SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

ASSESSMENT OF THE EFFECTS OF TREE SPECIES DIVERSITY ON FOREST BIODIVERSITY AND ECOSYSTEM FUNCTIONING

FORBIO

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SCIENCE FOR A SUSTAINABLE DEVELOPMENT
(SSD)

Biodiversity

FINAL REPORT

ASSESSMENT OF THE EFFECTS OF TREE SPECIES DIVERSITY ON FOREST BIODIVERSITY AND ECOSYSTEM FUNCTIONING

FORBIO
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SUMMARY

Forests are biodiversity hotspots worldwide with 70% of terrestrial biodiversity being included in forested landscapes. However, deforestation, forest degradation and fragmentation lead to an increasing rate of species extinctions. Hence, predicting the consequences of changes in species numbers, in distribution patterns of taxa, and of shifts in dominance, has become a major challenge for community and ecosystem ecology. However, until now the relationships between biodiversity and ecosystem functioning in forests have been largely underexplored

Therefore, the overall aims of the BELSPO cluster project FORBIO are: to review, synthesize and disseminate existing knowledge about the benefits and drawbacks of mixed stands vs monocultures (WP1); and to establish a highly innovative, large-scaled forest biodiversity experiment to evaluate the impact of increasing tree diversity on forest ecosystem functioning (WP2).

To achieve the first objective, a so-called 'white paper' has been compiled by the FORBIO team members which has been published in Dutch as a special issue of the BosRevue and in French as a special issue of Forêt Wallone. Among stakeholders, many different opinions exist about the functioning of mixed forests and therefore the scientific evidence was confronted with stakeholder perceptions on ecosystem services in mixed forests compared to monocultures. The principal outcome was that stakeholders appear to have quite strong opinions on the functioning of mixed vs monoculture stands, whereas the review of the scientific literature highlighted the lack of specific information on forest ecosystem services in mixed forests compared to monocultures, in particular from studies where confounding factors can be eliminated or accounted for.

The second objective was met by establishing two large-scaled tree diversity experiments in Zedelgem (Flanders) and Gedinne (Wallonia). Based on a state-of-the-art experimental design, 32 810 and 33 304 trees of five different species were planted in 42 and 44 experimental plots in Zedelgem and Gedinne, respectively. A third experiment with a similar design will be established in Hecthel-Eksel (Flanders) in 2011.

FORBIO's short-term contributions to sustainable development are mainly related to the fact that the project has introduced the state-of-the-art concepts and empirical support on the various relationships between biodiversity and ecosystem functioning to a large audience of forest owners, managers, users and scientists in Belgium. In the long-run, FORBIO will significantly contribute to a better understanding of the importance of tree species diversity for the functioning of forest ecosystems and the ecosystem services that they provide thanks to the establishment of the two (and soon three) large-scaled tree diversity experiments. Furthermore, the experiments, embedded in the worldwide TreeDivNetwork, will most likely continue to act as an attractor for researchers from Belgium and abroad.

Keywords: ecosystem functioning, functional biodiversity, biodiversity experiments, temperate forest, mixed forest, stakeholder perceptions, sustainable forest management.

1. INTRODUCTION

1.1 Context

Forests are biodiversity hotspots worldwide with 70% of terrestrial biodiversity being included in forested landscapes. However, deforestation, forest degradation and fragmentation lead to an increasing rate of species extinctions. Hence, predicting the consequences of changes in species numbers, in distribution patterns of taxa, and of shifts in dominance, has become a major challenge for community and ecosystem ecology.

Recent research provides increasing evidence that this biodiversity crisis is indeed not only an ethical problem, but a potential threat to ecosystem processes and services. Especially in grassland ecosystems an increased understanding of the functional role of biodiversity has been achieved. Large-scaled experiments (e.g. Hector *et al*. 1999, Spehn *et al*. 2005) showed significant positive impacts of plant diversity and composition on ecosystem processes such as biomass production, nutrient use, decomposition, etc. However, the explanation for such relationships is more controversial. Some authors (e.g. Huston 2000) attributed these relationships to pure 'sampling effects', i.e. the higher chance to include species with particular traits, while others (e.g. Hector *et al*. 2002) proposed complementarity in resource use and/or facilitation as the principal drivers. Today, there is growing consensus that complementarity and/or facilitation do frequently occur (e.g. Spehn *et al*. 2005).

However, until now the relationships between biodiversity and ecosystem functioning in forests have been largely underexplored. Nevertheless, research on this topic could give an answer to important issues for sustainable forest management in Belgium and elsewhere. As many conifer (pine, spruce) plantations in Belgium get older, conversion to more mixed stands becomes an important management option. The latter is also supported by a range of international and national policy documents (e.g. the Pan-European Criteria and Indicators by MCPFE, EU Habitat Directive, Flemish Criteria for Sustainable Forest Management, Pro Silva guidelines). But will mixed forests be more productive, have a more pronounced microclimate, have more control over energy, water and material fluxes, be more resistant to disturbances, and/or host a higher diversity of associated species? Although these questions have puzzled forest ecologists for a very long time[1] and despite the fact that some work on the ecological and socio-economic consequences of mixing of (mostly commercially important) tree species has already been done (e.g. Kelty *et al*. 1992, Olsthoorn *et al*. 1999), no unequivocal answers have been formulated yet due to methodological problems and the lack of a rigorous conceptual framework. The challenge for the current project is, therefore, to transfer the recent insights gained from the studies on synthetic grassland communities to mixed forest stands.

[1] E.g. the following statement by von Cotta in 1828: 'Since not all tree species utilize the resources in the same manner, growth is more lively in mixed stands and neither insects nor storms can do as much damage; also, a wider range of timber will be available everywhere to satisfy different demands….'

1.2 Objectives

The overall aims of this cluster project are:

(1) to review, synthesize and disseminate existing knowledge about the benefits and drawbacks of mixed stands vs monocultures with respect to the three components of sustainability (ecology, sociology and economics) and to provide areas of communication (meetings, conferences, discussion groups) between the whole community concerned with forest ecology, biodiversity and management in order to initiate an active network (a 'community of practice') for forest biodiversity research and management in Belgium (Work Package 1);

(2) to establish a highly innovative, large-scaled tree diversity experiment to evaluate the impact of increasing tree diversity on forest ecosystem functioning. This experimental platform will provide a highly innovative research facility for national and international scientists from a wide range of disciplines, with the purpose of deepening the understanding of the mechanisms behind diversity-ecosystem functioning relationships in forests (Work Package 2).

2. METHODOLOGY AND RESULTS

The project consists of two Work Packages (WPs) linked to the two objectives stated in section 1.2. Below the outcome of the tasks that were done within the two WPs, each consisting of four tasks (WP1.1-WP1.4 and WP2.1-WP2-4), will be described in detail.

WP 1: Review, synthesis and dissemination of existing knowledge on Biodiversity and Forest Ecosystem Functioning (BFEF)

Task WP1.1 Review & synthesis of existing (and perceived) knowledge on BFEF

Among stakeholders, many different opinions exist about the functioning of mixed forests and therefore the objective of this task was (1) to review the existing scientific evidence on ecosystem service delivery in monospecific versus mixed forests and (2) to confront the scientific evidence with stakeholder perceptions on ecosystem services in mixed forests compared to monocultures.

1. Review & synthesis of existing knowledge on BFEF

For the complete results of the review and synthesis of existing knowledge on BFEF we refer to the so-called 'white paper' that has been compiled by the FORBIO team members and which has been published in Dutch as a special issue of the BosRevue (see Annex 1.1) and in French as a special issue of Forêt Wallone (see Annex 1.2). Nadrowski *et al*. (2010) recently published a synthesis of BFEF research as well.

Looking at the results that have been published, we found that, in general, tree species mixtures usually favour forest biodiversity but only a few organisms are reported to be inherently associated with tree mixtures and that mixing effects are strongly dependent on the tree species involved. The identity of the tree species in the mixtures also appeared to be important to explain the observed tree diversity productivity and the tree diversity decomposition relationships. Furthermore, additive, non-additive antagonistic and non-additive synergistic effects have all been shown to occur and effects can vary depending on the site conditions. However, until now most conclusions are based on mixtures with only two species and effects of confounding factors could not always be controlled for. Concerning the diversity-stability relationships most information is available on the effects of insect pests in monocultures versus mixtures. In general, less damage is observed in mixtures but, again, mixture effects depend on the tree species involved. Furthermore, tree diversity effects tend to vary according to the feeding guilds. Little information is available on the relationships between tree diversity and abiotic risks such as wind, fire and flooding. Based on the limited scientific information that is available, it is clear that generalizations and simplifications with respect to the functioning of mixed versus monoculture stands should be avoided.

2. Existing vs perceived knowledge on BFEF

The question was whether the very nuanced picture on tree diversity ecosystem functioning relationships that emerges from the scientific literature is also reflected in the opinions that live among the stakeholders. Specifically, we addressed, through a questionnaire, the following questions:

(1) Which management objectives are perceived as most important?
(2) Does the importance of management objectives depend on the stakeholder group or region?
(3) What is the perception of ecosystem services in mixed forests compared to monocultures?
(4) Does the perception of ecosystem services depend on the stakeholder group or region?
(5) Is this perception consistent with scientific knowledge?

2.1. Material and methods

2.1.1. Study area

We examined perception of ecosystem services in mixed compared to single-species forests (monocultures) in two regions of Belgium: Flanders and Wallonia. Flanders (13 521 km^2) is located north of Belgium and forest covers 10.8% of the Flemish territory. The principal tree species is pine (63 550 ha), followed by poplar, oak, and mixed noble species (between 10 250 and 19 060 ha) (Campioli *et al*. 2009; Vande Walle *et al*. 2005). Private ownership is about 70% (areal basis); main public owners are towns and the region. The main forest area of Flanders is situated in the Kempen natural region ('Campine' in French) situated in north-eastern Belgium at an altitude of 10 to 100 m. Poor sandy soils (Podzols) are predominant and agriculture is the main land use.
Wallonia (16 845 km^2) is located in the southern part of Belgium and forest covers 32.3% of the Walloon territory. The principal tree species is spruce (171 700 ha), followed by oak (81 600 ha), mixed noble species (57 100 ha) and beech (42 200 ha). About 50% of the forests are privately owned and main public owners are towns and the region. The main forest area of Wallonia is situated in the Ardenne natural region, situated in south-eastern Belgium at an altitude of 200 to 694 m. Poor, loamy soils (Dystric Cambisols) are dominant in the Ardennes and pasture and forest are the main land uses.

2.1.2. Survey methodology

The perception of ecosystem services in mixed stands compared to monocultures was investigated in Flanders and Wallonia. The web-based anonymous questionnaires (implemented with SurveyMonkey) were established in Flemish and in French and invitations to respond were distributed to stakeholders by e-mail among key contact persons of forestry/nature associations, forest managers (private and public), users and scientists. This process is referred to as ‘‘snowballing’’, whereby one informant puts the researcher in touch with other important stakeholders.
In Flanders, targeted organisations were ANB, Bosgroepen, Landelijk Vlaanderen, VBV - Pro Silva, Natuurpunt, UVB, FEDEMAR-Nl and Flemish forest scientists. In Wallonia, FEDEMAR-Fr, DNF, Forêt Wallone, Pro Silva Wallonie, SRFB, Natagora, Conseil Supérieur Wallon des Forêts et de la Filière Bois, Forests Experts Organisation and Walloon forest scientists were contacted. These organisations were targeted because their members have a potential influence on the management of

forests through their profession, their involvement in environmental research and/or environmental/forest organisations.
Each questionnaire was enclosed with a cover letter identifying the purpose of the study and key contact researchers. In the questionnaire, monocultures have to be understood as single-species stands (regardless whether coniferous or deciduous, native or non-native). Mixed stands have to be understood as multi-species stands, with different possibilities on spatial distribution of the different species (mixing in small groups or by tree for example). The questionnaire was open for one month in April 2009.

2.1.3. Questionnaire structure

As a general frame for the questionnaire, the 'Millenium Ecosystem Assessment' (MEA 2005), assessing the consequences of ecosystem change for human well-being, was selected (Fig. WP1.1). The questionnaire consisted of four sections: (1) participants' profile, (2) free listing of three key concepts associated with mixed stands, (3) association of key concepts with either mixed stands or monocultures, and (4) importance of management objectives and ecosystem services in mixed stands versus monocultures.
Within this report, results on management objectives and ecosystem services are presented. For the management objectives, respondents were asked to express the degree of importance of provided objectives on a 5 point Likert (1: no importance, 5: very important) scale (Table WP1.1). In the latter part, respondents were asked to express their degree of agreement (5 point Likert-scale; 1: totally disagree, 5: totally agree) with statements related to the provisioning (production/quality, financial return), supporting (biodiversity, nutrient cycling, resistance), regulating (climate, air, soil, water) and cultural (aesthetics, recreation) ecosystem services, comparing mixed stands to monocultures (Table WP1.2). As life on earth is at the basis of all ecosystem services, we classed items related to biodiversity within the 'supporting' ecosystem service class. Questions were randomly distributed and relations to ecosystem services were not revealed. The sense of the questions (service better in mixed stands or monocultures) was also randomly attributed.

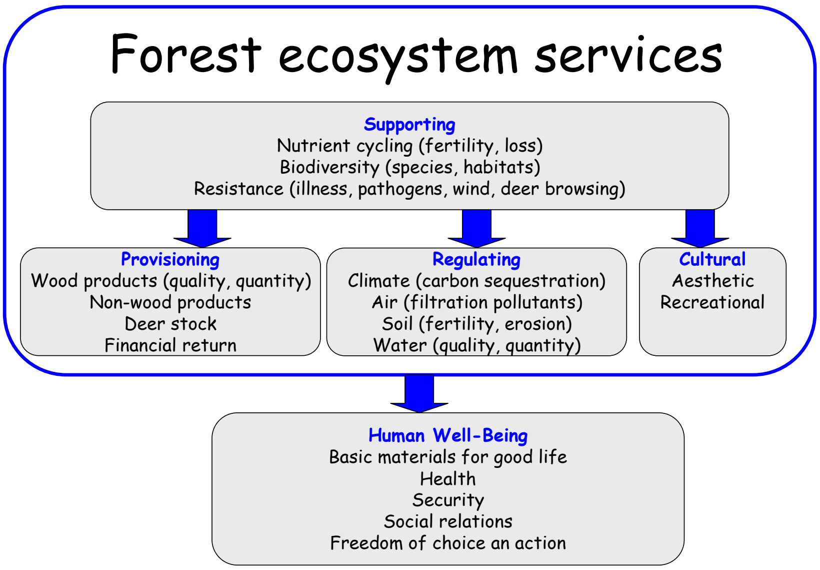


Figure WP1.1*: Forest ecosystem goods and services addressed in this study and their relation to well-being (modified from MEA 2005 & Sepälä et al. 2009).*

Table WP1.1: Summary of survey items related to management objectives[a] within the four ecosystem service classes

Service class	Abbreviation	Items
Supporting	Storm	Decrease risk from storms
	Disease	Protect forests against insects and illness
	Biodiversity	Maintain/protect biodiversity of associated species
	Fire	Protect forests against fire
	Soil	Preserve soil quality (structure and nutrients)
Regulating	Carbon	Maintain/improve carbon storage capacity
	Air	Ensure the air purification capacity of the canopy
	Erosion	Protect soils against erosion
	Flood	Limit flood risks
Provisioning	Game	Maintain game population for maximising hunting revenues
	Wood-private	Ensure wood supply to individuals (i.e. firewood)
	Wood quality	Ensure the production of wood of high quality
	Wood	Ensure the supply of wood to the timber industry
	Water	Protect water quality
	Products	Ensure the presence and the possibility to collect non-wood products (fruits, mushrooms, ...)
	Deciduous	Diversify deciduous and coniferous species
	Profitability	Ensure profitability
Cultural	Culture	Preserve a cultural heritage
	Life	Provide an environment where it is pleasant to live

[a]Respondents were asked to express the importance they attribute to the listed management objectives on a 5 point Likert scale

2.4. Data analysis

Data collection resulted in 367 returned questionnaires. Stakeholders were grouped into practitioners (P; comprising owners and managers) and scientists (S). Scientists were grouped into 'S' regardless whether they were also owners or managers. We hypothesized that the perception of scientists is primarily influenced through their access to the scientific literature. Responses of forest workers and recreationists were too infrequent to allow statistical analyses and hence were omitted. Response questionnaires containing significant numbers of missing values (no response) were discarded from the dataset, resulting in a total number of 267 responses used in the final dataset. For the analyses, results of questions assuming a better service in monocultures were inversed. The degree of agreement is therefore expressed towards a statement assuming a better service in mixed stands. As some items relating to same service class may result in opposite responses, the use of a summative scale was considered inappropriate and Likert items were analysed individually.

Differences in the response variables between the stakeholders and regions were tested with permutational analysis of variance (Anderson 2001). The age of the respondents was used as a covariate in the analysis. The technique is a semi-parametric analogue to traditional analysis of variance that is applicable to ordinal data. The sum of squares for each explanatory variable (stakeholder, region, age) is calculated from a matrix containing the pairwise distances among samples (here: respondents), based on a set of response variables. Because of the ordinal nature of the response variables, we applied the Gower dissimilarity measure with Podani's (1999) extension to ordinal variables. The significance of the pseudo-F value was tested with 999 permutations. The *gowdis* function (FD package) in R 2.11.1 was used to calculate the dissimilarities, and the *adonis* function (vegan package) performed the permutational analysis of variance (Laliberté & Shipley 2010; Oksanen et al. 2010; R Development Core Team 2010). Univariate permutational analysis of variance (PerANOVA) was performed to assess the differences in response variables of individual items within each ecosystem service class, whereas multivariate PerMANOVA assessed differences in response variables of the four ecosystem service classes globally.

Table WP1.2: Summary of survey items related to the perception of ecosystem services in tree species mixtures (*versus* monocultures)[a] within the four ecosystem service classes.

Service class	Abbreviation	Items
Supporting	Storm	Mixed stands are more unstable against storms*
	Disease	Mixed stands are more vulnerable to pathogens (insects, fungi, bacteria, etc.)*
	Habitats	Mixed stands provide a greater diversity of habitats
	Bacteria	Mixed stands provide a greater diversity of bacteria
	Fungi	Mixed stands provide a greater diversity of fungi
	Mosses	Mixed stands provide a greater diversity of mosses and lichens
	Plants	Mixed stands provide a greater diversity of flowering plants
	Invertebrates	Mixed stands provide a greater diversity of insects and other invertebrates
	Birds	Mixed stands provide a greater diversity of birds
	Mammals	Mixed stands provide a greater diversity of mammals
	Soil	Soil impoverishment in nutrients is higher in mixed stands*
	Nutrients	In mixed stands, nutrient availability is generally higher
	Browsing	Mixed stands are more vulnerable to game damage*
Regulating	Carbon	Mixed stands store less carbon*
	Air	Mixed stands contribute more to air purification
	Erosion	Mixed stands reduce erosion risks
	Flood	Mixed stands allow a better regulation of water (quantity)
	Water	Pollutant charge (acids, nitrates,…) in waters under mixed stands is higher*
	Fertility	Mixed stands improve soil fertility
Provisioning	Game	Mixed stands maintain higher game populations
	Productivity	Mixed stands are generally less productive*
	Wood quality	Mixed stands allow the production of higher quality wood
	Products	Mixed stands allow the collection of higher quantities of fruit/mushrooms
	Invest	Mixed stands require higher more financial investments*
	Profit	Mixed stands are less profitable*
	Profit-game	In mixed stands, the financial return from hunting is more important
	Profit-wood	In mixed stands, the financial return from wood production is less important*
Cultural	Recreation	Mixed stands offer more recreation opportunities
	Aesthetic	Mixed stands have a higher aesthetic value

[a]Respondents were asked to express their agreement to the listed items on a 5 point Likert scale
*Responses of these items were inversed for data analyses

2.3. Results

2.3.1. Respondent's profile

A total of 267 responses were analyzed, of which 165 were from Wallonia and 102 from Flanders (Table WP1.3). The number of scientists responding in each region was similar, but a higher number of practitioners responded to the questionnaire in Wallonia (117 against 47 in Flanders). Scientists represented 54% of respondents in Flanders, against 29% in Wallonia. For the total sample, scientists represented 39%

and practitioners 61% of the sample population. The age distribution of the respondents differed between the two regions, with a higher mean age in Wallonia, mainly due to the higher age of practitioners.

Table WP1.3: Socio-demographic characteristics of the survey sample for Flanders (n = 102) and Wallonia (n = 165) and the total sample (n = 267).

		Flanders		Wallonia		Total sample	
		%	n	%	n	%	n
Stakeholder	Scientist	54	55	29	48	39	103
	Practitioner	46	47	71	117	61	164
Age structure	20-34 years	45	46	24	40	32	86
	35-49	36	37	27	45	31	82
	50-64	18	18	30	50	25	68
	65-79	1	1	17	28	11	29
	80-94	0	0	1	2	1	2

2.3.2. Perceived importance of management objectives

Lowest importance (mean score ≤ 3.5) was attributed to the management objectives related to maintaining the game population, providing protection against fire, ensuring wood supply to individuals and ensuring the presence of non-woody products (Fig. WP1.2). Highest importance (mean score ≥ 4.3) was attributed to the management objectives related to maintaining the biodiversity of associated species, preserving soil quality, protecting water quality and providing an environment where it is pleasant to live.

There were, however, significant differences (*P* < 0.05) in the importance ascribed to management objectives between regions and between stakeholders (Table WP1.4). In Wallonia, significantly higher importance was assigned to decreasing the risks of storms (STORM in Fig. WP1.2), protection against diseases (DISEASE), fire (FIRE) and erosion (EROSION), and services related to the wood sector such as wood supply (WOOD), wood quality (WOOD QUALITY) and profitability (PROFITABILITY). In Flanders, higher importance was assigned to the protection of biodiversity of associated species (BIODIVERSITY), the presence of non-woody products (PRODUCTS), the diversification of deciduous and coniferous species (DECIDUOUS) and the provisioning of an environment where it is pleasant to live (LIFE).

Compared to practitioners, scientists attributed a higher importance to numerous objectives related to supporting, regulating and provisioning services (Fig. WP1.2). Lower importance was assigned by scientist to decreasing the risks of storms (STORM) (Wallonia only), wood quality (WOOD QUALITY) and profitability (PROFITABILITY).

Multivariate PerMANOVA indicated that the importance of regulating services was thought to be higher by scientists compared to practitioners (Table WP1.4). For the other service classes, the interaction term was significant. Data indicated that less importance was attributed to objectives linked to supporting services by practitioners in Flanders and to objectives linked to cultural services by practitioners in Wallonia. Scientists in Wallonia showed a slightly higher score for management objectives linked to provisioning services.

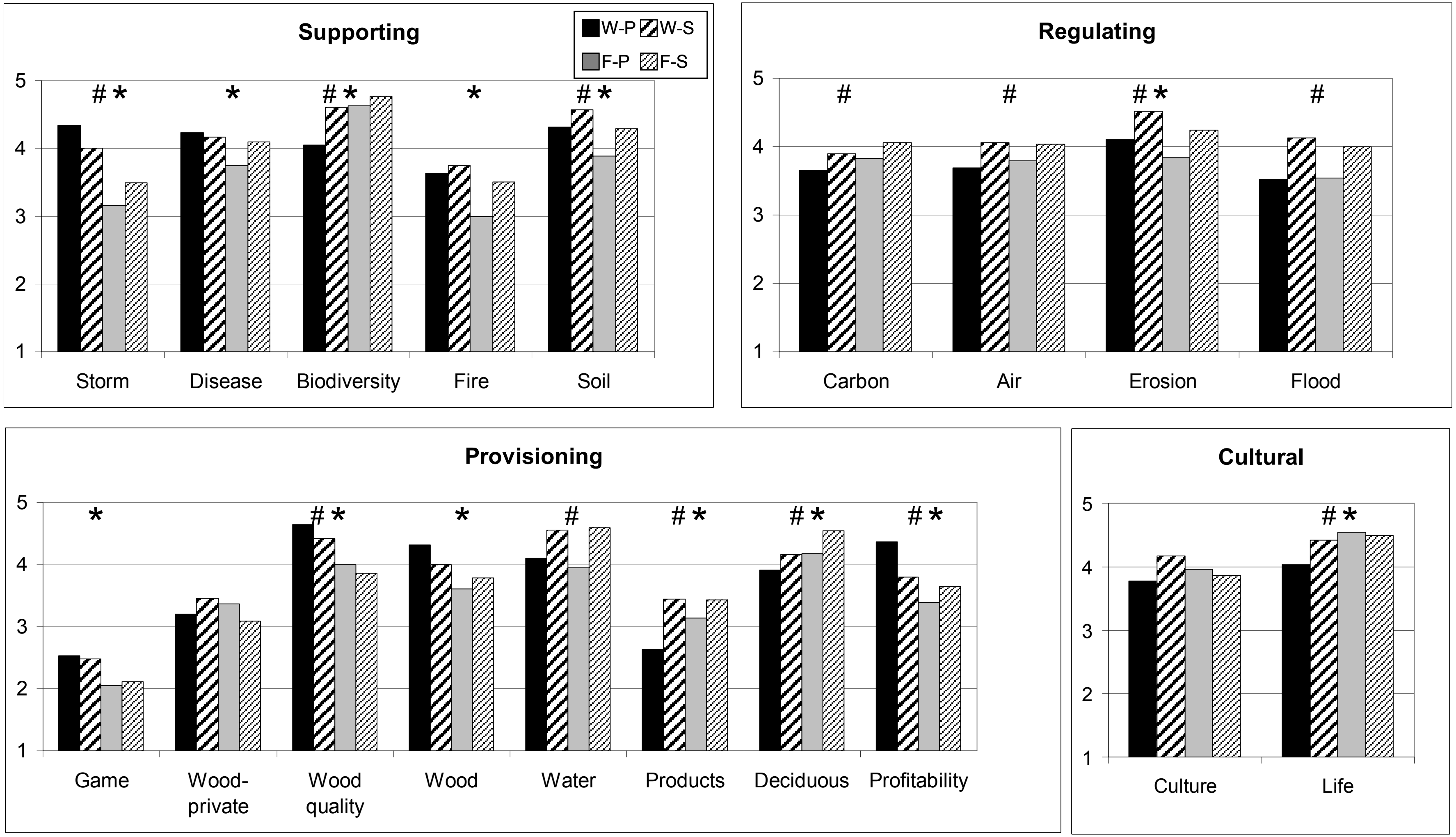


Figure WP1.2*: Survey respondents' importance attributed to management objectives on a 5 point Likert (1 = no importance, 5 = very important). Values are means; W: Wallonia, F: Flanders, P: Practitioners, S: Scientists. #: significant difference between stakeholders; *: significant difference between regions (P < 0.05, PerMANOVA, see Table WP1.4).*

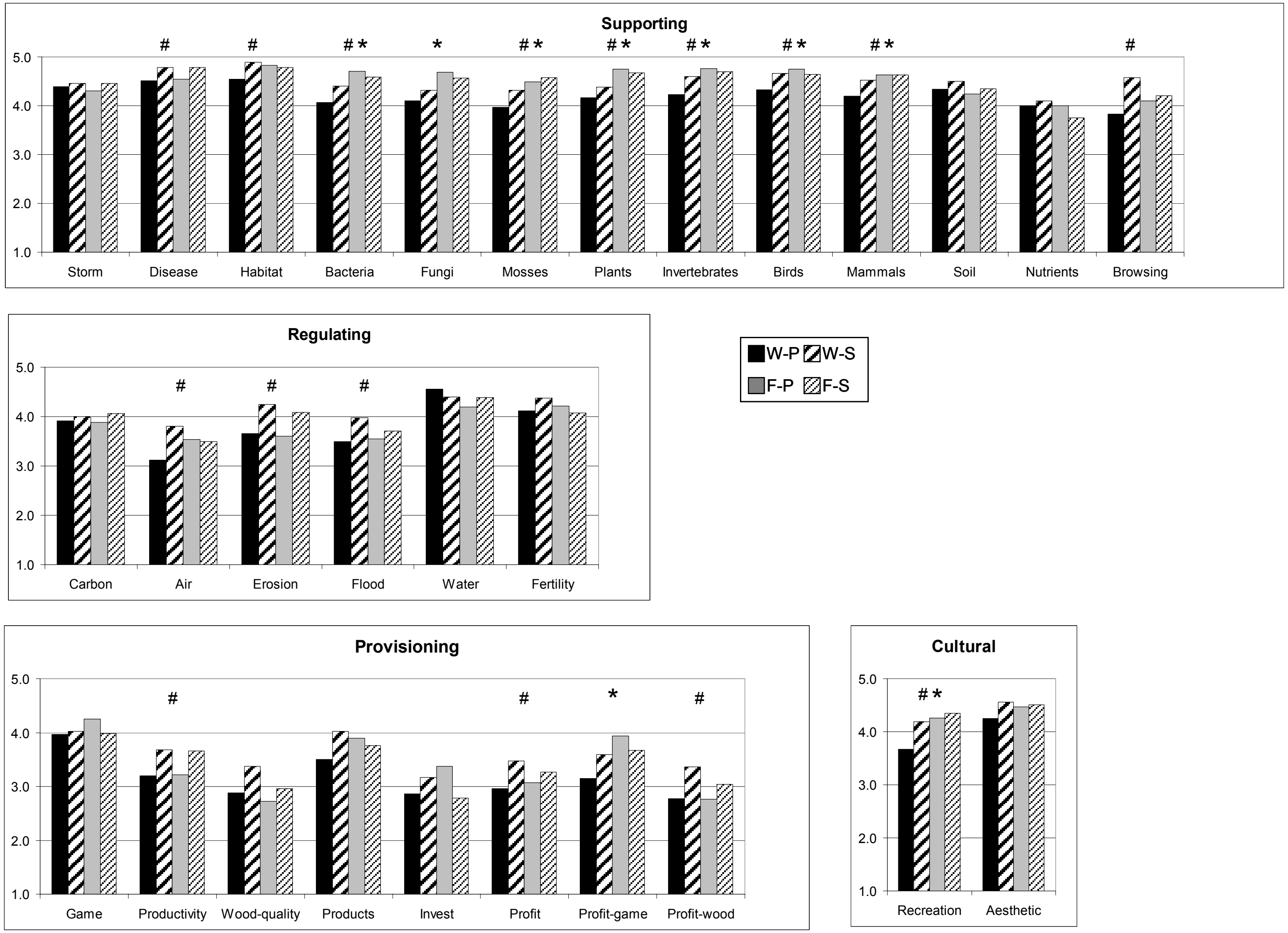


Figure WP1.3: *Survey respondents' perception of ecosystem services in mixed stands, compared to monocultures on a 5 point Likert (1 = totally disagree, 5 = totally agree). Values are means; W: Wallonia, F: Flanders, P: Practitioners, S: Scientists. #: significant difference between stakeholders; *: significant difference between regions (P < 0.05, PerMANOVA, see Table WP1.5).*

Table WP1.4: Results (*P* values) of univariate and multivariate permutational analysis of variance (Per(M)ANOVA) testing differences in response variables between stakeholders and regions on the importance attributed to management objectives. Significant differences ($P < 0.05$) are indicated in bold.

Univariate PerANOVA

Service class	Abbreviation	Stakeholder	Region	Age	Stakeholder x Region
Supporting	Storm	**0.024**	**0.001**	0.274	**0.012**
	Disease	0.768	**0.006**	0.687	0.055
	Biodiversity	**0.001**	**0.001**	0.249	0.054
	Fire	0.199	**0.001**	0.029	0.261
	Soil	**0.038**	**0.004**	0.985	0.543
Regulating	Carbon	**0.044**	0.212	0.736	0.941
	Air	**0.014**	0.701	0.77	0.593
	Erosion	**0.003**	**0.017**	0.312	0.961
	Flood	**0.002**	0.793	0.346	0.662
Provisioning	Game	0.405	**0.004**	0.581	0.753
	Wood-private	0.881	0.613	0.991	0.058
	Wood quality	**0.001**	**0.001**	**0.064**	0.794
	Wood	0.065	**0.001**	0.779	0.063
	Water	**0.001**	0.534	**0.020**	0.278
	Products	**0.001**	**0.046**	0.960	0.073
	Deciduous	**0.001**	**0.004**	0.891	0.621
	Profitability	**0.001**	**0.001**	0.269	**0.001**
Cultural	Culture	0.122	0.799	0.259	**0.028**
	Life	**0.006**	**0.001**	0.884	**0.041**

Mulitivariate PerMANOVA

Service class	Stakeholder	Region	Age	Stakeholder x Region
Supporting	**0.004**	**0.001**	0.242	**0.017**
Regulating	**0.001**	0.259	0.488	0.733
Provisioning	**0.001**	**0.001**	0.350	**0.006**
Cultural	**0.010**	**0.041**	0.425	**0.017**

2.3.3. Perceived ecosystem services in mixed forests compared to monocultures

There was a general agreement that supporting services are higher in mixed stands than in monocultures (Fig. WP1.3) with a mean Likert score generally above 4. Respondents also generally agreed that regulating services were higher in mixed stands. We noted, however, a high percentage of respondents who did not know an answer to some items related to regulating services, particularly for water regulation (FLOOD, 22%), pollutant charge in waters (WATER, 29%), air purification capacity (AIR, 22%) and carbon storage (CARBON, 29%). The opinion related to provisioning services was globally neutral (mean score around 3), except for items related to hunting and non-woody products, which were thought to be higher in mixed stands. Cultural services (aesthetics and recreational/educational opportunities) were also perceived higher in mixed stands.

An analysis of regional differences (univariate PerANOVA) indicated a significantly higher score in Flanders for numerous supporting services related to biodiversity, for financial return from hunting and for recreational opportunities (Fig. WP1.3, Table WP1.5).

A significant difference between stakeholders has been detected for numerous items related to supporting services, indicating that the agreement was lower for practitioners compared to scientists. The difference in the mean score between the two stakeholder groups was generally more pronounced in Wallonia than in Flanders, resulting in a significant interaction term for some items. The agreement for the regulating services of air purification (AIR), erosion risk (EROSION) and water regulation (FLOOD) was higher for scientists than for practitioners. Similarly, the score for provisioning services (productivity, profit and profit from hunting) and one cultural service (recreative opportunities) was higher for scientists compared to practitioners. A high percentage of respondents did not know whether profit from hunting would be different in mixed stands compared to monocultures.

According to multivariate PerMANOVA, the degree of agreement that supporting and cultural services would be higher in mixed stands was lower for practitioners in Wallonia compared to practitioners in Flanders and scientists in both regions. The analysis also indicated a higher score for regulating and provisioning services among scientists compared to practitioners.

2.4. Stakeholder opinions versus scientific literature

Stakeholders generally believe that supporting services related to biodiversity and resistance are higher in mixed stands compared to monocultures. This is globally supported by the scientific literature. However, a recent literature review (Nadrowski *et al*. 2010) stresses that the impact of diversity *per se*, versus the presence of specific tree species, needs to be considered and that no simple assemblage rule can be defined.

Provisioning services are perceived to be lower or equal in mixed stands, which is not entirely in line with data from the literature reporting lower, equal, and higher productivity in mixed stands compared to monocultures. The discrepancies in the literature may be explained by numerous confounding factors, differing between the studies and sites investigated, so that the attribution of an effect on productivity to one specific factor is difficult. After reviewing 21 studies (excluding studies with confounding factors) Thompson *et al*. (2009) have recently concluded that diversity generally increases the productivity of forests. However, it should be stressed that for the provisioning services diversity *per se* seems less important than the identity of the species in the mixtures. Financial return is clearly thought to be equal or lower in mixed stands compared to monocultures. However, the study of Knoke *et al.* (2005) indicated that mixed forests can have an economic advantage if the problem is analysed from the perspective of a risk-averse decision.

Higher carbon storage is clearly thought to be occurring in mixed stands, which is in clear contrast with the scientific literature, where data are basically lacking.

Table WP1.5: Results (*P* values) of univariate and multivariate permutational analysis of variance (Per(M)ANOVA) testing differences in response variables between stakeholders and regions on perception of ecosystem services in mixed stands compared to monocultures. Significant differences ($P < 0.05$) are indicated in bold.

Univariate PerANOVA

Service class	Abbreviation	Stakeholder	Region	Age	Stakeholder x Region
Supporting	Storm	0.445	0.689	0.944	0.732
	Disease	**0.001**	0.856	0.225	0.895
	Habitat	**0.009**	0.159	0.470	**0.018**
	Bacteria	**0.036**	**0.001**	0.064	0.054
	Fungi	0.116	**0.001**	0.806	0.100
	Mosses	**0.005**	**0.001**	**0.032**	0.419
	Plants	**0.048**	**0.001**	0.229	0.172
	Invertebrates	**0.006**	**0.001**	0.067	**0.033**
	Birds	**0.033**	**0.020**	0.254	**0.018**
	Mammals	**0.009**	**0.003**	0.800	0.130
	Soil	0.340	0.254	0.759	0.861
	Nutrients	0.542	0.283	**0.047**	0.293
	Browsing	**0.001**	0.942	0.180	**0.029**
Regulating	Carbon	0.412	0.905	0.445	0.837
	Air	**0.019**	0.479	**0.016**	**0.070**
	Erosion	**0.001**	0.484	0.203	0.888
	Flood	**0.018**	0.529	**0.032**	0.450
	Water	0.459	0.054	0.362	0.136
	Fertility	0.474	0.520	0.104	0.112
Provisioning	Game	0.688	0.235	0.579	0.196
	Productivity	**0.002**	1.000	0.056	0.938
	Wood quality	0.058	0.111	0.09	0.537
	Products	0.059	0.426	0.364	**0.035**
	Invest	0.774	0.512	0.072	**0.025**
	Profit	**0.013**	0.900	**0.010**	0.462
	Profit-game	0.098	**0.005**	0.685	**0.048**
	Profit-wood	**0.009**	0.386	**0.012**	0.475
Cultural	Recreation	**0.003**	**0.009**	0.845	0.120
	Aesthetic	0.057	0.406	0.076	0.348

Mulitivariate PerMANOVA

Service class	Stakeholder	Region	Age	Stakeholder x Region
Supporting	**0.004**	**0.001**	0.111	**0.017**
Regulating	**0.011**	0.999	0.125	0.067
Provisioning	**0.012**	1.000	0.056	0.191
Cultural	**0.005**	**0.006**	0.300	0.183

2.5. Conclusion

In our enquiry, supporting, regulating, cultural services and one provisioning service (hunting) were perceived to be higher in mixed stands, compared to monocultures. Provisioning services were perceived to be equal or lower compared to monocultures. A high percentage of respondents expressed that they did not know about regulating services in mixed vs monospecific forest stands.

Regional differences indicated a significantly higher score in Flanders for numerous supporting services related to biodiversity, for financial return from hunting and for recreational opportunities.

Practitioners in Wallonia generally scored lower than scientists. In particular, they were not convinced of the economic advantages of mixed stands. The limited number of available research results so far indicate that the financial return of mixed forests may, in the long-term, be higher. However, more results based on realistic situations must be generated to create a more definite answer on the profitability of mixed versus monoculture stands.

In general, the comparison with the scientific literature highlighted the lack of specific information on forest ecosystem services in mixed forests compared to monocultures, in particular from studies where confounding factors can be eliminated or accounted for. This is in contrast with the quite strong opinions that many stakeholders have on the functioning of mixed vs monoculture stands.

Task WP1.2 Follow-up committee meetings

The members that agreed to participate in the Follow-Up Committee are given in Table WP1.6.

Table WP1.6: Overview of the organizations that agreed to participate in the Follow-Up Committee and their attendance at the two meetings.

Organisation	*Representative*	*Present Oct '08?*	*Present June '09?*
Pro Sylva Wallonie	Michel Letocart	No	No
BIM	Stéphane Vanwijnsberghe	No	No
FEDEMAR	François De Meersman	Yes	No
Pro Sylva Vlaanderen	Guy Geudens	No	Yes
Forêt Wallone	François Baar / Delphine Arnal	Yes	No
ANB	Carl De Schepper / Wim Buysse	No	Yes
Bosgroepen	Wim De Maeyer	Yes	No
Landelijk Vlaanderen & KBBM	Tom Anthonis	Yes	No

Two Follow-Up Committee meetings have taken place (on 3 October 2008 and 9 June 2009). The contributions of the Follow-Up Committee were the following: (1) At the meeting in 2008 valuable input has been given on the contents of the questionnaire and on the most appropriate way to distribute it to the different stakeholders; (2) At the meeting in 2009 only two stakeholders were present but nevertheless they provided valuable input on the interpretation of the questionnaire results and on the way the results could be distributed to a larger audience. The minutes of the Follow-Up Committee meetings can be found in Annexes 2.1-2.2.

Since the focus during the later phases of the FORBIO project shifted towards the design and establishment of the experiments it was decided to enlarge the Follow-Up Committee by organizing a workshop with scientists involved in tree diversity experiments worldwide. The workshop took place in Ghent on 24 November 2009. The benefit for the FORBIO project has been twofold: (1) bringing the world's top-class specialists to Belgium to discuss about tree diversity experiments allowed to fine tune the experimental design and to receive info on the do's and don'ts when establishing such experiments; (2) the second major benefit was that the workshop allowed to integrate FORBIO in the (informal) network called TreeDivNet which brings together all large-scaled tree diversity experiments worldwide (Fig. WP1.4). The workshop was a big success. Twenty four persons attended the workshop, representatives of all experimental sites were present and several follow-up actions were identified. The minutes of the workshop can be found in Annex 2.3.

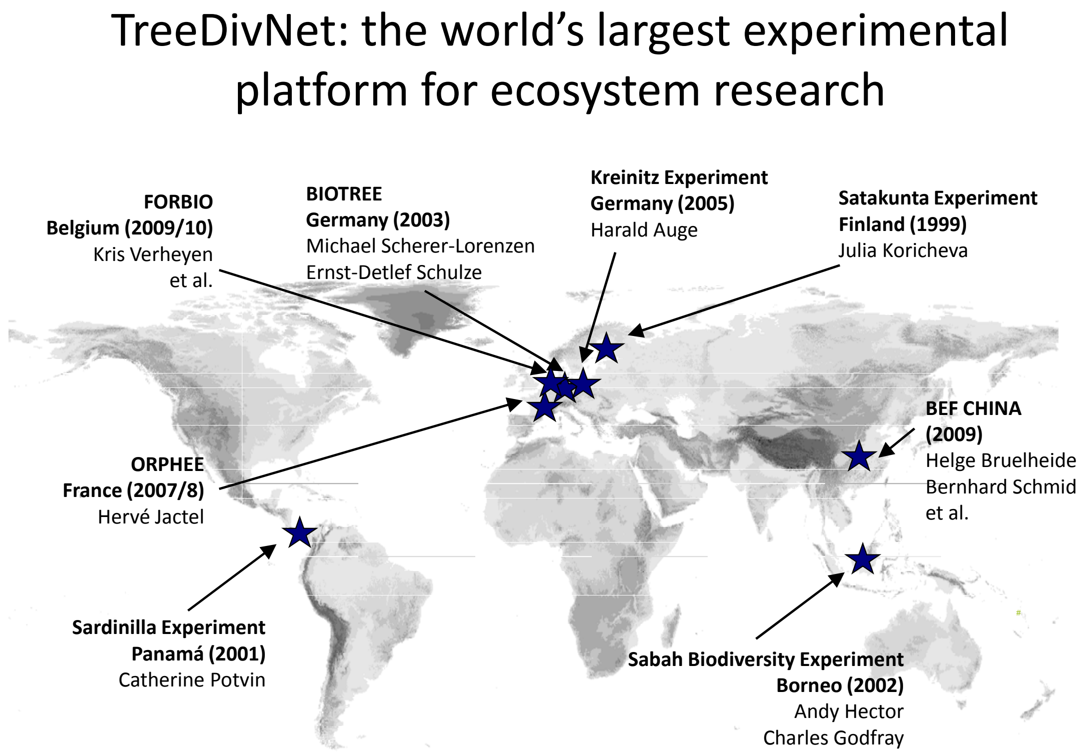


Figure WP1.4*: Map showing the locations of the tree diversity experiments that participate in TreeDivNet. Together these experiments make the world's largest experimental platform for ecosystem research.*

Task WP1.3 Conference

The white paper and questionnaire results will be presented at a one-day conference on 4 February 2011 in Wépion (announcement and program can be found in Annex 3). The targeted audience for the conference are forest owners, forest managers, scientists, policy makers and the forest exploitation and wood industry sector. The conference is organized by the FORBIO team, DGO 3 and Forêt Wallone with Pro Silva Wallonie, SRFB and UVCW as partners. The conference is financed by DNF and no admission fee will be asked.

Task WP1.4 Website

A website (http://forbio.biodiversity.be) has been developed as a national and international showcase of the project and a tool for the dissemination of results. The site is placed under the umbrella of the Belgian Forum on Forest Biodiversity (Belgian Biodiversity Plaform) as contents and target audience are rather similar and potential synergies are numerous. Early 2011, a major update of the website is scheduled as the site will in the future also serve as the portal for the TreeDivNet. Responsibility for this update will be taken by Kris Verheyen (UGent).

WP 2: Design and establishment of a tree diversity experiment

The aim of this WP is to establish a highly innovative, large-scaled tree diversity experiment to evaluate the impact of increasing tree diversity on forest ecosystem functioning. This experimental platform will provide a highly innovative research facility for national and international scientists from a wide range of disciplines, with the purpose of deepening the understanding of the mechanisms behind diversity-ecosystem functioning relationships in forests. Furthermore, the FORBIO experiment will be integrated in TreeDivNet, the world's largest experimental platform for ecosystem research (cf. Task WP1.2). The TreeDivNet-experiments will allow to quantify, for a wide range of forest ecosystem functions and services, their individual and joint relationships with tree diversity. Within this larger framework, the FORBIO-experiment will enable to establish these relationships for tree species and forest communities particularly relevant for Belgium.

Task WP2.1 Experimental design

Based on the guidelines by Sherer-Lorenzen *et al*. (2005), we opted for a 'classical' synthetic community approach and not for an omission or addition approach for our tree biodiversity experiment. In such a synthetic community approach monocultures and increasingly species rich mixtures will be planted on an environmentally homogeneous site. All species combinations should occur and at least one (blocked) replication is needed.

To gain a better insight in the appropriate statistical design, two study visits have taken place:
(1) In early July 2008 five members of the FORBIO team (B. Muys, Q. Ponette, K. Vandekerkhove, K. Ceunen and K. Verheyen) have visited the BIOTREE experiment (www.biotree.bgc-jena.mpg.de/index.html) in Thuringia, Germany. Locally, this excursion was lead by Dr. Detlef Schulze, former director of the Max-Planck Institute in Jena.
(2) In September 2008, K. Verheyen visited Dr. Michael Scherer-Lorenzen (then at ETH), Dr. Andy Hector and Dr. Bernhard Schmidt (both at the University of Zurich) in Zurich to further discuss the details of the experimental set-up.

Finally, the following experimental design has been fixed:
- Species pool of five site-adapted, functionally dissimilar species (*Betula pendula, Tilia cordata, Fagus sylvatica, Quercus robur* and *Pinus sylvestris* in Flanders; *Fagus sylvatica, Quercus petraea, Acer pseudoplatanus, Larix* x *eurolepis* and *Pseudotsuga menziesii* in Wallonia);
- Four diversity levels (1, 2, 3 and 4 tree species), five plots per diversity level and one replication -> 4x5x2 = 40 plots;
- All five species have similar frequencies (20/40) and all two-species combinations have similar frequencies as well (10/40)

To assure a sufficiently high functional dissimilarity between the selected tree species, Euclidean distance-based Functional Attribute Diversity (FAD) as proposed by Walker *et al*. (1999) was calculated for all possible five species combinations of a pool of 13 common tree species in Belgium (*Acer pseudoplatanus, Betula pendula,* *Carpinus betulus, Fagus sylvatica, Fraxinus excelsior, Larix decidua, Pinus sylvestris, Populus tremula, Prunus avium, Pseudotsuga menziesii, Quercus petraea, Tilia cordata and Ulmus glabra*) using data on eight functional traits (leaf phenology, height growth rate, root architecture, root growth rate, crown volume, shade tolerance, litter carbon to nitrogen (C/N) ratio and stand volume growth). Trait data were obtained from Dr. Michael Scherer-Lorenzen and are similar to the traits used by Scherer-Lorenzen *et al.* (2007), although some litter C/N values were changed by K. Verheyen. The resulting FAD distribution was bell shaped (Fig. WP2.1) with a mean of 143. The FAD of the selected species pools was 160 in Flanders and 113 in Wallonia, which is clearly above and below the mean, respectively. It should be noted, though, that site-suitability of the selected tree species was considered more important than functional dissimilarity as the latter criterion is, among other, highly dependent on the selected traits.

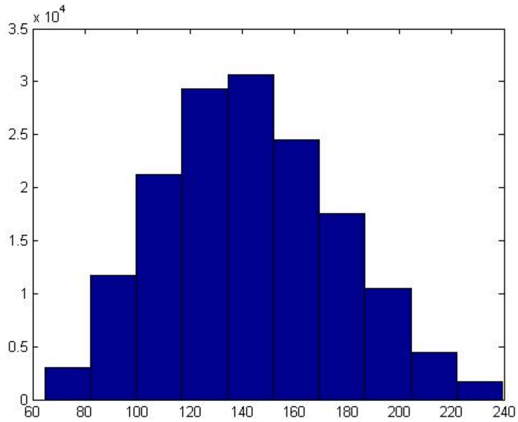


Figure WP2.1*: Frequency distribution of the Functional Attribute Diversity (FAD) of the 1287 possible five-species combinations selected from a pool of 13 tree species. The Euclidean distance-based FAD was calculated using eight different traits.*

Finally, a genetic diversity component has been incorporated in the design as well. This has been achieved by using an equal mixture of three different provenances of one species (oak in Flanders and beech in Wallonia) in one series of 20 plots and by using only a single provenance in the other series of 20 plots. Two monoculture blocks of the two additional provenances have been added so that the total number of plots in Flanders and Wallonia is 42[2].

Related EML-files in Data_Archive_ExpSites, folder Experimental design[3]:
- Experimental_Design_Gedinne_2008_EML.xls
- Experimental_Design_Gedinne_tree_maps_v080111_EML.xls
- Experimental_Design_Zedelgem_2008_EML.xls
- Experimental_Design_Zedelgem_tree_maps_v220610_EML.xls

[2] Given a surplus of trees in Wallonia, 44 plots were planted; see Task WP2.4.

[3] All data related to the experimental sites have been archived following an Ecological Metadata Language (EML) standard provided by Dr. Karin Nadrowski (Leipzig University, Germany). More info on EML can be found in Fegraus *et al*. (2005)

Task WP2.2 Site selection

Two sites have been selected to establish the experiment: one in Flanders (Zedelgem) and one in Wallonia (Gedinne). An overview of the general site characteristics is given in Table WP2.1 and Fig. WP2.2 and WP2.3.

Table WP2.1: Overview of the general characteristics of the sites selected for the tree biodiversity experiment.

Characteristics	Zedelgem (Flanders)	Gedinne (Wallonia)
Local name	Vloethemveld	Gribelle & Gouverneur
Size	~9.5 ha	2 x ~4.5 ha
Altitude (m a.s.l.)	11-16 m	421-426 m (Gouverneur) & 367-376 m (Gribelle)
Soil type (Belgian Soil Map)	Relatively dry sandy soil (Zbh) to moderately wet loamy sand soil (SdP)	Moderately dry stony loam soils (Gbb; both sites)
Former land-use	Agriculture (mainly arable)	Forest (spruce plantation)
Owner	Flemish Region	Town of Gedinne
Local manager	Agentschap Natuur en Bos (ANB)	Division de la Nature et des Forêts (DNF)

The site managers (ANB in Flanders and DNF in Wallonia) both have given their full support and have guaranteed that both sites can be used for scientific research in the long-run. A formal agreement between the site owners/managers and the FORBIO team still needs to be established, though.

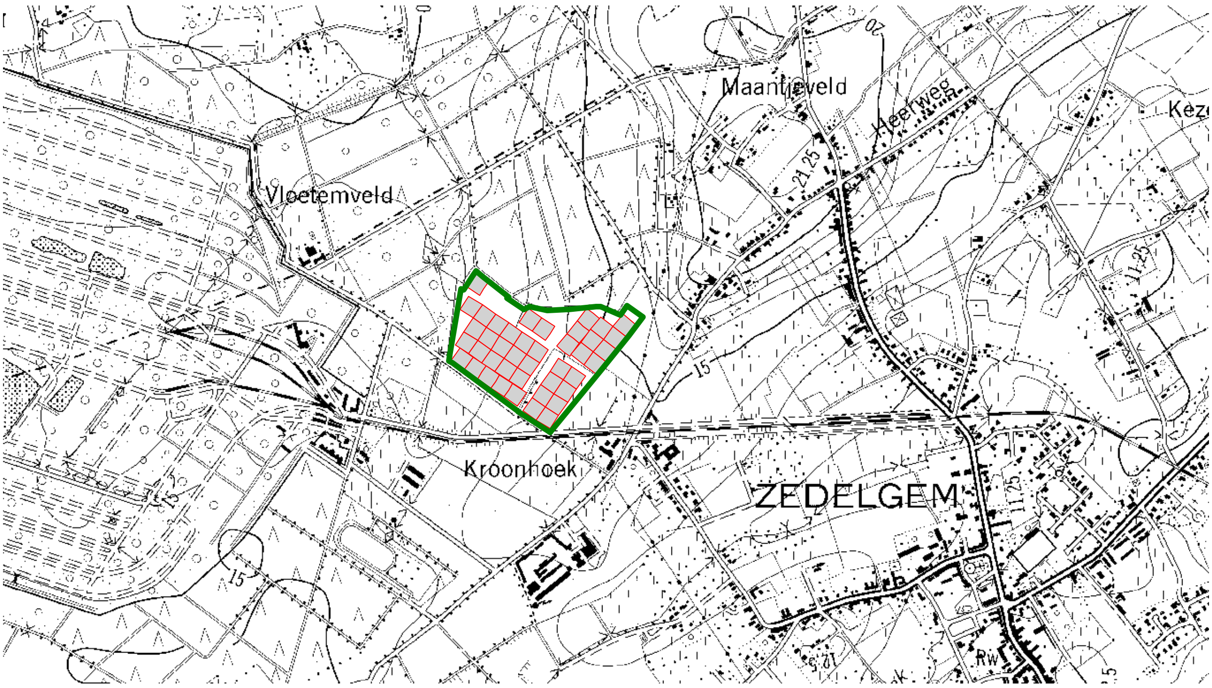


***Figure WP2.2**: Map with the location of the experiment in Flanders, Zedelgem (scale is ~1:10 000).*

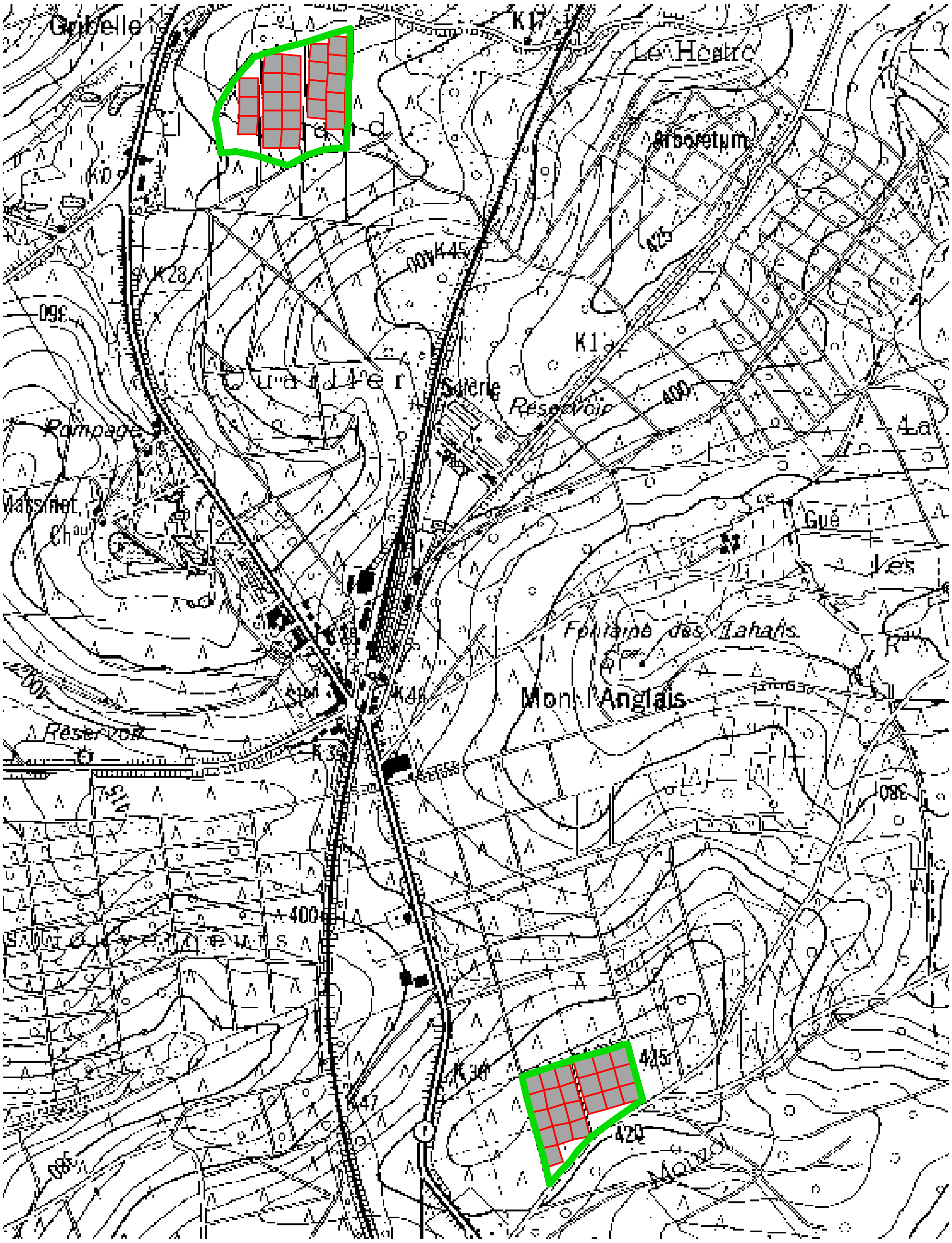


***Figure WP2.3**: Map with the location of the two experimental sites in Wallonia, Gedinne. Gribelle is the northern site, Gouverneur the southern one (scale is ~1:15 000).*

Task WP2.3 Site characterization

Before planting, both experimental sites have been characterized in detail. The site characterization consisted of an extensive survey of the soil characteristics across the sites combined with detailed soil profile descriptions in soil pits (only in Zedelgem)[4].

The protocol for the survey is summarized in Table WP2.2 and a map with the survey locations is given in Fig. WP2.4 and WP2.5. At each sampling point, samples were taken with a ~3 cm diameter gouge auger on five spots: at the sampling point and at 0.5 m distance in all four cardinal directions. For each soil depth, the samples were pooled for chemical analysis.

Table WP2.2: Overview of the soil survey protocols in Zedelgem and Gedinne.

	Zedelgem (Flanders)	**Gedinne (Wallonia)**
Timing of sampling	June-July 2009	October 2009
# sampling locations	156	54 (Gribelle) & 54 (Gouverneur)
Sampling depths	0-10 cm and 10-20 cm	0-20 cm and 20-40 cm
Soil profile description	0-60 cm. Depth and color of plough layer, depth and color of other horizons	0-60 cm. Depth and color of horizons; qualitative measure of penetration resistance of auger
Chemical characteristics*	pH(H_2O), pH(KCl), P_{tot} (mg kg^{-1}), N_{tot} (%), C (%)	pH(H_20), pH(KCl), P_{tot} (mg kg^{-1}), N_{tot} (%), C (%)

* Soil samples were dried for 48 h at 40 °C before sieving over a 2 mm mesh. The pH was measured using a glass electrode (Orion, model 920A) after extracting 14 ml soil in a 70 ml H_2O or KCl (1 M) solution, respectively. Total P concentration was determined according to the colorimetric method of Scheel (1936) with molybdenum vanadate as color reagent after acid wet digestion ($HClO_4$:HNO_3 in a 1:5 ratio). Carbon and nitrogen concentrations were determined by elemental analysis (Variomax CNS, Germany).

[4] In Gedinne (Gribelle) a field visit with Quentin Ponette and the eminent soil expert Frantz Weissen occurred in February 2009. This visit confirmed that the Gribelle site was probably an ancient forest and that the codes used on the Belgian Soil Map were more or less correct.

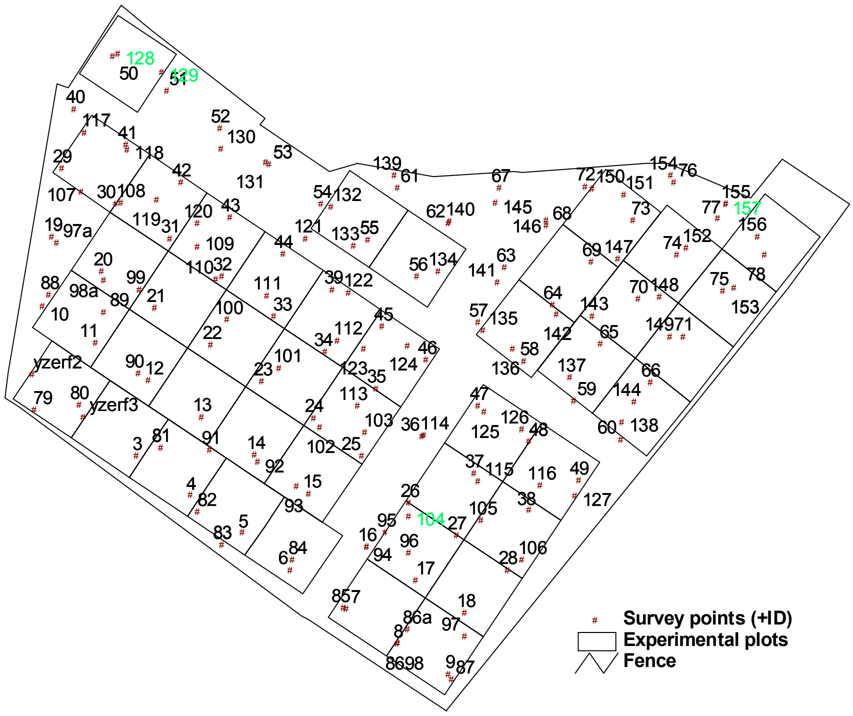
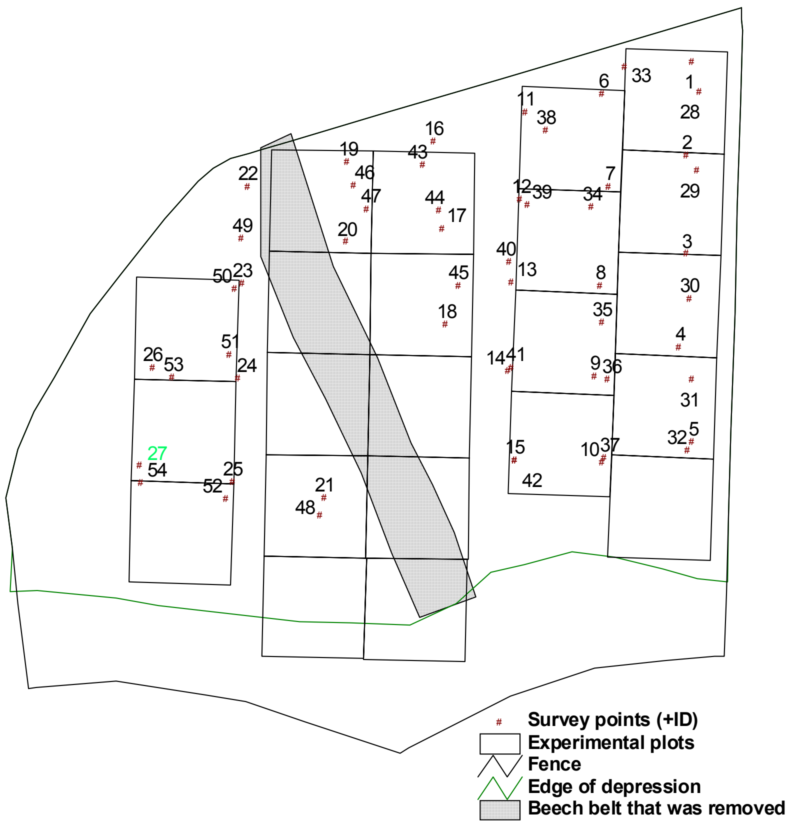


***Figure WP2.4**: Location of the 156 soil survey points in Zedelgem.*



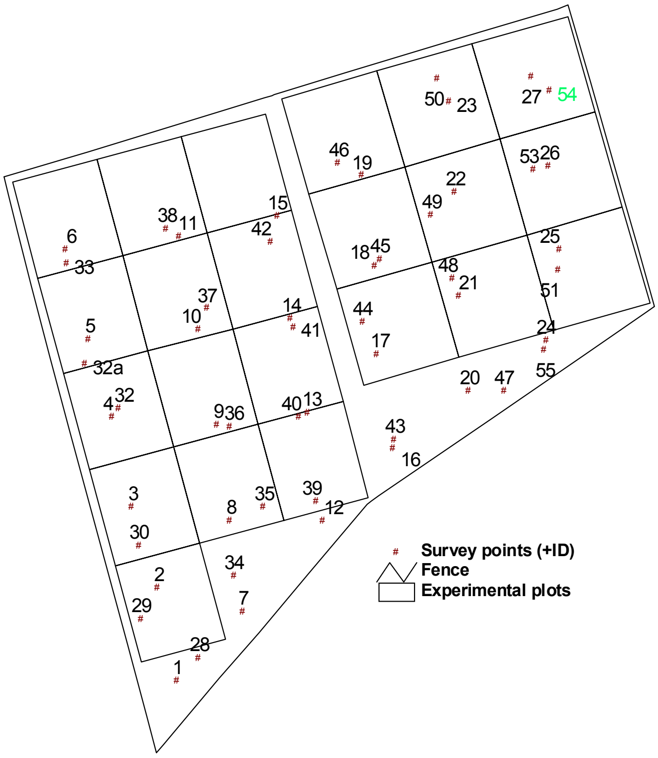


***Figure WP2.5**: Location of the 2 x 54 soil survey points at Gribelle (Gedinne; top panel) and Gouverneur (Gedinne; lower panel)*

In Zedelgem, four soil profile pits were dug along the (small) altitudinal gradient that is present on the site (Fig. WP2.6). The two pits located at the extremes of this gradient (no 1 and 2) were described in detail with the assistance of Dr. Geert Baert (HoGent) in August 2009. Additionally, samples were taken from five depths to determine the bulk density, soil texture and a number of chemical soil characteristics (pH(H_2O), pH(KCl), P_{tot} and bio-available P, K, Ca, Mg, Na and Al). For the chemical analysis, soil samples were dried for 48 h at 40 °C before sieving over a 2 mm mesh. The pH was measured using a glass electrode (Orion, model 920A) after extracting 14 ml soil in a 70 ml H_2O or KCl (1 M) solution, respectively. Total P concentration was determined according to the colorimetric method of Scheel (1936) with molybdenum vanadate as color reagent after acid wet digestion ($HClO_4$:HNO_3 in a 1:5 ratio). Soil samples were further analysed for NH_4-Acetate-EDTA extractable P and cations (extraction: 10 g dry soil shaken for 30 minutes in 50 ml NH_4-Acetate-EDTA solution: 192.5 g NH_4Acetate + 50 ml acetic acid + 29. 225 g EDTA diluted to 2 l). P concentrations were again determined according to the method of Scheel (1936), cation concentrations were analysed using Atomic Absorption Spectrophotometry (VARIAN AA220).

***Figure WP2.5**: Location of the four soil pits that were dug at the Zedelgem site with the location of the experimental plots plotted on top.*

The height above sea level in Zedelgem ranges from 11.5 m in the western part to 15.5 m in the eastern part (Table WP2.3). The altitude further decreases westwards in the direction of the Vloethemveld depression. The depth of the Ap horizon (plough layer) is on average 23 cm but is quite variable. Soil pH is still relatively high due to the former agricultural land-use. For the same reason, total P stocks are high as well. The C and N concentrations were relatively variable. The average C concentration (1.36%) is lower than the target concentration for arable land (1.8-2.8% according to the Soil Service of Belgium (Bodemkundige Dienst van België). Pearson correlation coefficients between the C concentrations in the 0-10 cm and the 10-20 cm soil layers were always very high ($r_{pearson} > 0.89$). Hence, below we will only focus on the 0-10 cm layer.

Table WP2.3: Overview of the site and soil characteristics in Zedelgem with n = number of observations and CV = Coefficient of Variation. See Table WP2.2 for more details about the soil variables.

Soil variable	**N**	**Mean**	**CV (%)**	**Min.**	**Max.**
Height above sea level (m)	160	13.38	7.77	11.48	15.48
Plough layer depth (cm)	156	35.96	23.14	17.00	60.00
0-10 cm soil layer					
$pH(H_2O)$	156	6.22	3.75	5.28	6.80
pH(KCl)	156	5.08	6.92	4.31	6.59
P_{tot} (mg kg^{-1})	156	1111	15.75	613	1732
N (%)	152	0.10	25.92	0.07	0.17
C (%)	152	1.36	24.46	0.84	2.12
C/N	152	13.51	12.02	10.94	18.71
10-20 cm soil layer					
$pH(H_2O)$	156	6.22	3.81	5.54	6.75
pH(KCl)	156	5.07	6.71	4.29	5.95
P_{tot} (mg kg^{-1})	156	1132	15.76	610	1753
N (%)	152	0.10	23.28	0.07	0.16
C (%)	152	1.35	23.45	0.85	1.99
C/N	152	13.41	12.34	10.45	17.56

Some patterns emerge when the spatial distribution of the soil variables is mapped (Fig. WP2.6-WP2.9). The depth of the plough layer seems somewhat larger at the higher, eastern part of the site (Fig. WP2.6). This is confirmed by the significant correlation between the height above the sea level and the plough layer depth ($r_{pearson}$ = 0.28, P = 0.001, n = 156). A similar trend exists for pH(KCl) (Fig. WP2.7; $r_{pearson}$ = 0.34, P < 0.001, n = 156) and for the C concentration in particular (Fig. WP 2.8; $r_{pearson}$ = 0.60, P < 0.001, n = 152). The total P concentration exhibits a different pattern (Fig WP2.9): the lowest concentration is found in the southeastern part of the site which has had a different land-use history than the rest of the sites. The southeastern part has been a grassland for a long period of time and was probably less heavily fertilized. The preliminary soil survey has thus proved very useful as it has uncovered some important gradients in the site which should be taken into account when attributing the treatments to the 42 experimental blocks (see Task WP2.4).

***Figure WP2.6**: Depth of the plough layer at the Zedelgem site with the location of the experimental plots plotted on top.*

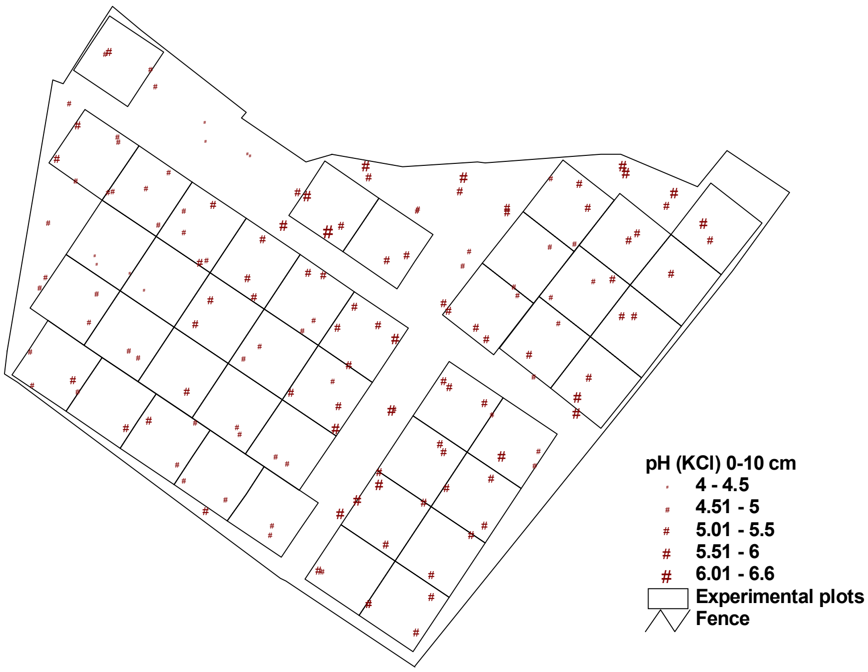


***Figure WP2.7**: pH(KCl) of the 0-10 cm soil layer at the Zedelgem site with the location of the experimental plots plotted on top.*

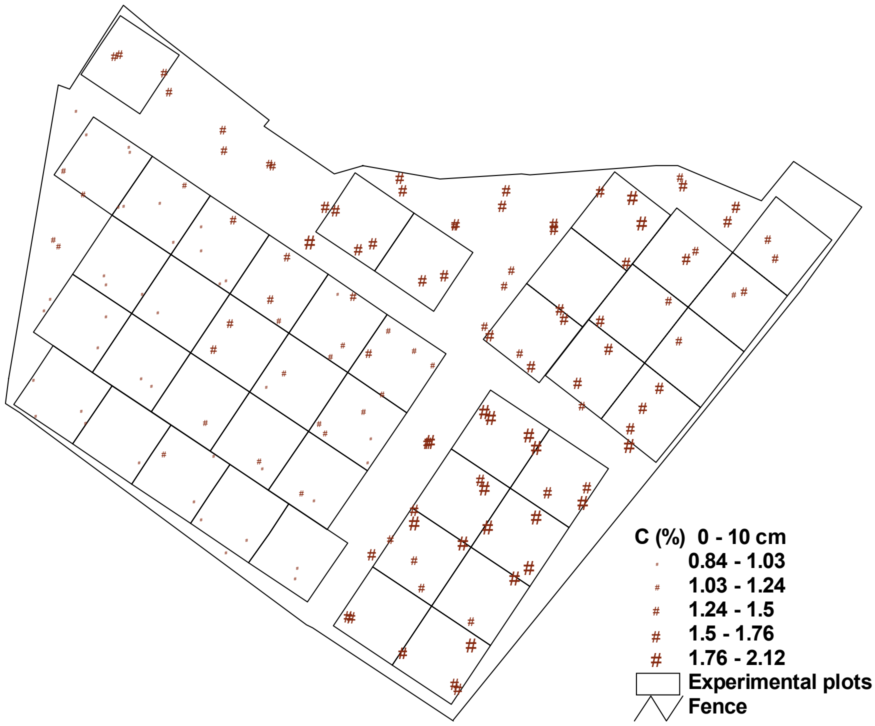


Figure WP2.8: *C concentration of the 0-10 cm soil layer at the Zedelgem site with the location of the experimental plots plotted on top.*

Figure WP2.9*: Total P concentration of the 0-10 cm soil layer at the Zedelgem site with the location of the experimental plots plotted on top.*

The soil pit descriptions largely corroborated the results of the soil survey and matched well with the classification given by the Belgian Soil Map. Soil pit no 1 (Table WP2.4 and Fig. WP2.10a) was located at the lower end of the altitudinal gradient and exhibits a typical A-C profile, i.e. a soil that lacks clear horizon development due to the limited downward water movement as a result of the high (winter) water table. The pH clearly increases with depth. The bulk density (BD) of the soil is high and although this cannot be derived from the BD measurements, a compact layer was present at the bottom of the A horizon. The texture is sandy, but a considerable silt fraction (~15%) is present. Elevated bio-available and total P concentrations are confined to the A horizon. Soil pit no 2 (Table WP2.4 and Fig. WP2.10b) was located at the higher end of the altitudinal gradient and exhibits a A-B-C profile due to the fact that downward water movement frequently occurs at this location. In soil pit no 2 a so-called post-podzol or degraded humic/iron B horizon is present. This horizon is characterized by the occurrence of disjunct spots of organic matter in the B horizon. The BD of the soil is lower than in pit no 1, but also here a compact layer was present at the bottom of the A horizon. The pH of the deeper horizons is lower than in pit nr 1 and does not increase with depth. Elevated bio-available and total P concentrations are also confined to the A horizon. The texture is sandy and the silt % is clearly lower than in pit no 1.

Table WP2.4: Overview of the characteristics of the two soil pits (see Fig. WP2.5 for the exact location) that were described in detail. See text for more details on the analytical procedures.

Pit ID	Horizon	Depth (cm)	Sampling depth (cm)[$]	Dry BD (kg/m³)*	pH(H_2O)	pH(KCl)	Pbio-av (mg/kg)	Ptot (mg/kg)	K (mg/kg)	Na (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	Al (mg/kg)	Clay (%)	Clay/silt (%)	Silt (%)	Silt/Sand (%)	Sand (%)
1	Ap	0-26	5-10	1393	6.46	5.26	125.09	1172	81.23	12.87	95.41	891.2	<1.5	1.99	2.38	15.2	4.83	75.6
	Ap	0-26	20-25	1574	-	-	-	-	-	-	-	-	-	1.83	2.09	13.7	4.82	77.6
	C	26-63	32-37	1698	7.10	5.58	10.29	235	135.85	11.25	160.3	679.2	<1.5	1.96	2.3	15.7	5.73	74.3
	C	26-63	53-58	1641	7.29	5.24	1.48	86.9	113.17	2.57	132.09	385.8	<1.5	1.52	2.03	6.93	1.76	87.8
	Cg1	63-100	80-85	1596	7.38	5.75	0.72	261	81.31	5.17	83.25	605.3	<1.5	2.27	2.8	15.5	4.42	75
	Cg2	>100	110-115	1641	7.81	5.69	1.92	177	45.01	8.25	79.52	834.1	<1.5	2.12	3.08	16.8	6.2	71.8
2	Ap	0-38	5-10	1210	6.48	5.03	44.79	1171	163.72	6.64	102.87	567.6	3	1.56	1.91	11	3.36	82.1
	Ap	0-38	27-32	1352	6.39	5.04	46.47	1221	95.27	2.24	85.1	664.4	5	1.66	2.13	10.9	3.15	82.2
	Bhir	38-70	43-48	1253	6.34	4.71	0.97	154	91.36	1.36	41.37	410.9	38	1.49	1.42	9.04	3.14	84.9
	Bhir	38-70	58-63	1397	6.33	4.76	0.28	109	57.49	1.36	26.5	184	12	1.64	1.48	4.86	1.33	90.7
	C	>70	87-93	1601	6.49	4.80	0.39	43.7	60.83	2.3	51.11	187.3	<1.5	1.32	1.14	3.29	1.58	92.7

[$]: depth at which the soil samples were taken; *: Dry Bulk Density

a) Zedelgem soil pit no 1 (classified as Sdp) **b) Zedelgem soil pit no 2 (classified as Zbh)**

***Figure WP2.10**: Pictures of two soil points that were dug at the Zedelgem site in the summer of 2009 (see Fig. WP2.5 for the exact location).*

Table WP2.5 gives an overview of the site characteristics at the Gedinne sites. The height above sea level of the Gouverneur site at Gedinne ranges from 421 to 427 m. The Gribelle sites is situated ~50 m lower and the altitude ranges from 367 to 376 m. The depth of the A_h horizon is ~18 cm and comparable between both sites. However, the A_h depths are quite variable. Soils are acidic but the pH is significantly higher at the Gribelle site. The same holds for the total P concentration. The variability of the total P concentration is higher at the Gouverneur site. The C and N concentrations are variable at both sites but do not differ significantly. The relatively high C concentrations are probably related to the ancient forest land-use on both sites. The C/N ratio is significantly lower at the Gribelle site. At both sites, the pH is slightly higher and the C concentration and C/N ratio are lower in the 20-40 cm layer. Interestingly, the correlations between the values of the 0-20 cm and 20-40 cm layers were much lower than at the Zedelgem site. Significant correlations were found for pH(H2O) ($r_{pearson}$ = 0.52), pH(KCl) (r = 0.42), P_{tot} (r = 0.78) and C/N (r = 0.47). However, C- and N-concentrations were not significantly correlated (r = 0.08). The low correlations are explained by the fact that in Zedelgem all samples were taken in the deep A_p-horizon, whereas different horizons were sampled in the shallow versus deep samples in Gedinne.

At the Gribelle site, some patterns emerge when the spatial distribution of the soil variables is mapped which is mainly due to correlations with the height above the sea level. At Gribelle, the height gradually decreases from the northeastern towards the southwestern corner. The pH(H_2O) and pH(KCl) in the 0-20 cm layer is higher at higher elevations ($r_{pearson}$ = 0.54, $p < 0.001$, n = 54 and r = 0.41, p = 0.002, n = 54, respectively), whereas the P_{tot}, N- and C-concentrations and the C/N ratio in the 0-20 cm layer decrease with increasing altitude (r = -0.31, p = 0.024, n = 54; r = -0.28, p = 0.043, n = 54; r = -0.34, p = 0.013, n = 54 and r = -0.33, p = 0.016, n = 54, respectively).

Less pronounced spatial patterns are present at the Gouverneur site. Here, only the C/N ratio of the 0-20 cm layer is correlated with the height above the sea level (r = -0.37, p = 0.006, n = 53) and P_{tot} concentrations are somewhat lower in the northeastern part of the site.

Table WP2.5: Overview of the site and soil characteristics at the two Gedinne sites (Gouverneur and Gribelle) with n = number of observations per site and CV = Coefficient of Variation. See Table WP2.2 for more details about the soil variables.

	Gouverneur					**Gribelle**				
Soil variable	**N**	**Mean**	**CV (%)**	**Min.**	**Max.**	**N**	**Mean**	**CV (%)**	**Min.**	**Max.**
Height above sea level (m)	54	423.78	0.44	421	427	54	373.70	0.59	367	376
A horizon depth (cm)	53	17.57	31.96	8	35	54	19.54	27.64	11	32
0-10 cm soil layer										
pH(H_2O)	54	*4.29**	4.74	3.908	4.91	54	*4.50*	4.14	4.06	5.08
pH(KCl)	54	*3.64*	6.64	3.129	4.19	54	*3.93*	4.72	3.46	4.26
P_{tot} (mg kg^{-1})	54	*415*	17.95	269	581	54	*493*	9.57	399	581
N (%)	53	0.36	33.39	0.09	0.65	54	0.37	19.92	0.24	0.54
C (%)	53	6.42	39.40	1.42	13.25	54	5.96	25.66	3.56	9.73
C/N	53	*17.50*	9.17	14.89	20.75	54	*15.86*	9.15	11.75	19.42
10-20 cm soil layer										
pH(H_2O)	54	*4.51*	3.07	3.96	4.75	54	*4.57*	2.36	4.35	4.99
pH(KCl)	54	*4.08*	4.68	3.40	4.31	54	*4.26*	1.80	4.05	4.40
P_{tot} (mg kg^{-1})	54	*348*	19.09	235	608	54	*409*	12.01	285	515
N (%)	53	0.16	54.19	0.07	0.52	53	0.16	36.60	0.06	0.49
C (%)	53	2.58	58.64	1.14	8.19	53	2.33	37.81	0.67	6.68
C/N	53	*16.33*	8.94	14	19.71	53	*14.45*	8.86	11.22	17.76

*: significantly different (*P* < 0.05) between Gouverneur and Gribelle (tested with one-way ANOVA)

In conclusion, the preliminary soil survey at the Gedinne sites has thus proved very useful as well and has uncovered some important gradients which should be taken into account when attributing the treatments to the 42 experimental blocks (see Task WP2.4).

Related EML-files in Data_Archive_ExpSites, folder soil:
- Soil_Gedinne_Survey_2009_EML.xls
- Soil_Zedelgem_Survey_2009_EML.xls
- Soil_Zedelgem_Soil pits_2009_EML.xls

Task WP2.4 Installation & initial measurements

Table WP2.6 gives an overview of the actions that have taken place in Zedelgem and Gedinne to prepare the sites for planting.

Table WP2.6: Overview of the actions to prepare the Zedelgem and Gedinne sites for planting.

Zedelgem		Gedinne	
What?	**When?**	**What?**	**When?**
Loosening of the compacted layer at the bottom of A_p horizon (Dutch: 'diepgronden')*	Spring 2009	Removal of beech belt at Gribelle site (see Fig. WP2.5 for exact location).	Autumn 2009
Establishment of a hare/rabbit and wild boar proof fence (80 cm above ground, 20 cm below ground + barbed wire at ~20 cm height). Total cost: € 15616	August 2009	Establishment of a deer proof fence (2 m high)	Winter 2010
Rotary cultivation of the entire site	Autumn 2009	'Gyrobroyage' (French) of the two sites	Winter 2010

* While digging the soil pits (see Task WP2.3) it appeared that this measure has not been very effective at first sight.

In Zedelgem a (non-effective) loosening of the soil has taken place, a fence has been established (Fig. WP2.11a) and the entire site has been worked with a rotary cultivator just before planting (Fig. WP2.11c). At Gedinne, a beech belt needed to be removed first at the Gribelle site (see Fig. WP2.11d and Fig WP2.5), a deer proof fence was erected (Fig. WP2.11b) and the entire site has been subjected to 'gyrobroyage' (French).

The trees in Zedelgem were ordered by the Agentschap for Natuur en Bos (Table WP2.7). Provenances were selected based on the availability in the nurseries and following a discussion with Kristien Vander Mijnsbrugge (INBO: Research Institute for Nature and Forest).

Table WP2.7: Overview of the characteristics of the trees that were planted at the Zedelgem site. All trees were obtained from the nursery Vereecke-De Cleene (Sleidinge), except *Quercus robur* prov. Kwekerijweg which was obtained from Sylva (Waarschoot).

Species	Provenance	Code	Number ordered	Number planted
Fagus sylvatica	Zoniënwoud	3+0; 100+ cm	7000	6243
Betula pendula	Urkenbos	1+1; 100+ cm	7000	6255
Pinus sylvestris	Groenendaal	1+2; 30+ cm	6850	6273
Tilia cordata	Süddeutsches Hügel- und Bergland	1+1; 100+ cm	7000	6233
Quercus robur 1	Vekedelle West	1+3; 100+ cm	4500	4474
Quercus robur 2	Warandeduinen (painted orange)	3+0; 100+ cm	2500	1672
Quercus robur 3	Kwekerijweg (painted blue)	3+0; 100-125 cm	1900	1659
			36750	32810

a) Fence (Zedelgem, August 2009) b) Fence (Gedinne – Gribelle; August 2010)

c) Rotary cultivated site (Zedelgem; January 2010) d) Beech belt (Gedinne – Gribelle; February 2009)

***Figure WP2.11**: Pictures depicting some features of the Zedelgem and Gedinne sites prior to planting.*

The experimental plots in Zedelgem were established in November 2009 using a precision GPS (Fig. WP2.12). The size of all 42 plots is exactly 42 m x 42 m. Each corner is permanently marked with aluminium angle stakes ('hoekprofielen' in Dutch) with the open side directed towards the plot.

Based on the results of the soil survey (see Task WP2.3), the treatments and replications were attributed to the experimental plots so that no covariation exists between the diversity treatment and any of the measured soil variables nor between the presence/absence of a tree species and any of the soil variables. This was tested with one-way ANOVAs with tree diversity or the presence or absence of a single species as factor and the soil variables listed in Table WP2.3 as response variables. **This is a major strength of the FORBIO-experiment compared to the other tree diversity experiments worldwide**. The resulting design is given in Fig. WP2.12 and Table WP2.8. Block no 1 comprises the plots 1-20 on the eastern site of the site and block no 2 comprises the plots 20-42 on the western side of the site.

In each experimental plot, 28 x 28 = 784 trees were planted on a grid, 1.5 m x 1.5 m apart. In mixed plots, individual species were randomly assigned to homogeneous cells of 3 x 3 trees (or 3 x 4 or 4 x 4 at the edges) (Fig. WP2.13). This was done to increase the probability that all species survive sufficiently long enough in the mixture on the one hand but to make sure that interspecific interactions occur as soon as possible. All trees received an individual number ranging from 1 (northern corner of plot no 1; see Fig. WP2.13) to 42 x 784 = 32 928. However, in practice only 32 810 trees were planted as in plots 30 (778 trees), 31 (728 trees) and 32 (728 trees) less trees were planted due to the presence of a ditch.

***Figure WP2.12**: Diversity treatments allocated to the 42 experimental plots at the Zedelgem site. Plots 1-20 comprise block no 1 and Plots 21-42 block no 2.*

Table WP2.8: Overview of the treatments allocated to the 42 experimental plots at Zedelgem.

Plot ID	Block ID	Sp. no	Beech	Oak	Oak provenance no.			Birch	Lime	Pine
					Pr. 1	Pr. 2	Pr. 3			
1	1	4	1	0	0	0	0	1	1	1
2	1	1	0	0	0	0	0	1	0	0
3	1	3	1	1	1	0	0	0	0	1
4	1	2	0	0	0	0	0	1	0	1
5	1	2	1	0	0	0	0	0	1	0
6	1	4	1	1	1	0	0	0	1	1
7	1	3	0	1	1	0	0	1	1	0
8	1	1	0	0	0	0	0	0	0	1
9	1	3	1	0	0	0	0	1	0	1
10	1	2	0	0	0	0	0	0	1	1
11	1	1	1	0	0	0	0	0	0	0
12	1	4	1	1	1	0	0	1	1	0
13	1	1	0	0	0	0	0	0	1	0
14	1	2	1	1	1	0	0	0	0	0
15	1	1	0	1	1	0	0	0	0	0
16	1	4	1	1	1	0	0	1	0	1
17	1	2	0	1	1	0	0	1	0	0
18	1	3	0	1	1	0	0	0	1	1
19	1	3	1	0	0	0	0	1	1	0
20	1	4	0	1	1	0	0	1	1	1
21	2	1	0	1	1	0	0	0	0	0
22	2	4	0	1	1	1	1	1	1	1
23	2	4	1	1	1	1	1	1	1	0
24	2	3	0	1	1	1	1	0	1	1
25	2	2	1	0	0	0	0	0	1	0
26	2	2	0	0	0	0	0	1	0	1
27	2	1	0	0	0	0	0	0	0	1
28	2	3	1	1	1	1	1	0	0	1
29	2	4	1	0	0	0	0	1	1	1
30	2	1	1	0	0	0	0	0	0	0
31	2	3	1	0	0	0	0	1	1	0
32	2	3	0	1	1	1	1	1	1	0
33	2	2	0	1	1	1	1	1	0	0
34	2	3	1	0	0	0	0	1	0	1
35	2	4	1	1	1	1	1	0	1	1
36	2	2	0	0	0	0	0	0	1	1
37	2	2	1	1	1	1	1	0	0	0
38	2	1	0	1	0	1	0	0	0	0
39	2	1	0	0	0	0	0	1	0	0
40	2	1	0	0	0	0	0	0	1	0
41	2	4	1	1	1	1	1	1	0	1
42	2	1	0	1	0	0	1	0	0	0

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	Plot 1= 4 soorten				Beuk	Berk	Linde	Den																						
2																														
3	afstand		0.8	2.3	3.8	5.3	6.8	8.3	9.8	11	13	14	16	17	19	20	22	23	25	26	28	29	31	32	34	35	37	38	40	41
4		X/Y	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
5	0.8	1	1	29	57	85	113	141	169	197	225	253	281	309	337	365	393	421	449	477	505	533	561	589	617	645	673	701	729	757
6	2.3	2	2	30	58	86	114	142	170	198	226	254	282	310	338	366	394	422	450	478	506	534	562	590	618	646	674	702	730	758
7	3.8	3	3	31	59	87	115	143	171	199	227	255	283	311	339	367	395	423	451	479	507	535	563	591	619	647	675	703	731	759
8	5.3	4	4	32	60	88	116	144	172	200	228	256	284	312	340	368	396	424	452	480	508	536	564	592	620	648	676	704	732	760
9	6.8	5	5	33	61	89	117	145	173	201	229	257	285	313	341	369	397	425	453	481	509	537	565	593	621	649	677	705	733	761
10	8.3	6	6	34	62	90	118	146	174	202	230	258	286	314	342	370	398	426	454	482	510	538	566	594	622	650	678	706	734	762
11	9.8	7	7	35	63	91	119	147	175	203	231	259	287	315	343	371	399	427	455	483	511	539	567	595	623	651	679	707	735	763
12	11	8	8	36	64	92	120	148	176	204	232	260	288	316	344	372	400	428	456	484	512	540	568	596	624	652	680	708	736	764
13	13	9	9	37	65	93	121	149	177	205	233	261	289	317	345	373	401	429	457	485	513	541	569	597	625	653	681	709	737	765
14	14	10	10	38	66	94	122	150	178	206	234	262	290	318	346	374	402	430	458	486	514	542	570	598	626	654	682	710	738	766
15	16	11	11	39	67	95	123	151	179	207	235	263	291	319	347	375	403	431	459	487	515	543	571	599	627	655	683	711	739	767
16	17	12	12	40	68	96	124	152	180	208	236	264	292	320	348	376	404	432	460	488	516	544	572	600	628	656	684	712	740	768
17	19	13	13	41	69	97	125	153	181	209	237	265	293	321	349	377	405	433	461	489	517	545	573	601	629	657	685	713	741	769
18	20	14	14	42	70	98	126	154	182	210	238	266	294	322	350	378	406	434	462	490	518	546	574	602	630	658	686	714	742	770
19	22	15	15	43	71	99	127	155	183	211	239	267	295	323	351	379	407	435	463	491	519	547	575	603	631	659	687	715	743	771
20	23	16	16	44	72	100	128	156	184	212	240	268	296	324	352	380	408	436	464	492	520	548	576	604	632	660	688	716	744	772
21	25	17	17	45	73	101	129	157	185	213	241	269	297	325	353	381	409	437	465	493	521	549	577	605	633	661	689	717	745	773
22	26	18	18	46	74	102	130	158	186	214	242	270	298	326	354	382	410	438	466	494	522	550	578	606	634	662	690	718	746	774
23	28	19	19	47	75	103	131	159	187	215	243	271	299	327	355	383	411	439	467	495	523	551	579	607	635	663	691	719	747	775
24	29	20	20	48	76	104	132	160	188	216	244	272	300	328	356	384	412	440	468	496	524	552	580	608	636	664	692	720	748	776
25	31	21	21	49	77	105	133	161	189	217	245	273	301	329	357	385	413	441	469	497	525	553	581	609	637	665	693	721	749	777
26	32	22	22	50	78	106	134	162	190	218	246	274	302	330	358	386	414	442	470	498	526	554	582	610	638	666	694	722	750	778
27	34	23	23	51	79	107	135	163	191	219	247	275	303	331	359	387	415	443	471	499	527	555	583	611	639	667	695	723	751	779
28	35	24	24	52	80	108	136	164	192	220	248	276	304	332	360	388	416	444	472	500	528	556	584	612	640	668	696	724	752	780
29	37	25	25	53	81	109	137	165	193	221	249	277	305	333	361	389	417	445	473	501	529	557	585	613	641	669	697	725	753	781
30	38	26	26	54	82	110	138	166	194	222	250	278	306	334	362	390	418	446	474	502	530	558	586	614	642	670	698	726	754	782
31	40	27	27	55	83	111	139	167	195	223	251	279	307	335	363	391	419	447	475	503	531	559	587	615	643	671	699	727	755	783
32	41	28	28	56	84	112	140	168	196	224	252	280	308	336	364	392	420	448	476	504	532	560	588	616	644	672	700	728	756	784
33																														

Figure WP2.13: Example of the planting scheme and tree numbers. Here the four species plot no 1 is shown.

Due to bad weather conditions and a too wet soil, tree planting at the Zedelgem site had to been done in two periods: between 3 and 5 December 2009 and between 24 and 27 March 2010. In December 2009, plots 1-18 were planted (although some plots could not be planted entirely due to a too wet soil). The non-planted trees were stored on the site during the winter 2009-2010 to be planted in March 2010. Planting has been done, among others, with employees of the Agentschap voor Natuur en Bos, co-workers of the Laboratory of Forestry (UGent) and of the Division of Earth and Environmental Sciences (KULeuven) and dozens of volunteers. It is estimated that in total **250 person days** have been mobilized to do the planting! Such a large workforce was necessary as all planting holes needed to be dug manually to achieve the desired precision in planting distances (Fig WP2.14).

***Figure WP2.14**: Digging holes at the Zedelgem in December 2009 (left picture) and March 2010 (right picture).*

The trees in Gedinne were ordered by the Division de la Nature et des Forêts (Table WP2.9). Provenances were also selected based on the availability in the nurseries and following a discussion with Alain Servais (Comptoir Forestier at Vielsalm).

Table WP2.9: Overview of the characteristics of the trees that were planted at the Gedinne sites. All trees were obtained from the nursery Gailly Jourdan (Paliseul), except *Fagus sylvatica* provenance 3 which was obtained from a German nursery.

Species	Provenance	Code	Number planted
Acer pseudoplatanus	2 Mélange (Belgium, Wallonia, Sud Sillon Sambre et Meuse)	2/0 80+	6004
Pseudotsuga menziesie	2WB0552 FENFFE (Belgium, Wallonia, Sud Sillon Sambre et Meuse)	S2r1 40+	6171
Larix x eurolepis	0WB0557 CIERGNON F2 (Belgium, Wallonia)	1/1 40+	6116
Quercus petraea	7WB0174 CULEE DE FAULX (Belgium, Wallonia, Bas Plateaux Mosans)	S2 50/100	6062
Fagus sylvatica 1	8 Mélange (Belgium, Wallonia, Ardennes)	S2	4645
Fagus sylvatica 2	France FSY102 Nord	50/80	2213
Fagus sylvatica 3	Germany 81017 Württembergisch-Frankisches Hügelland	50/80	2193
			33304

The experimental plots in Gedinne were established in the winter 2010 using a precision GPS (Fig. WP2.15). As there was a surplus of prov. 2 and prov. 3 beech trees, two additional plots (no 43 and 44) were established at the Gribelle site, making a total of <u>44 plots</u>. The size of all plots is exactly 42 m x 42 m. However, due to surface constraints plots 30-42 at the Gouverneur site in Gedinne were smaller, notably 37 m x 42 m. Similar to Zedelgem, each corner is permanently marked with aluminium angle stakes ('hoekprofielen' in Dutch) with the open side directed towards the plot.

Based on the results of the soil survey (see Task WP2.3), the treatments and replications were attributed to the experimental plots so that no covariation exists between the diversity treatment and any of the measured soil variables nor between the presence/absence of a tree species and any of the soil variables. This was tested in a same way as at the Zedelgem site with one-way ANOVA's with tree diversity or the presence or absence of a single tree species as factor and the soil variables listed in Table WP2.5 as response variables.

The resulting design is given in Fig. WP2.15 and Table WP2.10. Block nr 1 comprises the plots 1-20 and 43-44 at Gribelle and block nr 2 comprises the plots 21-42 at Gouverneur.

In the experimental plots 1-29 and 43-44, 28 x28 = 784 trees were planted on a grid, 1.5m x 1.5m apart. In plots 30 to 42, 28 x 25 = 700 trees were planted. In mixed plots, individual species were randomly assigned to homogeneous 3 x 3 cells as was done in Zedelgem. All trees received an individual number ranging from 1 (northwestern corner of plot nr 1; see Fig. WP2.13) to [(31 x 784) + (13 x 700)] = 33304.

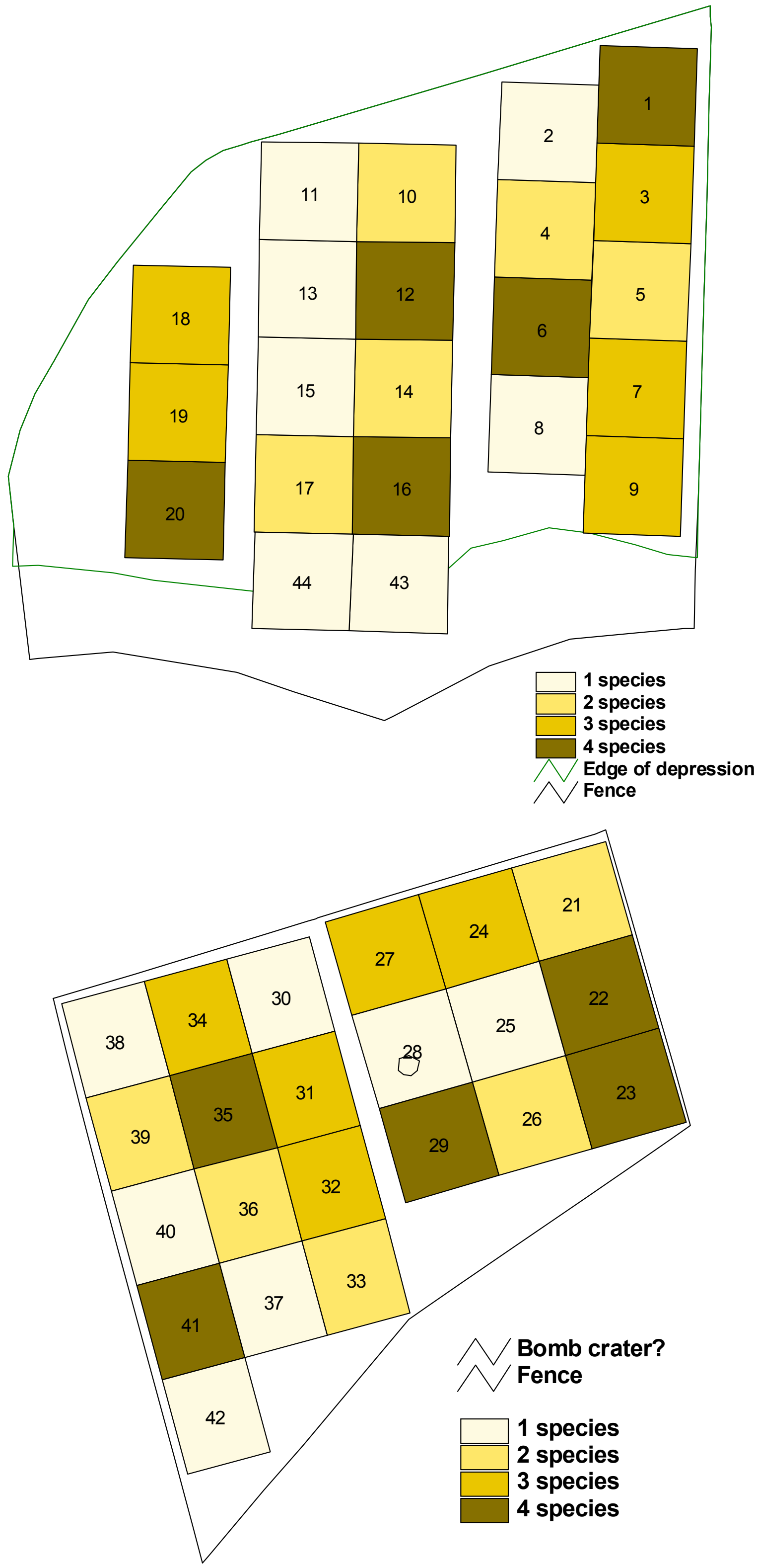


Figure WP2.15: *Diversity treatments allocated to the 44 experimental plots at the Gedinne sites. Plots 1-20 and plots 43-44 comprise block nr 1 (Gribelle) and plots 21-42 comprise block nr 2 (Gouverneur).*

Table WP2.10: Overview of the treatments allocated to the 44 experimental plots at Gedinne.

Plot ID	Block ID	Sp. no	Oak	Beech	Beech provenance no.			Maple	Larch	Douglas
					Pr. 1	Pr. 2	Pr. 3			
1	1 (Gri)	4	1	0	0	0	0	1	1	1
2	1 (Gri)	1	0	0	0	0	0	1	0	0
3	1 (Gri)	3	1	1	1	0	0	0	0	1
4	1 (Gri)	2	0	0	0	0	0	1	0	1
5	1 (Gri)	2	1	0	0	0	0	0	1	0
6	1 (Gri)	4	1	1	1	0	0	0	1	1
7	1 (Gri)	3	0	1	1	0	0	1	1	0
8	1 (Gri)	1	0	0	0	0	0	0	0	1
9	1 (Gri)	3	1	0	0	0	0	1	0	1
10	1 (Gri)	2	0	0	0	0	0	0	1	1
11	1 (Gri)	1	1	0	0	0	0	0	0	0
12	1 (Gri)	4	1	1	1	0	0	1	1	0
13	1 (Gri)	1	0	0	0	0	0	0	1	0
14	1 (Gri)	2	1	1	1	0	0	0	0	0
15	1 (Gri)	1	0	1	1	0	0	0	0	0
16	1 (Gri)	4	1	1	1	0	0	1	0	1
17	1 (Gri)	2	0	1	1	0	0	1	0	0
18	1 (Gri)	3	0	1	1	0	0	0	1	1
19	1 (Gri)	3	1	0	0	0	0	1	1	0
20	1 (Gri)	4	0	1	1	0	0	1	1	1
21	2 (Gou)	2	1	0	0	0	0	0	1	0
22	2 (Gou)	4	0	1	1	1	1	1	1	1
23	2 (Gou)	4	1	1	1	1	1	1	1	0
24	2 (Gou)	3	0	1	1	1	1	0	1	1
25	2 (Gou)	1	0	1	1	0	0	0	0	0
26	2 (Gou)	2	0	0	0	0	0	1	0	1
27	2 (Gou)	3	1	1	1	1	1	0	0	1
28	2 (Gou)	1	0	0	0	0	0	0	0	1
29	2 (Gou)	4	1	0	0	0	0	1	1	1
30	2 (Gou)	1	1	0	0	0	0	0	0	0
31	2 (Gou)	3	1	0	0	0	0	1	1	0
32	2 (Gou)	3	0	1	1	1	1	1	1	0
33	2 (Gou)	2	0	1	1	1	1	1	0	0
34	2 (Gou)	3	1	0	0	0	0	1	0	1
35	2 (Gou)	4	1	1	1	1	1	0	1	1
36	2 (Gou)	2	0	0	0	0	0	0	1	1
37	2 (Gou)	1	0	0	0	0	0	1	0	0
38	2 (Gou)	1	0	1	0	1	0	0	0	0
39	2 (Gou)	2	1	1	0	0	0	0	0	0
40	2 (Gou)	1	0	0	0	0	0	0	1	0
41	2 (Gou)	4	1	1	1	1	1	1	0	1
42	2 (Gou)	1	0	1	0	0	1	0	0	0
43	1 (Gri)	1	0	1	0	1	0	0	0	0
44	1 (Gri)	1	0	1	0	0	1	0	0	0

The planting at the Gedinne sites has been done by employees of the nursery Gailly Jourdan, but was supervised by the UGent technician Kris Ceunen and by the UCL technician Pierre Lhoir. The planting started in early April 2010 and lasted until mid May 2010. However, five plots (no 23, 32, 34, 36 and 41) at the Gouverneur site could not be entirely planted anymore in spring 2010. The planting of these plots had to be postponed to early spring 2011, when also the restocking of trees that died during the summer of 2010 will take place (see below).

During the summer of 2010 vegetation management has taken place both at Zedelgem and at the Gedinne sites. In Zedelgem this has been done by mowing a 1 m wide strip in all the rows, whereas in Gedinne this was done with a scythe and a brushcutter.

In the late summer of 2010, the survival has been assessed using a standardized protocol (Table WP2.11) in Zedelgem and at the Gedinne sites. The scoring has been done by Kris Ceunen at the Zedelgem site and by Pierre Lhoir at the Gedinne sites.

Table WP2.11: Overview of the survival scores that were given to decide whether or not (re-)planting was necessary.

Zedelgem		**Gedinne**	
Survival score	**(Re)planting?**	**Survival Score**	**(Re)planting?**
0: lacking tree	Yes	0: lacking tree	Yes
1: dead	Yes	1: dead	Yes
2: uncomplete foliage (>1/3 foliage loss) and/or dead terminal bud	Yes	2: uncomplete foliage (>1/3 foliage loss) and/or dead terminal bud	Yes
3: uncomplete foliage (<1/3 foliage loss) and living terminal bud	No	3: uncomplete foliage (<1/3 foliage loss) and living terminal bud	No
4: complete foliage and living terminal bud	No	4: complete foliage and living terminal bud	No
		5: trees cut by during the vegetation management	Yes
		6: strongly leaning tree that cannot be adjusted to grow straight anymore	Yes

The results of the survival analysis are given in Table WP2.12. In Zedelgem, 5447 (~17%) trees need to be (re)planted. The replanting rate differs strongly between species and provenances. Birch, lime and oak provenance Kwekerijweg show excellent survival, whereas especially pine and oak provenance Warandeduinen exhibit poor survival. The poor survival of pine is probably partly due to the cold winter combined with wet field conditions. The poor survival of the oak provenance is due to the bad quality of the plants (too long, slender shoots combined with small roots). It should be noted that during the spring planting in March some lime trees that were selectively eaten by hare during the winter months were already replaced so the high survival rate is a slight overestimation. The replanting of the trees will be done in January 2011.
At the Gedinne sites, 6517 (~21 %) trees need to be (re)planted. Especially maple exhibits high survival rates. The beech provenances 2 and 3 exhibit the lowest survival rates. Beech in general probably suffered from the rather late planting dates. Furthermore, the quality of the provenance 3 beech trees obtained from Germany was very low. In addition, 2475 trees that could not be planted anymore in spring 2010 (see above) still need to be planted as well. (Re)planting will be done in early spring 2011.

Table WP2.12: Overview of the (re-)planting rates at the two experimental sites as assessed by the survival scoring in the late summer 2010.

Zedelgem		**Gedinne**	
Species	**(Re)planting?***	**Species**	**(Re)planting?**
Fagus sylvatica	22.1 (1380)	*Acer pseudoplatanus*	5.1 (270)
Betula pendula	5.2 (326)	*Pseudotsuga menziesie*	20.7 (1157)
Pinus sylvestris	43.0 (2698)	*Larix x eurolepis*	18.6 (1036)
Tilia cordata	1.8 (115)	*Quercus petraea*	23.5 (1324)
Quercus robur 1	24.9 (114)	*Fagus sylvatica 1*	19.3 (886)
Quercus robur 2	47.2 (790)	*Fagus sylvatica 2*	25.3 (544)
Quercus robur 3	1.4 (24)	*Fagus sylvatica 3*	61.3 (1300)

*: % of trees having survival scores 0-2 in Zedelgem and 0-2 & 5-6 in Gedinne. Absolute number of trees that needs (re)planting between brackets. $: % calculated based on planted no of trees in spring 2010, i.e. 30929.

During the survival scoring in Zedelgem in the late summer of 2010, Kris Ceunen has systematically noted the presence of some leaf herbivores on the different tree species (results not shown).

Finally, time-0 soil samples have been collected in all experimental plots at the Zedelgem site in autumn 2010. In each plot, soil samples were taken with a gouge auger at 0-10 cm, 10-20 cm and 20-30 cm depth. Samples were taken along the two diagonals at 10, 20, 30, 40 and 50 m from the corner. As the crossing of the diagonal was sampled only once, 9 samples were taken per plot. Per plot, the samples were mixed per depth, meaning that in total 42 x 3 = 126 samples were collected. The samples were unequivocally coded as follows: Ze_41_0-10_2010. Samples (~0.5 kg) were dried (~48 h at 40 °C), milled, sieved (2 mm) and stored at the Laboratory of Forestry in Gontrode.

In early 2011, samples will be collected at the Gedinne sites as well following a similar procedure.

Related EML-files in Data_Archive_ExpSites, folder Experimental design and folder Trees:
- Experimental_Design_Gedinne_2008_EML.xls
- Experimental_Design_Gedinne_tree_maps_v080111_EML.xls
- Experimental_Design_Zedelgem_2008_EML.xls
- Experimental_Design_Zedelgem_tree_maps_v220610_EML.xls
- Tree_Survival_Zedelgem_Survey_2010_EML.xls
- Tree_Survival_Gedinne_Survey_2010_EML.xls

3. POLICY SUPPORT

FORBIO's short-term contributions to sustainable development are mainly related to the fact that the project has introduced the state-of-the-art concepts and empirical support on the various relationships between biodiversity and ecosystem functioning to a large audience of forest owners, managers, users and scientists in Belgium (see also Dissemination and Valorisation section). Raising awareness on the existence and nature of these relationships is very topical, as is illustrated by the recent approval of the creation of an Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; www.ipbes.net). Also, providing correct, empirically supported information is needed as we found that there is still a large gap between stakeholders' perceptions on the functioning of mixed versus monoculture forests and the actual scientific evidence that is available to underpin these perceptions. Based on the limited scientific information that is available, it is clear that generalizations and simplifications with respect to the functioning of mixed versus monoculture stands should be avoided, whereas stakeholders (including scientists) are often convinced that mixed forest always function better.

In the long-run, FORBIO will significantly contribute to a better understanding of the importance of tree species diversity for the functioning of forest ecosystems and the ecosystem services that they provide thanks to the establishment of the two (and soon three; see Table 4.2) large-scaled tree diversity experiments. Furthermore, the experiments, embedded in the worldwide TreeDivNetwork, will most likely continue to act as an attractor for researchers from Belgium and abroad. Therefore, the FORBIO experiments will maintain an active network (a 'community of practice') for forest biodiversity and ecosystem functioning research Belgium.

4. DISSEMINATION AND VALORISATION

FORBIO has been very active in the dissemination of information on the project and on the topic of biodiversity and ecosystem functioning to a wider audience. In Table 4.1 an overview is given of the dissemination activities that have taken place.

Table 4.1. Overview of the dissemination types that have been used to distribute information on the FORBIO-project and on the topic of biodiversity and ecosystem functioning.

Dissemination type	Details
Publication	Special FORBIO issue of BosRevue (see Annex 1.1)
Publication	Special FORBIO issue of Forêt Wallone (see Annex 1.2)
Publication	Five posters and a leaflet have been made and were presented at the Foire de Libramont on 24-29 July 2009 (see Annex 1.3)
Publication	International peer-reviewed scientific paper on the questionnaire results (see Task WP1.1)
Publication	K. Verheyen wrote five FORBIO-related contributions for the Scientific Block-Calender 2011 of Natuur & Techniek (see Annex 1.4)
Website	See: http://forbio.biodiversity.be
Meeting	Follow-up Committee meeting on 3 October 2008 (see Annex 2.1)
Meeting	Follow-up Committee meeting on 9 June 2009 (see Annex 2.2)
Seminar	TreeDivNet workshop on 24 November 2009 (see Annex 2.3)
Seminar	Keynote presentation on '*Functional forest biodiversity, ecosystem services and the role of management*' by K. Verheyen at the conference 'Adapting Forest Management to Maintain the Environmental Services: Carbon Sequestration, Biodiversity and Water' held in Koli, Finland from 21-24 September 2009 (see: http://www.metla.fi/tapahtumat/2009/koli)
Seminar	FORBIO conference on 4 February 2011 (see Annex 3)
Seminar	With financial support of the Prince Filip Fund (see Table 4.2), a two-day seminar (first day will consist of lectures on forest biodiversity and ecosystem functioning and second day will be a field trip to the experimental site in Gedinne) will take place 31 March 2011 and on 4 April 2011. More than 50 Master students from UGent, KULeuven, ULB, ULG and UCL will participate in this seminar.
Press release	On 3 December 2009, UGent has distributed a press release at the start of the planting of the FORBIO-experiment in Zedelgem (see Annex 4.1). This release received was picked up by a lot of media, including the national and regional TV and radio (VTM, WTV, Radio 1 and Radio 2), newspapers (e.g. Laatste Nieuws, Nieuwsblad, see Annex 4.2-4.3) and magazines (Karaat).

Next to dissemination, FORBIO has also been very active in the valorisation of the activities that have been done during the project, mainly by trying to attract extra research money to the experimental sites that have been established. An overview is given in Table 4.2.

Table 4.2. Overview of the submitted project proposals that are building upon the outcomes of the FORBIO-project.

Project title	Funding body	Budget	Status
Present and future ecosystem services provided by mixed forests in Belgium	BELSPO SSD_Call no 5	€ 359 839 (Four partners: KULeuven (coordinator), UGent, ULG and UCL)	Not approved
FunDivEurope: Functional significance of forest biodiversity in Europe (24 partners, coordinated by Uni Freiburg)	EU-FP7	€ 542 680 (UGent + UCL as associated partner) + € 294 000 (KULeuven + ULG as associated partner). Total project budget is 7 million euro.	Approved (started Oct 2010)
Francqui post-doc grant for Dr. V. Vanparys	Francqui Fund	Six month post-doc salary & additional costs	Not approved
Seminar entitled: ‘Biodiversity for forest ecosystem functioning’ (see Table 4.1)	Prince Filip Fund	€ 1500 to pay for the seminar costs	Approved (started Oct 2010)
Short Rotation Coppices (SRC) for biodiversity in agricultural landscapes.	ADLO	€ 75 000. Proclam vzw coordinates this project; UGent has an advisory role. Within the scope of this project two experimental SRC with a tree diversity treatment included have been established at Zedelgem and Ryckevelde0	Approved (started early 2010)
PhD project entitled: ‘Interactions nutritionnelles en peuplements forestiers mélangés: occurrence et mécanismes’	UCL, Fonds Speciaux de Recherche	~€ 50 000 covering salary costs for 15 months + extra project money. Candidate (Jordan Guiz, Fr) has to apply for a grant to complete his PhD.	Approved (started Oct 2010)
Basic measurements in a large-scale forest biodiversity experiment to evaluate the impact of tree species diversity on forest ecosystem functioning	FWO Research Grant	€ 39 978 to equip the Zedelgem site with lysimeters, to do point-0 measurements and to pay summer students to monitor tree survival during the first three growing seasons	Not Approved
Establishement of a 3th experimental FORBIO site in Hechtel-Eksel (Pijnven)	Agentschap voor Natuur en Bos	€ 45 000 to pay a technician and costs to coordinate the establishment of the experiment	Approved

The long list of research proposals indicate that the FORBIO project has successfully acted as a catalyst to stimulate research on (forest) biodiversity and ecosystem functioning. On top of this list, it should be noted that the Agentschap voor Natuur en Bos and the Division de la Nature et des Forêts provided or will provide logistical support, which is worth ~€ 50 000 per site, to install the experiments in Zedelgem, Gedinne and the additional site in Hechtel-Eksel (Pijnven) that will be planted in 2011.

The BELSPO investment of € 100 000 in the FORBIO-cluster project has resulted in the generation of over 1 million euro of additional research money (i.e. an output-input ratio > 10)!

The reasons for this success are due to the nature of the BELSPO SSD projects which allow for unique and very effective transregional collaborations. The flexibility that BELSPO offers in terms of research and funding certainly has, without any doubt, contributed to the success of the project as well.

5. PUBLICATIONS (see Task WP1.1 & Annexes 1.1.-1.4)

5.1 International peer-reviewed FORBIO-publications

- Carnol, M., Baeten, L., Branquart, E., Heughebaert, A., Muys, B., Ponette, Q. & Verheyen, K. (2011) Ecosystem services in mixed forests and monocultures: comparing stakeholders' perceptions and scientific knowledge. *Forest Ecology and Management*, in preparation.

5.2 National peer-reviewed FORBIO-publications

- Verheyen, K. & Branquart, E. (2010) La recherche sur la biodiversité et le fonctionnement des écosystèmes forestiers. *Forêt Wallone*, 106, 6-16.
- Branquart, E. & De Keersmaeker, L. (2010) Effets du mélange d'essences sur la biodiversité forestière. *Forêt Wallone*, 106, 17-26.
- Muys, B. & Aubinet, M. (2010) Peuplements mélangés et productivité. *Forêt Wallone*, 106, 27-32.
- Ponette, Q. (2010) Effets de la diversité des essences forestières sur la décomposition des litières et le cycle des elements. *Forêt Wallone*, 106, 33-42.
- Grégoire, J.C. (2010) Résistance et résilience des peuplements melanges vis-à-vis des stress (a)biotiques. *Forêt Wallone*, 106, 43-48.
- Carnol, M. & Verheyen, K. (2010) Les services écosystémiques dans les forêts mélangées et pures: perception des utilisateurs et connaissances scientifiques. *Forêt Wallone*, 106, 49-59
- Verheyen, K. (2010) Les forêts mélangées: leurre ou panacée? *Forêt Wallone*, 106, 60-61.
- Verheyen, K. (2010) Relaties tussen biodiversiteit en het functioneren van ecosystemen. *BosRevue*, 32, 2-5.
- Branquart, E. & De Keersmaeker, L. (2010) Effecten van boomsoortenmenging op de biodiversiteit. *BosRevue*, 32, 6-8.
- Muys, B. & Aubinet, M. (2010) Effecten van boomsoortenmenging op primaire productie en koolstofvastlegging. *BosRevue*, 32, 9-11.
- Ponette, Q (2010) Effecten van boomsoortenmenging op de strooiselafbraak en de nutriëntencyclus. *BosRevue,* 32, 12-15.
- Grégoire, J.C. (2010) Weerstand en veerkracht van gemengde bestanden. *BosRevue*, 32, 16-17.
- Carnol, M. & Verheyen, K. (2010) De percepties van bosgebruikers over de ecosysteemdiensten die gemengde bossen leveren. *BosRevue*, 32, 18-21.

5.3 Other FORBIO publications

- Five posters and a leaflet, distributed at the Foire de Libramont (24-29 July 2009)
- Five FORBIO-related contributions for the Scientific Block-Calender 2011 of Natuur & Techniek

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ANNEXES

ANNEX 1: COPY OF THE PUBLICATIONS
- ANNEX 1.1: Special FORBIO issue of BosRevue
- ANNEX 1.2: Special FORBIO issue of Forêt Wallone
- ANNEX 1.3: FORBIO posters presented at the Foire de Libramont
- ANNEX 1.4: FORBIO-related contributions for the Scientific Block-Calender 2011 of Natuur & Techniek

ANNEX 2: MINUTES OF THE FOLLOW-UP COMMITTEE MEETINGS
- ANNEX 2.1: Minutes of the first Follow Up Committee Meeting
- ANNEX 2.2: Minutes of the second Follow Up Committee Meeting
- ANNEX 2.3: Minutes of the TreeDivNet workshop

ANNEX 3: ANNOUNCEMENT OF FORBIO CONFERENCE ON 04/02/11

ANNEX 4: MEDIA COVERAGE OF THE FORBIO-EXPERIMENT
- ANNEX 4.1: UGent Press Release
- ANNEX 4.2: Article Laatse Nieuws
- ANNEX 4.3: Article Nieuwsblad

The annexes are available on our website
http://www.belspo.be/belspo/ssd/science/project_en.stm