests of the Exploratory Platform, where the plot-level understorey diversity showed no significant differences between the tree species richness levels. The variability in this overstorey effect can be explained by the fact that the overstorey diversity may influence the environmental conditions in two different ways. On the one hand, the presence of multiple tree species in a plot may lead to a heterogeneous distribution of resources (Yankelevich et al. 2006). This increases the compositional differences between patches in a plot, and hence increases the understorey species richness at the plot-level. On the other hand, a mixed overstorey may also create new conditions as a result of averaging of tree species effects or interactive effects of tree species on the environment. These new environmental conditions in the mixed stand may impede the presence of certain understorey species or provide opportunities for new understorey species compared to the component tree species monocultures. This results in a higher, lower or equal plot-level understorey species richness compared to the component tree species monocultures. At BIOTREE and in the mature forests of the Exploratory Platform, the compositional differences with other plots were significantly higher for monoculture plots than for mixed plots (i.e. beta diversity). Namely, monocultures have distinct influences on resources and soil conditions, leading to larger differences with other plots, while mixtures often share the same tree species or species with a similar environmental impact. From the understorey results of the Exploratory Platform we also concluded that combining different mixed plots of one specific tree species richness level into a single forest had a positive or negative effect on the forest-level understorey species richness compared to a combination of monoculture plots, depending on the region (i.e. gamma diversity). However, combining plots of different tree species richness levels into a single forest on average had a neutral to positive effect on the forest-level understorey species richness compared to a combination of monoculture plots. Hence, our results suggest that combining stands with different tree species richness levels into a single forest is the best way to get a sufficiently high forest-level understorey species richness.

Question 2: At the BIOTREE experiment, Germany, the overstorey composition affected the understorey biomass via tree species identity and diversity effects. Douglas-fir and especially spruce negatively influenced total aboveground understorey biomass, in contrast with the deciduous species. The negative effect of coniferous species on understorey biomass can be due to the higher Al concentrations and lower pH in the soil. Higher tree species richness positively affected graminoid and total biomass. As underlying mechanisms, complementarity in below-ground resource uptake might occur, or understorey biomass was promoted under diverse tree layers by increased nutrient supply and base saturation.

Location: Experimental Platform (BIOTREE Germany; Satakunta Finland); Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)


Deliverable D2.6. Knowledge Element: The understorey, a forest layer with an underestimated importance for ecosystem functioning. (http://fundiveuropektp.boku.ac.at/node/221)

Task 2.7: Soil biological activity
by Hans de Wandeler and Bart Muys, KUL

Hypothesis: Tree species composition rather than tree species richness affect belowground communities.
Evidence: The investigated functional groups of soil organisms, earthworms and micro-organisms, behave differently in relation to tree diversity. Microbial biomass is positively related to tree species richness, while...
Differently in relation to tree diversity. Microbial biomass is positively related to tree species richness, while earthworm communities had no clear relationships with tree species richness. The positive tree diversity effect on microbes might be explained by a higher diversity and quality of available carbon sources in soils with higher tree diversity (possibly through root exudates).

Both earthworms and micro-organisms are clearly influenced by the tree species identity in European forests. Our research demonstrates that earthworm biomass is positively related to leaf litter quality. This means that you find more earthworms under birch trees with palatable litter compared to spruce trees with recalcitrant litter. Like earthworms, soil microbial biomass and the metabolic diversity of soil bacteria are negatively related to the percentage of coniferous trees in the mixture. This might be explained through more recalcitrant organic compounds in conifer litter, leading to decreased palatability, and possibly toxicity of the intermediate litter decomposition products. It is confirmed by increased soil organic carbon in forests with these species.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)

Deliverable D2.7. Knowledge Element: Earthworms - engineers with important role for forest ecosystems. (http://fundiveuropektp.boku.ac.at/node/169)

3 WP 3: Provisioning and supporting services (WP leader: UCAM)
Task 3.1: Timber quality
by Adam Benneter and Jürgen Bauhus, ALU-FR
Question: Does tree species diversity influence stem quality?
Research has produced evidence that tree species diversity has the potential to improve productivity and a number of other ecosystem services within forests. Forest owners, however, must be able to manage and maintain their forests in a way that makes their contribution to societal ecosystem values sustainable also in economic terms. The provision of timber is the prime economic function of forests, which depends on productivity and the quality of the stems that can be extracted. Therefore, it is elementary to investigate how increased tree-species diversity influences stem quality.
Evidence: Assessing stem quality data we found that average plot-level stem quality decreased with higher tree species richness, but this effect was very small. In contrast, other commonly used and relatively easy to measure parameters had a much stronger influence on stand-level quality. Among the most important were tree size, the horizontal roundness of the crown and the proportion of the green crown. Our results showed that stands with higher mean tree diameter, higher average horizontal crown roundness and generally shorter crowns (40 % of the total height or less) were those with generally higher mean stem quality, largely irrespective of tree species richness. We conclude that there seems to be no compelling support for the notion that tree species diversity precludes managing for high timber quality at the stand-level.
Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D3.1. Knowledge Element: Timber quality vs. biodiversity - a contradiction? (http://fundiveuropektp.boku.ac.at/node/178)

Task 3.2: Net aboveground primary productivity and its response to climate change
Task 3.2: Net aboveground primary productivity and its response to climate change
by Tommaso Jucker and David Coomes, UCAM (USV)

Question: Are diverse forests more productive than species poor ones? What ecological mechanisms promote positive diversity – productivity relationships in forests?

Evidence: Across the FunDivEUROPE Exploratory plots we found that diverse forest stands are generally more productive than monocultures, particularly in the case of Mediterranean and Boreal forests. In addition to promoting productivity, we also found clear evidence that tree species diversity contributes to stabilizing productivity over time. As a result, interannual fluctuations in productivity are dampened in mixed-species forests, meaning that tree diversity can essentially be thought of as an “insurance policy” against hard times. Critical to explaining positive diversity – productivity relationships in forests is the ability of mixed-species stands to utilize aboveground space more efficiently compared to monocultures, thereby allowing them to intercept more light. We found that trees in diverse forest plots were able to pack their crowns more densely, and that this occurred primarily as a result of individual trees plastically adapting the shape and size of their crowns in response to competition with neighbours.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)


Deliverable D3.2. Knowledge Element: Uncovering the mechanisms behind positive diversity-productivity relationships in forests (http://fundiveuropektp.boku.ac.at/node/241)

Task 3.3: Root biomass production
by Timo Domisch and Leena Finér, LUKE

Question: How does tree species diversity affect below-ground biomass and production in European forest ecosystems? We hypothesized that fine root biomass, production and turnover will be greater in diverse forests than in monocultures, because niche differentiation in space among the roots of co-existing species leads to more efficient exploitation of available soil resources.

Evidence: We collected fine root biomass data with the coring method and determined fine production with the ingrowth bag method. For the identification of tree species from the biomass samples we used the near-infrared spectroscopy (NIRS). The results did not support our hypotheses. Tree or understorey vegetation fine root biomass, production and turnover were not related to the tree species diversity in the studied forests. However, there was some indication that in species rich forests fine roots grow more to deeper soil layers (20-40 cm) than in monocultures. Our results also indicate that fine root biomass is more affected by tree species identity than tree species diversity.

Location: Experimental Platform (BIOTREE Germany, Satakunta Finland) and Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)


Deliverable D3.2. Knowledge Element: Impacts of species diversity on root systems (http://fundiveuropektp.boku.ac.at/node/247)

Task 3.4: Leaf area index (LAI) and photosynthesis parameters
Task 3.4: Leaf area index (LAI) and photosynthesis parameters
by Martina Pollastrini and Filippo Buscotti, UFI

Question: Chlorophyll a fluorescence (ChlF) parameters and Leaf Area Index (LAI) are considered indicative for the photosynthetic efficiency of trees and forest. Tree diversity may affect photosynthesis because of the competition for light, or because of exploitation of soil resources (competition for water and nutrients)

Evidence: In the FunDivEUROPE explorative platform LAI increased from South to North (but decreased in Finland) and was highest in monocultures of conifers. No, or very weak relationships, were found between tree diversity expressed by mean of the Shannon Index and LAI. As far as the ChlF analysis were concerned, photosynthetic efficiency followed an ecological and geographical gradient. Photosynthetic efficiency was highest in the Central European sites (Poland Germany and Romania), and lowest at the extreme continental edges (Mediterranean: Italy and Spain; and boreal: Finland). Chlorophyll fluorescence contains also taxonomic information, and this study demonstrated that it was possible to recognize and discriminate singular species thanks to the analysis and combination of the different ChlF parameters. Conifers had, in general, higher photosynthetic efficiency than broadleaves.

The photosynthetic efficiency was influenced by the structure and composition of the forests. As general trend, such efficiency was higher in dense forests, with high values of LAI. The effect of tree diversity was variable in relation to the species and the sites. Picea abies, the most common tree species in the exploratory platform, showed opposite trends in Romania (where the photosynthetic efficiency increased with tree diversity) and in Finland (where it decreased). Quercus ilex, in Italy and Spain, decreased its photosynthetic efficiency with increasing tree diversity, whereas Quercus cerris (in Italy) showed the opposite trend. Specific interactions were observed in Finland, where Pinus sylvestris increased its photosynthetic efficiency when grown with Betula pendula, but not with Picea abies.

Location: Experimental Platform (BIOTREE Germany, Satakunta Finland) and Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)


Knowledge Transfer Platform: Photosynthetic responses of different tree species mixtures (http://fundiveuropektp.boku.ac.at/node/245)

Task 3.5: Nutrient stocks of soils
by Seid Muhie Dawud, Lars Vesterdal and Karsten Raulund-Rasmussen, UCPH

Questions: 1. Does tree species diversity increase soil nutrient status as reflected by increasing pH and decreasing C/N ratio? 2. Is species diversity a stronger driver for soil pH and C/N ratio than species identity? 3. In which parts of the forest soil profile do species diversity and identity affect pH and C/N ratio?

Evidence: Question 1: We found significant positive effects of diversity on forest floor pH and N stocks in the 0-10 cm layer but none or very limited influences of tree species diversity on C/N ratios in the sampled soil profile (forest floor and 0-20 cm) across all six regions of the Exploratory Platform. Influences of tree species identity (proportion of broadleaves vs. conifers) and site-related factors were much stronger drivers for soil pH and C/N ratio across the six regions. We conclude that tree species diversity has a positive effect on soil nutrient status, particularly pH and N stock, but a limited general effect on C/N ratio, and that effects appear to be context dependent.

Question 2: At the European level, species diversity had a stronger positive effect on soil pH and weaker impact on C/N ratio than tree species identity. Soil pH decreased and C/N ratio increased with the
Impact on C/N ratio than tree species identity. Soil pH decreased and C/N ratio increased with the proportion of conifers in the forest stands. In the Polish region (1-5 species), species identity was also a stronger driver than species diversity for the C/N ratio of the forest soil profile (forest floor and 0-40 cm). Soil carbon stocks in the sampled soil profile increased significantly with the proportion of conifers in mixed stands whereas a similar positive effect of species diversity was not quite significant. Among the five tree species, Scots pine proportion was most clearly associated with high forest floor C/N ratio whereas oak proportion was associated with low forest floor C/N ratio. Furthermore, the conifer Norway spruce was associated with higher C/N ratio in 10-20 cm, whereas the broadleaved species hornbeam was associated with lower C/N ratio in 30-40 cm. Increasing species diversity had a weak significantly positive effect on forest floor pH, but species identity in terms of conifer proportion had a strong significantly negative effect on pH in both the forest floor and the 0-10 cm layer. Among the individual tree species, high proportions of birch and hornbeam were associated with high topsoil pH whereas high Scots pine and Norway spruce proportions were associated with low topsoil pH. We conclude that species diversity had a slightly positive effect on nutrient status in terms of pH, but not on C/N ratio. Species diversity was a weaker driver for soil pH and C/N ratio than tree species identity.

Question 3: The vertical changes in nutrient status within the soil profile could be studied within the Polish region where soil sampling was accomplished to 40 cm depth. There was a clear vertical stratification in the effects of tree species diversity and tree species identity on C/N ratio, whereas pH was affected by species diversity and identity only in the topsoil. Soil C/N ratios increased significantly with species diversity in deeper layers (20-40 cm) and this was driven only by higher C stocks (see task 4.2) as N stocks were unchanged by species diversity in these layers. Forest floor pH increased significantly with species diversity, but there were no effects in the mineral soil layers.

Conclusion: The effects of species diversity on soil C/N ratio and pH were generally larger than expected from the respective monocultures of the same species. This suggests that there were synergistic effects within the studied 2-5 species mixtures in support of the niche complementarity hypothesis. More diverse forests would lead to higher soil nutrient status as reflected by higher topsoil pH, but on the other hand there was a negative effect on N status as indicated by higher C/N ratios in the deeper layers in Poland. It remains to be explored whether the latter effect is driven by more N poor organic matter inputs in these deeper layers or a more efficient uptake of N from soil organic matter in diverse stands. We conclude that tree species diversity had a positive effect on pH in the topsoil along with concurrent effects of tree species identity, but the effect of diversity was far weaker than that of species identity. Soil C/N ratios were higher in deeper mineral soil layers with increasing diversity suggesting either lower N inputs or more effective root exploitation of organic N in these deeper layers of more diverse stands.

Location: Experimental Platform (BIOTREE Germany, Satakunta Finland) and Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)

Publications from the project: Deliverable D3.4

Task 3.6: Nitrogen ecophysiology of trees
by Mariangela Fotelli and Kalliopi Radoglou, DIMITRIA

Questions: 1. Does functional diversity of trees affect their foliar nitrogen content and nitrogen resorption efficiency (NRE)? 2. Does NRE decline with increasing tree diversity due to potential complementary soil N use, which may reduce N-limitation at the community level?

Evidence: To address the above-mentioned questions, mature and senescent leaves were collected from the Exploratory platform. In parallel, a small-scale experiment conducted in Thessaloniki, Greece validated.
the Exploratory platform. In parallel, a small-scale experiment conducted in Thessaloniki, Greece validated
the sampling protocol of senescent leaves as appropriate for the determination of leaves’ NRE. In brief, all
leaf samples were analysed with Elemental Analysis and Near-Infra Red Spectroscopy and the nitrogen
and calcium content of mature and senescent leaves was determined, in order to calculate NRE. To
account for leaf mass loss occurring during senescence, NRE was calculated on a foliar Ca concentration
basis, since Ca is not resorbed during senescence. Overall, it was found that tree diversity affects both
foliar N content and NRE; N content increased while NRE decreased with increasing diversity level.
However, these patterns were not evident in each of the studied forest types, where environmental and soil
N availability parameters were the most important drivers. Moreover, species identity effects were
observed in the patterns of foliar N content.
Location: Exploratory Platform ((Finland, Romania, Poland, Germany, Italy, Spain) and Thessaloniki,
Greece.
Publications from the project: Deliverable D3.3

Task 3.7: Litter production and element fluxes
by Sandra Müller and Michael Scherer-Lorenzen, ALU-FR

Questions: Are diverse forests more productive than species poor ones? What ecological mechanisms
promote positive diversity – productivity relationships in forests?
One suggested mechanism that promotes positive diversity – productivity relationships in forest is the
ability of mixed-species stands to utilize aboveground space more efficiently compared to monocultures.
Results from T3.2 show that “diverse forest plots were able to pack their crowns more densely, and that
this occurred primarily as a result of individual trees plastically adapting the shape and size of their crowns
in response to competition with neighbours”. This result should be reflected in increased litter productivity
with increasing tree diversity, and should have consequences for nutrient cycling and soil biological
activity.

Evidence: A first very preliminary view on the data revealed that annual litter production per plot was
positively correlated with plot basal area across all exploratory Regions. This relation was more
pronounced when considering leaf litter input alone. The clear positive productivity – biodiversity
relationship found within T3.2 was not mirrored in litter production. At least at a first tentative glance, no
overall positive relation between total litter production per plot and tree diversity could be detected. This is
in accordance with the results from T3.4 where no or only weak relation between tree diversity and LAI
was found.

A species specific presentation of litter production in relation to tree diversity reveals that some species
show a positive trend in litter production with increasing tree diversity while other show a neutral or
negative trend. There seems to be a higher proportion of species with a high litter production that show a
positive litter – diversity trend.
Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Publications from the project: Deliverable D3.5

Task 3.8: Decomposition and mineralization
by François-Xavier Joly and Stephan Hättenschwiler, CEFE-CNRS

Question: Does leaf litter decomposition and nutrient release rates increase with increasing tree diversity?
Evidence: To address this question, we incubated freshly fallen leaf litter of different species in mixtures, in
forest plots where these tree species mixtures naturally occur, and measured the mass loss and nutrient
release of these leaves, after a long-term exposure in the field (between 6-18 months depending on the
Release of these leaves, after a long-term exposure in the field (between 6-18 months depending on the site). We then related how mass loss and nutrient release rates varied as a function of tree and litter diversity. Ongoing data analyses will allow assessing how tree and litter diversity influence litter decomposition and mineralization.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)

Publications from the project: François-Xavier Joly, Mathieu Coulis, Aurélien Gérard, Nathalie Fromin, Stephan Hättenschwiler (2015) Litter-type specific microbial responses to the transformation of leaf litter into millipede feces. Soil Biology and Biochemistry. doi: 10.1016/j.soilbio.2015.03.014

Task 3.9: Water balance and water use efficiency on different scales by Charlotte Grossiord, Damién Bonal, André Granier, INRA, and Arthur Gessler, ALU-FR

Question: Are species-rich forest ecosystems more resistant to drought than pure ones?

Evidence: In the context of global warming, information on how tree species diversity can influence the response of forest ecosystems to extreme climatic events such as drought is urgently needed. We assessed how tree species diversity influences important ecosystem functions of the water and carbon cycle including transpiration, carbon isotope composition and water extraction depth at the tree- and ecosystem-scale under contrasting soil water conditions. We found a significant effect of species diversity on these functions under drought conditions in some forest types only. The influence of species diversity on ecosystem resistance to drought thus seems highly context dependent and changes with local environmental and climatic conditions. In terms of forest management applications, we suggest that, at least in some regions, controlling for tree species diversity along with stand density and total basal area could be recommended to help forests adapt to drier conditions.

Location: Experimental Platform (BIOTREE, Germany; Satakunta, Finland), Exploratory platform (Finland, Romania, Poland, Germany, Italy, Spain)


Deliverable D3.7. Knowledge Elements: Biodiversity and the resistance of forest ecosystems to drought (http://fundiveuropektp.boku.ac.at/node/253). Biodiversity does not always improve resistance of forest ecosystems to drought (http://fundiveuropektp.boku.ac.at/node/244).
Task 3.10: Freshwater provisioning and water quality at landscape scale
by Simon Kolb and Klaus von Wilpert, FVA (ALT)
Question: How big is the impact of tree diversity, inhomogeneous stand structures and variable soil properties on spatially heterogeneous soil water contents?
Evidence: We measured soil water contents in several depths on 32 points on 10 plots along a North-South gradient in Europe. Additional information about soil hydraulic properties and stand parameters were taken on these measuring points as well as diversity aspects for spatial analyses. We used a general multivariate computational approach of stochastic gradient boosting (boosted regression trees, BRT) for statistical modelling to indicate dependencies between the key variable water content (coefficient of variation of soil water per plot) and soil and stand parameters. The Diversity parameters (Shannon-Index and tree diversity) as well as the horizontal tree distribution patterns (R-aggregation) were the predictors with strongest impact on soil water.
Location: Exploratory Platform, HIPs (highly instrumented plots)
Publications from the project: Deliverable D3.8

4 WP 4: Regulating services (WP leader: INRA)
Task 4.1: Carbon stocks in tree biomass
by David Coomes, UCAM
Question: Can airborne laser scanning (ALS) be used to accurately estimate forest carbon stock in mixed-species forests?
Evidence: Forests play a vital role in the terrestrial carbon cycle by sequestering CO2 from the atmosphere and storing it as woody biomass. Being able to robustly quantify the strength of the forest carbon sink is critical in order to predict how climate will change under current and future CO2 emission scenarios. Quantifying forest carbon stocks has traditionally relied on field data from forest inventories. However, establishing and maintaining national forest inventories is incredibly time consuming and expensive, meaning that often data on forest carbon stocks at the appropriate spatial and temporal resolution is lacking. Consequently, recent years have seen a push towards the development of remote sensing technologies which can guarantee reliable carbon stock estimates across vast spatial scales at a fraction of the cost of traditional forest monitoring approaches. In particular, airborne laser scanning (ALS) is emerging as an extremely promising technique for carbon monitoring. ALS can be used to accurately retrieve several key forest structural parameters, such as tree heights and canopy density, which in turn relate directly to forest carbon stocks.
We acquired ALS data covering the Exploratory sites in Spain and Italy. By linking the ALS data with information measured in the FunDivEUROPE field plots we developed models relating parameters measured from the air to carbon stocks estimated on the ground. Using these relationships calibrated in the FunDivEUROPE plots we were then able to estimate carbon stocks across entire forest landscapes with a high degree of fidelity, allowing us to understand how carbon storage varies spatially in these Mediterranean forests. Future work will aim to use the wealth of data generated from the ALS mapping campaign to determine whether carbon storage potential relates to tree diversity in European forests.
Location: Exploratory Platform, sites in Spain and Italy.
Publications from the project: Deliverable D4.1
Task 4.2: Carbon sequestration in soils
by Seid Muhie Dawud, Lars Vesterdal and Karsten Raulund-Rasmussen, UCPH

Questions:
1. Does tree species diversity increase soil carbon stocks?
2. Is species diversity a stronger driver for soil carbon stocks than species identity?
3. In which parts of the forest soil profile do species diversity and identity affect carbon stocks?

Evidence:

Question 1: We found some evidence that tree species diversity increases mineral soil carbon stocks based on studies of forest floor and mineral soil 0-20 cm in all six regions representing common European forest types. However, the positive effect on soil carbon was restricted to the carbon stock in the 0-10 cm layer of the mineral soil and the combined forest floor and 0-10 cm layer. Tree species identity (proportion of broadleaves vs. conifers in the mixed stands) and in particular site-related factors were stronger drivers of soil C stocks than species diversity across the six regions. We conclude that tree species diversity may have a positive effect on topsoil carbon stock across six European regions.

Question 2: At the European level, species diversity had a weaker effect on soil carbon stocks than tree species identity. Soil carbon stocks increased with the proportion of conifers in the forest stands in most regions, but this effect was mainly confined to the forest floor and 0-10 cm layer. Broadleaf-dominated stands had lower soil carbon stocks than conifer-dominated stands. In the Polish region (1-5 species), species identity was a stronger driver than species diversity for carbon stocks in the forest soil profile (forest floor and 0-40 cm). Soil carbon stocks in the sampled soil profile increased with the proportion of conifers in mixed stands whereas the positive effect of diversity on soil C stock was not significant. Among the five tree species, high Norway spruce proportion was most clearly associated with high forest floor C stocks whereas a high proportion of hornbeam was associated with low C stocks in the forest floor and the 30-40 cm layer. We conclude that species diversity is a weaker driver for soil carbon stocks than tree species identity.

Question 3: Carbon distribution within the soil profile could be studied within the Polish region where soil sampling could be accomplished to 40 cm depth. There was a clear vertical stratification of the effects of tree species diversity and tree species identity. Soil carbon stocks increased significantly with tree species diversity in deeper layers (20-40 cm). The positive species diversity effect was generally larger than expected from the respective monocultures of the same species. This indicates a synergistic effect of diversity within the studied 2-5 species mixtures in Poland. A positive relationship between soil carbon stocks and root biomass in the 30-40 cm layer suggested that belowground niche complementarity could be a driving mechanism for higher root carbon input and in turn a deeper distribution of soil carbon in diverse forests. Tree species identity in terms of conifer proportion affected carbon stocks positively only within the forest floor, but among the individual tree species an increasing proportion of hornbeam was also associated with lower C stocks in the 30-40 cm layer.

Conclusion: We conclude that tree species diversity may have a positive effect on carbon stocks in deeper layers of the mineral soil, whereas species identity effects were confined to the topsoil.

Location: Experimental Platform (BIOTREE Germany, Satakunta Finland) and Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)


Deliverable D4.2. Video: Soil carbon and biodiversity (https://www.youtube.com/watch?v=-wu-niy7c28&index=16&list=PL8nmJRIi21moFbNkl5xgjGOKIYgCMyd-1e)

Task 4.3: Resistance to insect herbivores
by Virginie Guyot, Bastien Castagnourel and Hervé Jactel, INRA
Questions: 1. Are mature forests with higher species diversity more resistant to forest pest insects? 2. Are mixed forests less susceptible to invasive forest pests?

Evidence: Question 1: Insect pest outbreaks, which are likely to increase under climate change, can dramatically reduce forest production. It is therefore important to develop forest management alternatives that could prevent insect damage. Recent literature reviews detected a significant decrease in insect herbivory in more diverse forests but these results were mainly obtained from observational studies focusing on one pest species and in mixed forests with only two or three tree species. In the FunDivEUROPE project we assessed crown defoliation by all type of insects in mature forests along gradients of tree species diversity ranging from one (pure forests) to five species mixtures, in six different countries from the Mediterranean to the Boreal biomes. Due to the very low level of damage in conifers, the analysis focussed on broadleaved tree species. For the first time we were able to reveal that the level of insect damage significantly decreased with increasing tree species diversity in European mature forests. The decrease in tree defoliation was stronger when deciduous focal trees were associated with conifers than with other deciduous tree species. Most of this beneficial diversity effect was obtained with two tree species mixtures. These findings suggest that the maintenance or improvement of tree species diversity, through forest conversion or afforestation with associations of conifers and broadleaves, represents a promising method of pest management.

Question 2: Biological invasions are one of the main causes of biodiversity loss, with severe consequences for ecosystem health and functioning. There is an exponential increase in the number of alien forest insects establishments in Europe. It is therefore urgent to prevent the impact of exotic pests in European forests. It is generally assumed that ecosystem invasibility, i.e. susceptibility to invasion by non-resident species, decreases with increasing species diversity. We tested this hypothesis in the FunDivEUROPE exploratory site of Italy where chestnut forests are currently experiencing the invasion of the Asian chestnut gall wasp, Dryocosmus kuriphilus, which can reduce chestnut production by up to 80%. We estimated the defoliation by the exotic gall wasp on 70 chestnut trees in 15 mature stands sampled along a gradient of tree species richness ranging from one species (chestnut monocultures) to four species (mixtures of chestnut and three broadleaved species). Chestnut defoliation was significantly lower in forest stands with higher tree diversity. Some particular tree species composition (e.g. presence of deciduous oaks) lead to higher resistance. Two main mechanisms can explain the better resistance of chestnuts in mixed forest: i) chestnut trees are more difficult to find and attack by gall wasps when surrounded by taller broadleaved neighbours and ii) native insect parasitoids, originating from oak galls, can shift and control Asian gall wasps. These results suggest that conservation biological control method, based on maintenance or development of tree species mixtures, might help to reduce the impact of invasive pest insects in European forests.

Location: Question 1: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain). Question 2: Colline Metallifere chestnut forests, Tuscany, Italy (one of the six FunDivEurope Exploratory sites)


Task 4.4: Beneficial organisms for pest regulation
by Yohan Charbonnier, Luc Barbaro and Hervé Jactel, INRA
Questions: 1. Are insectivorous bats effective insect predators in European forests? 2. Are more diverse forests better habitats for insectivorous birds and bats?
Evidence: Question 1: Insect pests are a major threat to forests worldwide and it is expected that climate change will further enhance insect herbivory, due to positive response of forest insects to warmer and drier conditions. Birds have long been considered as the only predatory vertebrates that are efficient pest regulators, but recent comparative studies in tropical forests have shown that insect predation by bats may be more significant than predation by birds. We applied an experimental approach to test this assumption in a large pine plantation forest in south-western Europe. Pheromone traps and ultrasound bat recorders were used to estimate the abundance and activity of pine processional moths and predatory bats along the edge of infested pine stands. Synthetic pheromone lures were utilized to artificially increase moth availability in order to test its effect on bat foraging activity. We observed that bat activity significantly increasing with moth abundance. The foraging activity of some bat species was significantly higher near pheromone lures, i.e. in areas of increased prey availability. Furthermore pine processory moth infestations decreased the following years in pine stands where bat activity was higher. These findings suggest that bats can adjust their predation activity to prey abundance, which may ultimately result in an effective regulation of pest populations. These observations are consistent with bats being useful agents for the biocontrol of insect pest populations in European forests.
Question 2: Birds and bats are important predators of forest pest insects but there is a growing concern that forest management intensification, with shorter rotations and larger areas planted with fast growing coniferous tree species might result in lower abundance and diversity of these insectivorous predators. We monitored the diversity of forest bird and bats species using bird songs and bat ultrasounds in 209 mature forests across Europe, along diversity gradients spanning from one tree species (pure forests) to five tree species (mixed forests). We identified a total of 26 bat species and 76 bird species. The diversity of bird or bat species did not increase with tree diversity but with the abundance of broadleaved tree species. In addition forests characterized by a clear understory and higher trees hosted more bat species. These relationships increased in magnitude with latitude, i.e. were stronger in northern European countries. The finding that both forest composition and structure do have an effect on bird and bat diversity paves the way for new forest management options, e.g. mixture of conifers and broadleaves, for improving pest insect regulation by native predators.
Location: Question 1: Forest of the Landes of Gascony, France. Question 2: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)
Task 4.5: Resistance to mammalian herbivores
by Harriet Milligan and Julia Koricheva, RHUL

Questions: 1. Does tree species richness and composition affect winter browsing and selectivity by moose (Alces alces)? 2. Does forest overstorey and understorey diversity affect deer browsing in the shrub layer? 3. Does forest overstorey and understorey diversity affect wild boar rooting activity?

Evidence: Question 1: Tree species richness had a significant positive effect on moose browsing, increased relative density of preferred species (pine and birch) in a plot led to an increase in browsing on less preferred species (spruce, larch, alder) growing in association.

Question 2: Percentage of understorey woody plants browsed was higher in forest stands with higher shrub species richness. This trend can be seen in all of the European forest types studied. Across the different forest types, higher tree species diversity lead to a greater percentage of understorey woody plants browsed and greater intensity of browsing. There was a decrease in selectivity by browsers with increasing tree species diversity. This pattern was seen in all forest types, with stronger trends in Poland, Germany, and Italy (which are the three sites with greatest diversity gradient).

Question 3: In both Poland and Italy rooting extent per plot decreased with increasing shrub evenness and increasing herb cover, and rooting extent increased with increasing tree diversity. The effect of overstorey Shannon index on rooting depth was positive, with higher maximum rooting depth in more diverse plots.

Location: Question 1: Experimental Platform (Satakunta, Finland). Question 2: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain). Question 3: Exploratory Platform (Poland, Italy)


Deliverable D4.5. Knowledge Element: Effects of tree species richness and composition on moose winter browsing and selectivity (http://fundiveuropektp.boku.ac.at/node/240)

Task 4.6: Resistance to fungal pathogens
by Diem Nguyen, Johanna Boberg, Jan Stenlid SLU

Questions: 1. Does tree species mixture affect foliar pathogen damage? 2. Does tree species mixture affect the fungal community composition in birch leaves from birch grown in plantations?

Evidence: Question 1: The incidence of fungal pathogen damage was visually assessed on leaves and conifer shoots from mature trees. Statistical models were used to determine the effect of tree species mixture on the level of damages found in all exploratory plots across Europe. The data indicated that there was no overall effect of tree species mixture on foliar pathogen damages at the European scale. Additionally, we specifically target one fungal pathogen that has been killing ash trees throughout Europe since the beginning of the 1990s to understand its biology, which can aid in developing control measures. We sampled the population of the ash dieback pathogen from ash trees in an area that is known to have...
We sampled the population of the ash dieback pathogen from ash trees in an area that is known to have the disease. We determined whether there was a tree species mixture effect that differentiates the population genetic structure of the pathogen. The data indicated that the population was genetically differentiated between the mixture that contained ash trees and the monoculture plot of ash trees.

Question 2: Birch leaves were collected from five trees per plot. Each plot included birch either from monocultures of birch to five species mixtures including birch. Birch DNA was processed for next generation sequencing, and data was analysed by ordination methods. The data indicated that there was no effect of tree species mixture on fungal community composition in birch leaves.

Location: Question 1: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain). Question 2: Experimental Platform (Satakunta, Finland)

by Lydia Höning and Helge Bruelheide, MLU


Evidence: Question 1: There was a negative effect of tree richness on the pathogen load of several common powdery mildew species. Moreover, we found strong tree species identity effects at the plot level as the presence of Quercus resulted in a high pathogen load.

Question 2: We found no effects of functional diversity on pathogen richness or load. However, we encountered strong species identity effects in plot species composition, as susceptible tree species contributed positively to each community's pathogen richness and load. Furthermore, testing for effects of particular leaf traits and geographical range size of host species revealed a significant effect of total leaf phenolics, which was unexpected as pathogen richness increased with increasing content in polyphenolics.

Question 3: We detected four and five fungal species on T. cordata and Q. petraea, respectively. High local tree diversity reduced i) total fungal species richness and infestation of T. cordata and fungal infestation of Q. petraea, and ii) infestation by three host-specialized fungal pathogen species. These effects were brought about by local tree diversity and were independent of host species proportion. In general, host species proportion had almost no effect on fungal species richness and infestation. Strong effects associated with the proportion of particular non-host neighbouring tree species on fungal species richness and infestation were however recorded.

Question 4: Plots with high birch clone richness displayed increased pathogen species richness, thus positively contributing to community biodiversity. In contrast, pathogen load of two birch clones decreased by local birch clone richness. Pathogen richness and load of a focal tree were unaffected by increasing proportion of the target tree's clone in the local neighbourhood, but depended on proportion of more or less susceptible birch clones.

Location: Question 1 and 2: Experimental Platform (BIOTREE Germany). Question 3: Experimental Platform (Kreinitz Germany). Question 4: Experimental Platform (Satakunta Finland)


Deliverable D4.6. Knowledge Element: Effects of biodiversity on the transmission of foliar fungal pathogens in the German tree diversity experiment BIOTREE (http://fundiveuropektp.boku.ac.at/node/39)

Task 4.7: Resistance to invasive species
by Harald Auge, UFZ

Question: How does biological diversity of native plant species influence the resistance of forest ecosystems to biological invasions by exotic vascular plants?

Evidence: In total, we found only two exotic species across all plots: Norway maple at the Polish site and maritime pine at the Italian site. Incidence and cover of these species in relation to diversity of the respective forest stands was analysed using generalized linear models. Frequency and cover of the two species were very low, and were not related to diversity of resident species (neither trees nor herbaceous species). According to theory, we expected a higher incidence of exotic species on plots with low diversity of resident natives, and a greater invasion resistance on more diverse plots. We suggest a low propagule pressure of exotics to be one possible explanation for the low incidence of exotic invasions on our sites. To disentangle the effects of covarying enviromental factors, propagule pressure and resident diversity on invasibility, experimentally “staged” invasions would be desirable. Since initiating experimental invasions in (semi-)natural forest ecosystems is usually not feasible due to ethical or legal reasons, we think that tree diversity experiments in later stages of stand development may provide a better opportunity to experimentally study the relationship between resident diversity and invasibility.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain)

Publications from the project: Deliverable D4.7

5 WP 5: Integration and scientific synthesis (WP leader: ULEI)

Task 5.1: Meta-analysis of diversity effects on stability and multi-functionality
by Alfons van der Plas, Eric Allan and Markus Fischer, UBE

Questions: 1. How does local-scale tree diversity affect forest multifunctionality? 2. How do small and large scale tree diversity affect forest landscape scale multifunctionality? 3. How can small-scale forest data be used to predict multifunctionality across Europe?

Evidence: Question 1: We quantified ecosystem multifunctionality for all 209 forest plots differing in diversity, as the number of ecosystem functions (16 in total) that exceeded a given threshold value. This assumes that forest managers can accept a certain loss of function but below a threshold the loss becomes unacceptable. When moderate levels of ecosystem functioning were required (50% threshold), biodiversity promoted multifunctionality. However at very high thresholds (90% threshold) monocultures had higher multifunctionality than diverse mixtures. We identified a novel mechanism driving this, which we called the jack-of-all-trades effect: diverse forests were jacks of many functions (many at moderate levels) but masters of few functions. This mechanism may drive positive diversity-ecosystem multifunctionality relationships in many of the world’s ecosystems.

Question 2: To explore biodiversity-functioning relationships at larger scales, we grouped plots into random landscapes and calculated α, β and γ diversity for the landscapes. We then developed new measures of landscape multifunctionality and calculated how many functions performed above a threshold across the whole landscape. When moderate levels of functioning were desired (50% threshold), both α- and β-diversity promoted landscape (γ-) multifunctionality. In contrast, when higher levels of functioning were required (90% threshold), β-diversity still promoted γ-multifunctionality, but α-diversity did not. These results show that loss of β-diversity (biotic homogenization) will have an even more negative effect on...
results show that loss of β diversity (biotic homogenization) will have an even more negative effect on ecosystem functioning than loss of local, α, diversity.

Question 3: We then used the data from the 209 exploratory plots to upscale to forest inventory plots to predict and map ecosystem services across Europe. We were able to validate the predictions for productivity and found good matches between predicted and observed values. We will use the predicted service levels to calculate continental scale variation in multifunctionality. We will then calculate multifunctionality under different scenarios of increasing forest diversity, to explore large-scale biodiversity functioning relationships.

Location: Exploratory Platform (Finland, Romania, Poland, Germany, Italy, Spain). Inventory Platform (Spain, France, Germany, Sweden and Finland)

Publications from the project: Deliverable D5.1

Task 5.2: Uncovering causality and mechanisms: Structural Equation and Hierarchical Bayesian modelling by Sophia Ratcliffe and Christian Wirth, ULEI

Question: Do the relationships between diversity and 14 ecosystem functions measured within the Exploratory Platform, change amongst the six FunDivEUROPE sites?

Evidence: We are interested in whether the sensitivity of ecosystem properties and functions to tree diversity are dependent on the context, i.e. the biotic and abiotic environment, and whether we can make generalisations about how the sensitivity of related ecosystem functions to diversity is affected by the biotic and abiotic environment. We used Bayesian hierarchical models to firstly determine the influence of diversity on each ecosystem function and then to model the slope of the diversity relationship as a function of different biotic (e.g. the maximum functional diversity of the region) and abiotic (e.g. water availability) drivers. All analyses are still in progress; however we have found that some BEF relationships are more dependent on climate than others. In addition, the scientific challenge of disentangling identity versus diversity control on ecosystem functioning was analysed for tree productivity using the inventory platform.

Publications from the project: Deliverable D5.2

Task 5.3: Forest inventory and environmental data integration and analysis by Paloma Ruiz-Benito, Jaime González Madrigal and Miguel Angel de Zavala, UAH


Evidence: Question 1: Diversity effects included both complementarity and selection mechanisms, measured respectively through functional diversity and functional identity measures. Diversity had a significant effect on both carbon storage and tree productivity, even when controlling for climatic and stand structural confounding factors.

Question 2: A positive diversity effect on tree growth (PDG) was more likely when a greater proportion of the stand basal area was occupied by functional types other than the focal tree. However, positive growth responses to diversity depended upon both identity and size of target trees with these effects being more patent for Boreal and Mediterranean large trees growing respectively in open and closed stands, and for juvenile boreal trees in closed stands.

Question 3: Our results showed that functional diversity increase tree net biomass increment after controlling for climate and stand structure, although the positive effect varied for the considered tree
controlling for climate and stand structure, although the positive effect varied for the considered tree species and neighboring ones. However, the largest changes in net biomass increment were recorded at low levels of functional diversity.

Question 4: We found that functional diversity directly determines growth and regeneration processes in forests across Europe. Furthermore, diversity modified growth, regeneration and mortality responses to biotic and abiotic conditions. Our results suggest that functional identity is a key factor determining forest dynamics. Particularly, we observed the highest mortality rates in forests dominated by conifers and the highest regeneration rates in forests dominated by broadleaved species.

Location: Inventory Platform (Spain, Germany, Wallonia-Belgium, Finland and Sweden)


Deliverable D5.3. Knowledge Elements: Tree diversity supporting forest adaptation under climate change (http://fundiveuropektp.boku.ac.at/node/250) Functional diversity and functional identity determine carbon storage and tree productivity in Spanish forests (http://fundiveuropektp.boku.ac.at/node/239) by Sophia Ratcliffe and Christian Wirth, ULEI

Question: What is the relative importance of functional diversity and functional identity for tree growth across a large climatic gradient?

Evidence: We found that tree biodiversity effects were relevant drivers of tree productivity across the entire European continent. Functional diversity was most important in the Mediterranean region, whilst functional identity effects were strongest at the latitudinal extremes of the continent, largely driven by maximum height.

Location: Inventory Platform (Spain, Germany, Wallonia-Belgium, Finland and Sweden)


Deliverable D5.3

Task 5.4: Mapping management effects on forest functional diversity of important European forest types by Sophia Ratcliffe and Christian Wirth, ULEI

Question 1: Does forest management decline functional diversity of European forests? 2. Future global change scenarios predict a dramatic loss of biodiversity for many regions in the world, reducing the resistance and resilience of ecosystem functions. Once before, during Plio-Pleistocene glaciations, harsher climatic conditions in Europe as compared to North America led to a more depauperate tree flora. We hypothesize that not only species number, but also functional diversity has been reduced in Europe as compared to North America.

Evidence: Question 1: We classified the inventory plots from the inventory platform to the European Forest Type classification based on species composition, climate and topography. Using mixed models, we assessed the influence of stand structure, species pool, climate and forest type on the species richness and functional dispersion of inventory plots. We found a consistent positive effect of management on both the species richness and functional dispersion in all forest types except for boreal and Acidophilous oak forests, in which there was a negative effect of management activity on both, species richness and functional dispersion. In Mediterranean coniferous forests there was no difference in species richness and functional dispersion between managed and unmanaged forest stands.

Question 2: We used variation in 26 traits for 154 North American and 66 European tree species and grid-based co-occurrences derived from distribution maps to compare the continents for functional diversity.
Based on co-occurrences derived from distribution maps to compare the continents for functional diversity. For gymnosperms we find similar functional diversity on both continents, whereas for angiosperms functional diversity is significantly greater in Europe than in North America. Our findings suggest that climate-driven extinction events may not necessarily reduce the functional diversity of continental floras and that functional resistance and resilience of entire continental floras are strong.

Location: Question 1: Inventory Platform (Finland, France, Germany, Spain, Sweden and Wallonia-Belgium). Question 2: Inventory Platform (European and North American temperate zone)

Publications from the project: Deliverable D5.4

Task 5.5: A model approach extending temporal and spatial scales by Mariana Pedro da Silva, Rupert Seidl and Manfred Lexer, BOKU

Questions: 1. Are species rich planted forests growing without management interventions more productive compared to monospecific stands? Are monospecific stands consuming less water compared to species rich stands? 2. Are species-rich forests buffering the C uptake and storage of forest ecosystems against the negative impacts from disturbances? 3. How are disturbance, diversity, and productivity related across different spatial scales in forest landscapes?

Evidence: Question 1: Stand-level simulations over 150 years with the hybrid patch model PICUS v1.51 indicated, that in general there was a negative complementarity effect of species richness on production due to asymmetric competition processes which were interrelated with species identity effects. Thus, the hypothesis that species richness is positively correlated with biomass production could not be confirmed under the specific conditions of the virtual experiment. Regarding water consumption the simulation results indicated increasing water use with increasing species richness.

Question 2: Long-term simulation results with the model iLand indicate that increasing tree species diversity on the landscape generally reduces the disturbance impact on carbon storage and uptake. However, the positive effect weakened or even reversed with successional development. Simulations furthermore indicate a clear positive relationship between diversity and resilience, with more diverse systems experiencing lower disturbance-induced variability in their trajectories of ecosystem functioning. Positive effects of tree species diversity are mainly driven by an increase in functional diversity and a modulation of traits related to recolonization and resource usage in the simulations. The results of our study suggest that increasing tree species diversity could mitigate the effects of intensifying disturbance regimes on ecosystem functioning and improve the robustness of forest carbon storage and the role of forests in climate change mitigation.

Question 3: Evidence: Simulations with the landscape and disturbance model iLand indicate an overall positive effect of disturbances on tree species diversity with regard to both within- (α) and between-stand (β) diversity. This positive effect persisted even under elevated disturbance frequencies. Productivity was enhanced by within- and between-stand diversity, yet the effect size decreased in later stages of successional development. Positive diversity effects were found to be strongly contingent on the available species pool, with landscapes containing species with different life-history strategies responding most strongly to disturbance-mediated diversity. We conclude that, rather than homogenizing disturbed areas, forest managers should incorporate the diversity created by disturbances into stand development to capitalize on a positive diversity effect on productivity.

Location: Exporatory Platform, German sites


Deliverable D5.5 Knowledge Element: Tree species diversity mitigates disturbance impacts on the forest
Question: Are mixed-species forests more resistant and resilient in the face of stress and disturbance than mono-specific forests?

Evidence: The evidence for the assumption that mixed species forests more resistant and resilient to stress and disturbance was reviewed based on studies that were conducted as part of this project as well as on other studies. The evidence for positive tree species diversity effects was strongest for biotic disturbances such as through pests and pathogens. A number of mechanisms were identified by which diversity reduces the level of damage to individual species or the community. However, there is no clear evidence in relation to abiotic stress factors. The impact of disturbances such as wind, fire, drought, flooding on forests depends largely on the properties of the tree species in the affected forest community. A positive mixing effect occurs therefore largely through risk spreading. However, mixed forests are not per se more resistant. Yet, structurally diverse forests appear to be more resilient since the advance regeneration allows a faster recovery from disturbance. In some situations, the stress may be even amplified in mixed-species forests, for example through drought stress.

Location: The review of studies that addressed the question of ecosystem stability focussed on European forests, including boreal, temperate Atlantic, temperate continental, and Mediterranean forests, but was not linked to a particular location.


Deliverable D5.6

Task 5.7: Developing the European Long Term Ecological Research network by Markus Fischer, Alfons van der Plas (UBE), Kris Verheyen (UGent) and Michael Scherer-Lorenzen (ALU-FR)

Question: 1. What lessons can be learned from several forest biodiversity-ecosystem functioning research projects, incl. FunDivEUROPE, about the role of tree diversity for the delivery of ecosystem services? 2. Are the results relevant for European policies? 3. How should a long-term research programme on biodiversity-ecosystem service relations in forests look like?

Evidence: Question 1: The lessons learned in several forest biodiversity-ecosystem functioning research consortia confirm that forest tree composition, tree identity and the local environment, not the least climate, largely drive forest functions in European forests, including production. In addition, tree biodiversity plays a very important, but so far neglected, role for the functioning of forest ecosystems. Increased diversity, among and within functional groups, affects many individual forest functions and their combination, i.e. ecosystem multifunctionality. While it appears that this effect of diversity is positive for many individual functions and for multifunctionality up to a certain level of each function, it may turn negative for individual functions and for multifunctionality, if very high values of functioning are required. Importantly, biodiversity also increases the temporal stability of functioning. Further, within-species diversity affects functioning by means of local adaptation and phenotypic plasticity, which both interact with tree species diversity. In addition to diversity within forest stands, landscape-scale diversity among stands also matters largely for forest functioning. Therefore, at the landscape level optimal forest function requires high biodiversity at both local and regional spatial scales.
Both local and regional spatial scales.

Question 2: These insights are highly relevant for the EU. They matter for sustainable development, the development of innovation in environmental technologies, the Common Agricultural Policy, the Forest Action Plan, the Protection of Forests in Europe, the European Community Biodiversity Strategy and Biodiversity Action Plan, the implementation of the Natura 2000 network and for climate policy. Moreover, they matter for national and paneuropean forest monitoring.

Question 3: The main challenges concern the consideration of a more comprehensive set of forest functions and, especially, services; of their relevance for different types of stakeholders; of main and side effects of obtaining services; of the role of diversity within and between tree species relative to, and in interaction with, the context of other drivers, such as climate, soils and management; and of diversity effects at the landscape scale, including the design of “optimal” landscapes. To address these challenges we suggest a hierarchical research approach combining a) experimental sites, b) intensively studied comparative sites with a clear diversity-targeted design (“Exploratories”), and c) systematically coordinated forest inventory networks. This entails a) expanding the network of tree diversity experiments to further countries, regions and forest types in Europe, b) expanding the FunDivEUROPE Exploratory Platform to other countries/regions/forest types and to also capture landscape scale information, and c) to add protocols/measurements to existing forest monitoring networks to get information on biodiversity and ecosystem services.


Deliverable D5.7

Potential Impact:
1 Potential impact, main dissemination activities and exploitation of results
1.1 Potential impact, including the socio-economic impact and the wider societal implications
1.1.1 Scientific impact
FunDivEUROPE has yielded a tremendous amount of data and significantly enlarged the scientific knowledge on the relationship between forest biodiversity, ecosystem functioning and the delivery of ecosystem services. To this end, an important feature of FunDivEUROPE was the integration of experimental, exploratory, and inventory data using a sound statistical design. Most importantly, the general sampling philosophy (“all measurements on all plots”) has been successfully implemented and applied by all participating research groups in the Exploratory Platform, providing high statistical power and enabling synthesis on multi-functionality and multi-diversity. The knowledge from the so far prevailing case-studies has therefore been extended to a level that links representativeness (i.e. the relevance of the findings for the existing forest ecosystems in the real landscape), comprehensiveness (i.e. the spectrum of ecosystem functions and services quantified) and orthogonality (i.e. the ability of a design to detect and quantify the effect of diversity per se against a background of various other influencing factors and covariates). Thus, the project has and will have a substantial scientific impact, as mirrored already by a high number of publications in high-impact international journals.

Covering the major European forest types, and being based on solid research Platforms, FunDivEUROPE has laid the ground for a European Long-Term Ecosystem Research Network that focuses on forest biodiversity and ecosystem functions/services. The initial network established here, can easily be extended by additional forest types and/or bioclimatic regions. The carefully established data collection protocols of FunDivEUROPE and their quality control allow a straightforward integration of further forest
protocols on FunDivEUROPE and their quality control allow a straightforward integration of further forest research plots. Such an enlargement of a European, or even global, network of forest research sites would certainly help to develop guidelines for future sustainable management of forest resources, taking into account the functional role of tree biodiversity. To address these challenges we suggest a hierarchical research approach combining a) experimental sites, b) intensively studied comparative sites with a clear diversity-targeted design ("Exploratories"), and c) systematically coordinated forest inventory networks. This entails a) expanding the network of tree diversity experiments to further countries, regions and forest types in Europe, b) expanding the FunDivEUROPE Exploratory Platform to other countries/regions/forest types and to also capture landscape scale information, and c) to add protocols/measurements to existing forest monitoring networks to get information on biodiversity and ecosystem services. As a first step, FunDivEUROPE has been contacted by LTER Europe to include the FunDivEUROPE field sites into the collection of metadata about the LTER-Europe sites.

1.1.2 Socio-economic impact and policy implications

Due to its pan-European dimension and the related “all measurements on all plots” philosophy, and its diverse array of beneficiaries, FunDivEUROPE has led to very fruitful international cooperation and intercultural exchange. All persons involved, but especially the PhD and Postdoc students, certainly profited from this exchange of ideas, perceptions and new friendships. Many students received their Bachelor, Master or PhD degree based on scientific work done in the project, which constitutes an important stage of their individual careers. The visit of field sites in often remote and rural areas of Europe by many students and researchers over several years had also direct economic impact on local economies.

Stakeholders from forestry, policy, and nature conservation at supranational as well as regional scales have been integrated at early stages within FunDivEUROPE to identify knowledge gaps, information needs, preferences regarding to ecosystem functions and related services as well as perceived risks for productive functions and nature conservation. This exchange of information was also helpful in formulating the research questions that were specifically addressed within the Workshop “Adaptability and stability of European forest ecosystems in relation to tree species diversity: a review of the scientific evidence and forest management options” (see Deliverable D5.6) to formulate (i) adaptation needs and strategies of European forests to global environmental changes, (ii) silvicultural options associated with the potential use of mixed species forests, which translate beneficial effects of diversity into concrete management practices and (iii) policy recommendations to achieve these goals.

ad (i): The potential of mixing species and species changes as concrete tools for active adaptation to global change seems to be high. Global change is expected to lead to shifting distribution ranges of European tree species. It is, however, difficult to predict the speed of this migration and the persistence potential of species in case of changing environmental conditions. One reasonable assumption is that mixed forests will be able to react more dynamically and heterogeneously to such changes and may therefore be better equipped in buffering and resisting negative effects than monospecific forests. One key result from FunDivEUROPE clearly supports this assumption: tree species diversity contributes to stabilizing productivity over time, meaning that tree diversity can essentially be thought of as an "insurance policy" against hard times, e.g. in face of drought (Jucker et al. 2014, Ecology Letters). Similarly, we found significant effects of tree species diversity on ecosystem resistance to drought, which however changed with local environmental and climatic conditions (Grossiord et al. 2014, PNAS). Thus, it can be suggested that economic evaluations should quantify the potential of admixtures of new tree species in mitigating a possible decline of highly profitable forest types consisting mainly of conifer species under warmer and...
possible decline of highly profitable forest types consisting mainly of conifer species under warmer and
drier conditions. In addition, the portfolio theory should be applied to mixed forests, investigating to which
degree mixtures are able to provide “substitute” functions in case of loss or migration of particular species.
Finally, an economic analysis of the process of active species changes (conversion) is needed in order to
facilitate a cost/benefit prediction of management operations needed for conversions. Thus, the project
laid the basis for a thorough risk assessment, which will result in the formulation of economically optimized
management recommendations.

ad (ii): While European forests often are potential mixed forests, human intervention has created a large
proportion of mono-specific forests. Where mixtures exist, they have often been deliberately selected for a
combination of desirable traits, such as valuable shade-intolerant hardwoods with other shade-tolerant
hardwoods for stem shading. In many cases, these mixtures have not been designed with redundancy in
ecosystem functions among the species as the goal. It becomes increasingly clear, however, that some of
these mixtures may not be optimal solutions in terms of increasing resilience and resistance in the face of
global change and thus do not necessarily comply any longer with society’s and landowners expectations
for provision of ecosystem services now and in the future.
The outcomes of the project helped to formulate silvicultural options for changing forest species
composition, which include advance regeneration beneath existing stand canopy, or regeneration for
clearcut or post-disturbance scenarios. Natural and artificial regeneration are both possible methods for
either scenario, while the greater stability and lower cost of natural regeneration may have to be weighed
against the more rapid reaction time and the deliberate control over genotypic diversity of artificial
regeneration.

A careful integration of natural processes leading to increases of diversity, e.g. gap creation through
disturbance or the establishment of natural regeneration provides valuable additional options for active
control of species composition. In this context, the promotion and maintenance of rare species proportions
within forests is another concern. Rare species can fulfill important ecological functions even when their
proportion is small. Some provide important services, such as fruit or aesthetic value.

Species diversity and the expected positive effects should also be considered at different spatial scales
and in concert with structural diversity. On the stand level and on the landscape level, differently spaced
and structurally mixed trees, stands and forests may react differently to disturbance and stress and thus
contribute to a portfolio where no single stressor or disturbance can have catastrophic effects. Thinning
and stand density regulation may support resistance and resilience, e.g. by allocating water resources to
only those trees that are considered vital to productivity and stability.
The introduction of exotic tree species may be a valuable strategy as exotics may be better adapted to
some of the stresses and disturbances expected under global change. However, invasiveness,
hybridization and the introduction of associated pests and pathogens are risks that must carefully be
weighed against possible positive properties such as high productivity and the enhancement of
biodiversity.

ad (iii): The aim of increasing forest species diversity to address the challenges of future forest
management must be based on an assessment of the consistency of existing EU and national regulations
and policies. The benefits of increasing species diversity are compatible with the aims of several existing
EU policies and strategies, e.g. its biodiversity policy, native species policy and the Europe 2020 strategy
and with a possible Climate Change Act and associated policies.

An important step is to analyze regional policy frameworks and identify commonalities and differences and
potential for adjustment. The historical development of regional differences is an important factor to be
considered regarding policy recommendations. Thus, policy recommendations are intended to act as a
Considered regarding policy recommendations. Thus, policy recommendations are intended to act as a general guideline and must in each regional case be harmonized with existing regulations, legal framework and societal realities through the use of incentives, legislation and certification. Before species diversification is promoted on a large scale, it is recommended to go through a process of trials, monitoring and adapting forest management approaches step-wise. It should facilitate the process of diversification as a bottom-up approach supported by top-down resourcing for monitoring and assessment of the suitability for larger-scale programs. Decision-support systems may be used and combined with social science approaches in order to monitor and enhance support for the measures. Cases in which the establishment of new forests are planned are especially suitable for introducing more species diversity, while management goals and expected ecosystem services will need to be harmonized with this goal. Subsidies can prove an effective instrument for increasing acceptance of more diverse forests, e.g. for afforestation of former agricultural land.

Since the creation and maintenance of more diverse forests will to a large degree influence the economic viability of some forests, efforts to increase knowledge regarding productivity, quality and economic value of diverse forests is needed. To achieve this, markets must be created or boosted for new tree species. Besides timber, non-wood forest products, carbon certificates or novel cellulose products may support the shift to more species-rich forests, while further tools include the support of industry-research partnerships and innovation and entrepreneurship in SMEs. Certification can help build accountability and trust and provide market advantages. Regional legislative bodies and regulators should consider linking subsidy and grant schemes to standards requiring good practices in management, including the maintenance and increase of species diversity.

Hunting guidelines and regulations can be adapted to strive for better protection of diverse forests from browsing. Furthermore, fencing and establishment costs could significantly be reduced with adapted hunting policies. The increased stability and adaptability of species diversity in forests can be an alternative to the reliance on pesticides to protect forests from pests and pathogens.

In sum, FunDivEUROPE provided a large array of new knowledge that together with insights stemming from reviewing existing literature will result in an ongoing process of formulating adaptive management guidelines and policy recommendations for the use of multi-diverse, mixed species forests that incorporate the benefits that biodiversity may provide for ecosystem functioning, stability and delivery of ecosystem services.

1.2 Main dissemination activities and exploitation of results
WP 6: Dissemination, knowledge transfer and stakeholder interaction (WP-leader: BOKU)
Task T6.1: Stakeholder interaction (Task leader: BOKU)
by Alfred Radl, Harald Vacik, and Manfred Lexer, BOKU

Activity: Harmonized stakeholder interaction happened at two levels. At supranational level a meeting with key stakeholders including forest owners associations and nature conservation NGOs was organized in Brussels to raise awareness about the FunDivEUROPE project and to receive feedback on general approaches and expected outcomes. At regional level stakeholder panels were organized in each of the six focal regions combining representatives of owners, administration, NGOs and managers. Altogether, 75 stakeholder representatives were interviewed on topics related to interests, opinions and beliefs on the diversity-ecosystem provisioning relationship as well as on expected outcomes and modes of knowledge transfer.
Impact: Most important effects of these stakeholder interaction activities were on one hand to raise awareness of stakeholders at supranational level about the project, on the other hand the direct confrontation of FunDivEUROPE scientists and researchers with stakeholder beliefs, expectations and constraints to increasing diversity in European forests.

Task T6.2: Development of a web-based knowledge transfer tool (Task leader: BOKU) by Alfred Radl, Harald Vacik, and Manfred Lexer, BOKU

Activity: The web-based knowledge transfer platform (KTP) was developed during project time and the technical implementation was successfully planned and completed. Several workshops with project partners and stakeholders were conducted to get feedback to the proposed conceptual structure and the functionality of the KTP. In total 125 expert profiles of key researchers in FunDivEurope were created including the upload of 142 related publications. So far, 16 knowledge elements were designed in relation to hypotheses and questions tackled in FunDivEurope. For supporting the knowledge transfer process 16 videos were produced to provide insights to the project research activities, the functional relationships between biodiversity and different ecosystem services. The videos are linked to knowledge elements and are also publicly available in YouTube. An introduction to the KTP was given during the annual meetings and the summer School in Poland in September 2013. The concept of the KTP was presented at several scientific conferences and workshops.

Impact: Until the end of the project the contents of the KTP were still under development and the final deployment of the webportal including its contents was done at project end. The KTP will be reachable in the web under the former domain of the EU project www.fundiveurope.eu which will support a wider dissemination of the findings and the knowledge transfer and exchange in general (The former project website will be available under www.project.fundiveurope.eu). However, up to March 2015 some knowledge elements have already been viewed more than 250 times, which is comparable high to some scientific publications. This will allow a wider dissemination of the results of FunDivEurope to the target groups. Especially the videos produced allow a low barrier excess to the complex relations between biodiversity and ecosystem services and target to policy makers and forest managers.


Activity: Research results have been presented at 68 scientific events, mostly conferences, with 83 talks and 33 posters. Important conferences during the project life have been the 11th INTECOL Congress, London, UK; the IUFRO World Congress, Salt Lake City, USA; the ESA Annual Meeting in Sacramento, USA; the British Ecological Society - French Ecological Society joint Annual Meeting, Lille, France; and the ClimTree Conference in Zürich, Switzerland; besides others.

37 peer reviewed publications in 26 different scientific journals are published so far, among them high ranked journals like Ecology Letters or PNAS, and at least 11 more will be published soon. Furthermore, three peer reviewed book chapters have been written in two different edited books.

Results were incorporated in higher education through lectures or talks in seminars at Universities in Basel, Zürich and Ghent. Furthermore the Exploratory Platform is used for field education of students and shall be used more intensely in education and for qualification works (PhD and PostDocs) in the future. The University of Leipzig installed an Arboretum 2014 as testing ground.

To reach the wider public three TV clips ran in local TV of Poland, France and Germany and five articles have been published in the popular press, in Germany and Romania. Furthermore, four press releases have been launched in Germany and France. Additionally, three online articles are available.

The project website is up to date and can be reached via www.project.fundiveurope.eu. It provides general
The project website is up to date and can be reached via [www.project.fundiveurope.eu](http://www.project.fundiveurope.eu). It provides general information about the project, including information about the different platforms (Experimental, Exploratory, Inventory) and the different Workpackages.

More online activities include a blog about RHUL’s work with mammals in the project ([https://rhulscience.wordpress.com/2012/07/04/does-forest-diversity-matter/](https://rhulscience.wordpress.com/2012/07/04/does-forest-diversity-matter/)) and two nice educative animations about the pine processary moth from INRA, online available ([https://vimeo.com/107229503; https://vimeo.com/91510826](https://vimeo.com/107229503; https://vimeo.com/91510826)) one of them also available within a knowledge element of the Knowledge transfer platform. Some participants additionally have featured FunDivEUROPE in their personal blogs. Seven presentations addressed a wider public, including the online FameLab contest, a communications competition designed to engage and entertain by breaking down science, technology and engineering concepts into three minute presentations, the Montpellier Biodiversity Festival in France and others. Results have been discussed with local forest stuff, forest managers and NGOs in two different workshops and in a conference attended by researchers and forest managers, all held with small groups in Suceava, Romania.

The policy-science interface was addressed in a workshop in Brussels, where coordinators of several EU-projects related to Biodiversity Research have been invited to discuss with members of the EU-commission General Directorates (“Workshop on Biodiversity and Ecosystem Services: a strategic dialogue between Science and Policy”, November 2011). There, best practice example on how to write Policy Briefs were presented and discussed. This knowledge has been used to create a policy brief about the projects outcomes of biodiversity effects in European forests.

Impact: Various media have been employed to address different target groups. The aims of FunDivEUROPE’s dissemination activities were to increase visibility, raise awareness, create understanding and stimulate action/application. The scientific community was addressed in various conferences and with publications in scientific journals. Stakeholders were addressed in workshops and with the knowledge transfer tool. The general public was reached with local and online media. Policy was directly addressed with a policy-interface meeting in Brussels, and a policy brief.

T.6.4: International summer school on the functional significance of forest biodiversity (Task leader: UWAR)

by Bogdan Jaroszewicz

Activity: The international summer school on functional biodiversity significance of forest biodiversity brought together PhD students and Postdocs involved in FunDivEUROPE for a 7-days intensive training course. In addition, the school was open for a limited number of selected students from outside FunDivEUROPE as well as for students from local Universities in Poland. The Summer School was held in Białowieża, Poland, one of the focal regions of FunDivEUROPE. The summer school included interactive lectures held by PIs of FunDivEUROPE, including Prof. Miguel Zavala (Spain), Prof. Jürgen Bauhus and Prof. Michael Scherer-Lorenzen (Germany), as well as visiting scientists, e.g. Prof. Jerzy Szwagrzyk (Poland), discussion rounds, practical exercises in the field and in the laboratory, and excursions. The focus was set on the linkages between theory and applications in forest and resource management, including practical exercises on field methods to improve the skills and methodological abilities of the participants across different disciplines. Additionally a one-day course on professional reporting of science news was integrated to the program.

Impact: A large group of PhD students and young scientists (overall 31 people from 12 countries) had been trained during the Summer School in the field of the management of European mixed forests, both in theory and practice. Aside of the training, the Summer School was efficient stage for networking activities between participants of the FunDivEurope project. The course on professional reporting of science was...
between participants of the FunDivEurope project. The course on professional reporting of science was inspiration for some students to create or further develop personal blogs and other dissemination activities, see T6.5).

T.6.5: Professional reporting on science news via mass-media tools
by Sandra Müller, Annette Gockele and Michael Scherer-Lorenzen, ALU-FR
Activity: A one day “Science in the media” course, held by Subcontractor Steve Thompson, STMedia, during the International Summer School (T6.4) provided training for young scientists from FunDivEUROPE, to enable them to communicate to a wider public. Participants should learn how to handle new mass media communication tools and how to address a broader audience. Participants learned how to combine various media tools efficiently (e.g. wordpressblogs, facebook and twitter). The participants were encouraged to produce contributions for the Knowledge-Transfer Platform (KTP) and received support in creating content.
Impact: Mass media tools allow delivering timely, relevant and understandable information about the relationship between forest biodiversity and ecosystem services to the general public, stakeholders and policymakers. The main achievement of the project is the creation of the Knowledge-Transfer Platform (KTP, T6.2) an interactive platform where latest results are presented user friendly and easy understandable. More contents are under development and the platform shall be maintained in the future. The course on professional reporting helped to create more and better contributions for the KTP.

List of Websites:

www.fundiveurope.eu
http://project.fundiveurope.eu

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Related documents

final1-fundiveurope-study-sites.pdf

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