

# CarboInvent

## Multi-source inventory methods for quantifying carbon stocks and stock changes in European forests

### Guidelines and improved standards for monitoring and verification of carbon removals in afforestation/reforestation joint implementation projects. Results of the monitoring case study in the test site in Hungary

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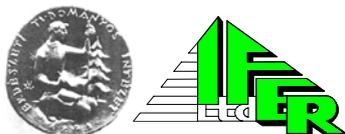
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## Summary

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This report develops a full budget of relevant greenhouse gases in an afforestation test area in Hungary. Among others, the country was selected for the study because of its history of intensive afforestation. The test area was established to model real afforestation/reforestation situations, where greenhouse gas emissions and removals are to be monitored complying with relevant provisions of the Kyoto Protocol and the Marrakesh Accords. Carbon stock changes in the following carbon pools were estimated: aboveground biomass, belowground biomass, litter and soil. Forest inventory data was used to estimate aboveground biomass carbon stocks and their changes. The forest inventory data were translated to carbon data using site specific factors that were developed in the study. The biomass campaign was also used to develop biomass equations to model and analyse situations where this data can be better used to arrive at more accurate estimates. The belowground biomass data, and their changes, were estimated using default factors. However, soil and litter carbon stock changes were estimated using site-specific data, using chronosequences of stands within the project test site. In order to develop carbon stock change data for periods of five years, i.e. for periods longer than the duration of the CarboInvent project, a model called CASMOFOR was used. An earlier version of this model was developed to be more user-friendly, and to produce more powerful outputs that could be used in monitoring of afforestation/reforestation projects. In addition to the emission and removal estimates, a complete uncertainty analysis was carried out to demonstrate the methods and the extent this uncertainty estimation could be used in projects. Finally, the report includes improved guidelines with respect to the methodologies that could be used in monitoring afforestation/reforestation projects. These guidelines can be used not only in joint implementation projects, but also in clean development mechanism (CDM) projects.

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## Összefoglaló (summary in Hungarian)

Ez a kutatási jelentés az Európai Unió által finanszírozott CarboInvent nevű kutatási program egyik zárójelentése. A jelentés egy erdőtelepítéssel létrehozott erdőterület üvegház hatású gáz leltárát írja le. Az említett erdőterület egy olyan ún. teszt terület, amelyen bizonyos, az IPCC által kiadott, Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG) c. módszertani könyvben leírt leltározási módszereket lehetett kipróbálni. Ezeket a módszereket kell alkalmazni olyan erdősítések monitorozására, amelyeket a Kyotoi Jegyzőkönyv értelmében szénlekötési célból létesítenek. Magyarországot a CarboInventen belül többek között azért választottuk ki e módszerek tesztelésére, mert az országban komoly múltja van az erdőtelepítéseknek.

A kutatómunka a következő széntárolók szénkészlet-változásának elemzésére terjedt ki: földfeletti biomassa, földalatti biomassa, avar és talaj. A földfeletti biomassa szénkészlet-változásának becslésére erdőleltári adatokat használtunk fel (az Országos Erdőállomány Adattárból). Az erdőleltári adatokat a teszt területen levezetett ún. biomassa átszámító tényezők segítségével konvertáltuk biomassa, ill. szén adatokká. A biomassa mérések során biomassa függvényeket is levezettünk annak modellezésére, hogy ezek a függvények pontosabb biomassa adatokat szolgáltatnak, amennyiben a faállományok felvételekor rendelkezésre állnak egyes fa adatok. A föld alatti biomasszát az IPCC által javasolt átszámító tényezők segítségével becsültük. A talaj és az avar szénkészletének változását idősorok elemzésével becsültük. A teszt terület egészének szénkészlet-változását a CarboInvent 3 éves tartamán túlnyúló 5 éves időszakon belül egy modell segítségével elemeztük. Ennek a modellnek egy korábbi változatát a CarboInvent ideje alatt továbbfejlesztettük: felhasználóbarátabbá és az outputokat tekintve használhatóbbá tettük. Ezt a modellt fel lehet használni tetszőleges erdősítési projekt tervezésekor, vagy monitorozásakor. A területre vonatkozó teljes szénleltáron kívül teljes hibabecslést is végeztünk annak demonstrálására, hogy milyen módszerekkel és milyen mértékben lehet a hibaszámítást elvégezni erdősítési projekteken. Végül fontos kiemelni, hogy ez a jelentés számos olyan útmutatást tartalmaz, amelyet fel lehet használni erdősítések monitorozásakor, s ami kiegészíti a fent említett GPG módszertani útmutatását. A jelentésben foglalt útmutatást jól fel lehet használni nemcsak az ún. közös végrehajtású erdősítési projektek, hanem az ún. CDM projektek monitorozására is.

Megjegyzés: a kutatási program megvalósításában több magyarországi intézmény is nagy segítséget nyújtott. Ezek az intézmények a Köszönetnyilvánítás („Acknowledgements”) fejezet alatt vannak felsorolva, l. a 86. oldalon.

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## List of Abbreviations

A	Afforestation
AB	Above ground biomass
BB	Belowground biomass
CDM	Clean Development Mechanism
CFB	Carbon Finance Business
CF	Carbon fraction
CI	CarboInvent
COP	Conference of Parties
CP	Commitment period
D	Deforestation
d <sub>1,3</sub>	Diameter at breast height (cm)
FM	Forest management
GHG	Greenhouse gas
GPG	Good Practice Guidance
h	Tree height (m)
JR	Joanneum Research
KP	Kyoto Protocol
LI	Litter
LULUCF	Land Use, Land-Use Change and Forestry
MA	Marrakesh Accords
NFD	National Forestry Database
NFI	National Forest Inventory
NIR	National Inventory Report

PCF	Prototype Carbon Fund
r	Root-to-shoot ratio
R	Reforestation
SO	Soil
UNFCCC	United Nations Framework Convention on Climate Change

## 1. Introduction

### 1.1. General remarks

This report contains all results of the work that has been done in connection with Deliverable 8.5 of the CarboInvent project<sup>1</sup>. The objective was to test available methods, and to improve guidance on them, that could be used for monitoring the carbon stock changes in afforestation (A) and reforestation (R) joint implementation (JI) projects<sup>2</sup> under Article 6 of the Kyoto Protocol (KP).

The report is closely linked to another report that is included in the report of Deliverable 8.1 (Somogyi, 2005), which analyses data needs of monitoring carbon stock changes, as well as emissions and removals of AR projects under Article 6 of the KP.

This report focuses on the analysis of methodologies of AR projects, thus, it is not the objective of this paper to develop reporting methodologies and data requirements for the *national* GHG inventories under the KP in general.

Complying with the original plan in WP8 of the CarboInvent project, this report uses experiences gained in a test site in Hungary as a case study to draw general methodological conclusions<sup>3</sup>. However, the objective of the CarboInvent project was to develop methodologies and improve guidance that can be applied in many inventory situations. Therefore, we put an emphasis on the general methodological guidance, but use many examples, partly because they were used to develop guidance, and partly because they help understand the guidance, so they can even be regarded as parts of the guidance.

The document has three elements: general guidance, specific examples from the Hungarian test site, and general examples for situations that were not directly tested in the test site. The general guidance is provided at the beginning of almost all sections. Then, if the methods that are dealt with in the section have been tested in the test site, relevant information is given on the data and the experiences on the method. Finally, for those situations that are well-known in the forest inventory community, e.g. sampling techniques, or diameter- and height measurements, and that have therefore not directly been tested in the test site, guidance is also given in separate sections. For these situations and elements of the monitoring, the reader is also encouraged to consult standard textbooks.

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<sup>1</sup> In this report, methodologies for afforestation/reforestation joint implementation projects are discussed. These will be referred to as AR JI projects, or AR projects, or just simply projects. The study has been conducted as part of the CarboInvent Project, which will be referred to as CarboInvent Project or CI Project.

<sup>2</sup> In addition to afforestations and reforestations, projects under Article 6 of the KP can include forest management, agroforestry and others. This paper only analyses afforestation and reforestation projects. Since the nature and the monitoring methodologies of these projects are the same for both A and R, we jointly refer to both of them as AR in the report.

<sup>3</sup> Any information on Hungary's choice must be regarded as preliminary, and are subject to change before her official report due later.

## 1.2. Relevant provisions and methodological guidance for AR JI projects

The reader is expected to be knowledgeable about the KP and its relevant provisions which form the context of the research described in this report. According to these provisions, afforestation, reforestation and deforestation (ARD) are the compulsory activities to be reported under Art. 3.3. However, these AR activities are different from those under Art. 6 and 12 that refer to afforestation/reforestation activities implemented within the mechanism of Joint Implementation (JI) and the Clean Development Mechanism (CDM), respectively. While the CDM projects target non-Annex I countries comprising mostly the developing countries, JI projects are conducted in Annex I countries. This paper is focused specifically on JI afforestation projects, which represent the target objects for application of the methodology principles described in this material. However, some of the methodological elements and guidance could also be used in planning and conducting monitoring activities in CDM projects.

As a methodological basis for this study, the newly published Good Practice Guidance (GPG) for the Land Use, Land Use Change and Forestry (LULUCF, IPCC 2004) was used, and the main aim was to test the methods suggested by this GPG. However, other available methodologies were also analyzed: in this document, we describe the key methodological aspects of the two currently running AR World Bank Carbon Finance Business (CFB) projects. Although other project methodologies might also be available, the CBF projects are specifically important because of two reasons: first, they were designed so as to be eligible under KP Art. 6., and second, CBF project methodologies are publicly available. The details on these projects and their measuring and monitoring methodologies are included in the next Section.

Note that there are currently several other AR projects in the planning and approval status. The methodologies of the monitoring of GHG emissions and removals in these projects are also in the approval phase. The UNFCCC website on CDM projects (<http://cdm.unfccc.int>) offers complete and up-to-date information on these methodologies.

## 1.3. Project methodologies of AR CBF projects

The World Bank Carbon Finance Business (CFB) projects (see <http://carbonfinance.org>) include various types of projects. Those related to afforestation/reforestation (AR) activities are funded by the Prototype Carbon Fund (PCF; <http://carbonfinance.org/pcf/>) or more recently by BioCarbon fund<sup>4</sup>. One of the

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<sup>4</sup> The BioCarbon Fund was established in 2004. It is focused on projects that sequester or conserve carbon in forest and agro-ecosystems. The Fund, a public/private initiative administered by the World Bank, aims to deliver cost-effective emission reductions, while promoting biodiversity conservation and poverty alleviation (<http://carbonfinance.org/biocarbon/home.cfm>). The establishment of the fund actually reflects the growing recognition of AR projects: while there were only two AR project under PCF, many new AR project are currently (as of 2005) in preparation under BioCarbon.

aims of the PCF projects is to generate emission reductions that are expected to be registered for the purposes of the Kyoto Protocol Art. 6 (JI) or Art. 12 (CDM). There are only two PCF projects related to AR that signed the Emission Reductions Purchase Agreements (ERPA), namely the Moldova Soil Conservation project and the Romania Afforestation project (Table 1). The following text presents brief information on these projects and the key issues from their monitoring plans. The details of the presented project methodologies can be found in publicly available documents located on the PCF web page.

**Table 1. Key information on the two World Bank Carbon Finance Business Prototype Carbon Fund (PCF) projects.**

(A Világbank “Carbon Finance Business” “Prototype Carbon Fund” által finanszírozott projektek főbb adatai.)

<b>Project Description</b>	<b>Moldova: Soil Conservation</b>	<b>Romania: Afforestation</b>
PCF Contracts (million US\$)	5.1	3.08
Area concerned (ha)	14,494	6,033
PCF ERPA Emission Reductions (t CO <sub>2</sub> eq.)	1,455,744	854,985
Total Project Emission Reductions Generation (t CO <sub>2</sub> eq.)	1,775,298	1,594,437

### 1.3.1. Moldova - Soil Conservation Project

The Moldova Soil Conservation Project is an AR project dealing with afforestation of degraded and eroded state-owned and communal agricultural lands throughout Moldova. The measuring and monitoring plan for the project was prepared by the staff from Winrock International, USA and Moldosilva, Moldova. The project monitoring plan (PMP) aims at fulfilling all up-to-date known requirements for the Kyoto Protocol Article 12 (CDM) projects. It includes baseline definition and its tracking over time, definition of project areas, selection of relevant forest carbon pools, description of applicable methodology to estimate the selected forest carbon pools and issues on sampling density determination and monitoring frequency.

#### 1.3.1.1. Baseline issues

PMP cites literature to support baseline assumption of likely carbon loss from soils, namely that any carbon loss that followed the previous cultivation on some areas presumably occurred prior the current project. This is vital as the project includes areas of different land-use history. The provision on soils permits treating these lands uniformly for baseline and initial stage conditions of soil carbon.

#### 1.3.1.2. Project area, stratification and sampling issues

The project discounts the annual average area under afforestation/reforestation in the country that occurred prior the PCF contribution. This is to include only the eligible afforestation/reforestation area, which represents the additional effect of the PCF activity.

The plan describes three ways of monitoring baseline sites, as well as project sites as for their overall performance: i) visual observation with photographic documentation ii) digital aerial photography of GPS-located transect in planted areas iii) remote sensing. Based on local resources, the plan assumes that only the visual observation and photographic diary would be used, while the other, more costly or technologically more demanding options would be applied later.

The plan recommends that initial stratification will be based solely on species composition, which identifies four key types of stands in the project. Other factors might be used later for post-stratification if it becomes reasonable.

As for the required sample size assessment for carbon held in aboveground biomass, the project used a preliminary assessment of carbon held in trees to determine anticipated variability within stands. Carbon stock was calculated from stem volume, species-specific wood density (actually assessed considerably higher than what IPCC LULUCF GPG recommends) and standard carbon fraction of 0.5 of dry mass. Several assumptions were made for variability assessment. The project inferred that to attain total error of  $\pm 10\%$  of the mean, the sampling error should be smaller and sets a target sampling error of  $\pm 7\%$ . It is unclear what procedure was used to assess sampling error with respect to the area particular strata or project. The plan assessed a limited number of sampling plots. Each sampling plot is sized 10x50 m, i.e., represents the area of 250 m<sup>2</sup>. With the above assumptions, the proposed sampling density per tree species stand type strata is about 0.02 %.

Concerning the stratification to reduce variability in estimation of soil carbon, the plan proposed soil stratification into two generalized soil classes, namely “rich” ( $> 70$  t C/ha) and “poor” ( $< 70$  t C/ha). The required sample size for soil carbon was also assessed in preliminary project studies. It was concluded that overly demanding sampling effort would be needed to detect soil carbon stock changes to be economically feasible. Hence, the proposed monitoring plan considers only two soil carbon measurement events, one at the beginning of the project and one at the point where soil carbon accrual is anticipated to slow. The plan mentions a specific sample size for soil inventory based on a procedure that was not described in the text.

The project plan strategy suggested independent sampling frameworks for aboveground biomass and soil carbon sampling. The aboveground biomass monitoring is based on permanent plots allocated by a random manner by superimposing a grid transparency over the site map. Sampling of soil carbon is based on temporary plots.

The plan contains a scheme for measurement events, starting with planting and soil carbon baseline measurement. It assumes the first biomass measurement five years after planting is finished. Henceforth, biomass monitoring should occur in 5-year and later in 10-year intervals. To enable annual reporting of project performance, the model CO2FIX will be used to estimate annual change in carbon stocks. These estimations will be adjusted after measuring events.

### 1.3.1.3. Five carbon pools

The project intends to estimate carbon held in all five pools as recommended by the GPG (IPCC 2003). The summary of the proposed methodology for particular components is shown in Table 2.

**Table 2. Carbon pools, methodology, data and monitoring frequency (adapted from the Moldova project monitoring methodology).**

(Széntárolók, módszertan, adatok és monitoring gyakoriság a Moldova projekt monitoring módszertanból.)

Carbon pool	Methodology, data	Monitoring frequency
Aboveground biomass	Systematic stratified sampling with permanent nested sample plots Tree diameters and project-specific biomass functions Trees only, no herbaceous vegetation monitored	5-year intervals up to age 25, 10-year interval later
Belowground biomass	Calculated from above-ground biomass, likely applying the root/shoot ratio of 0.2 (Cairns et al. 1997)	
Deadwood	Standing: as for aboveground biomass, classification into decomposition classes Lying: line intersect method (Warren and Olsen, 1964)	Standing: as for aboveground biomass Lying: at project start to establish baseline, later only if significant accumulations noted
Litter	Systematic stratified sampling for direct determination of dry mass	At project start to establish baseline, later only if significant accumulations noted
Soil	Systematic stratified sampling, determination from bulk density and CO <sub>2</sub> concentration, sampling depth 30 cm	At project start to establish baseline, repeated at project end (ca. 40 years later)

### 1.3.2. Afforestation project in Romania

The second of the AR World Bank Carbon Finance Business (CFB) Prototype Carbon Fund (PCF) projects plans to afforest over 6,033 ha of state-owned degraded agricultural lowlands in Romania. The project is to stabilize soils through planting of semi-naturalized (e.g., *Robinia pseudoacacia*) or native species (*Populus alba*, *Populus nigra*, *Salix sp.*, *Quercus sp.*, etc.).

The Monitoring Plan for Changes in Carbon Stocks in Forest Plantations was prepared by Romania's Institute for Forest Research and Management (ICAS) and a team from the National Forest Administration (Romsilva). It was reviewed by Sandra Brown of

Winrock International and Benoît Bosquet of the World Bank/PCF. The project monitoring plan (PMP) was designed so as to fulfill the requirements for the Kyoto Protocol Article 6 (JI) projects. Similarly as for the Moldova project, we note some major issues of the project and recommend consulting the complete project documentation (publicly available on PCF web page) for more details.

#### 1.3.2.1. Baseline issues

In case of the Romanian project, baseline information was prepared within a separate project that is described in the report “Romania Afforestation of Degraded Agricultural Land Project: Baseline Study, Emission Reductions Projections and Monitoring Plans” (Brown et al. 2002).

#### 1.3.2.2. Project area, stratification and sampling issues

Area delimitation relies on the use of forest management plans, forest maps and forest landmarks. Direct measurements are to be deployed only if required due to, e.g., some land loss from the total project area. The eventual area loss will be recorded and the corresponding area measured/estimated and consequently subtracted and excluded from calculations. The plan also recommends for the initial situation to create a collection of photographic images/views to be kept in the database of the project as a reference, although it is unclear if this project actually created such a database of its own.

In the baseline study, the expected project area was stratified based on soil and proposed species selected for planting. The final monitoring plan further adjusted these strata, based on actual location on project areas, soil types and thereby proposed species composition of newly established forest stands.

The optimal number of permanent monitoring plots was assessed by statistical approaches. It was assessed separately for soil and biomass. The higher of the two numbers was selected as the final number of monitoring plots to measure carbon content in both vegetation and soil. For vegetation the main criteria for stratification were the species planted and the areas to be planted in each county as performed in the baseline study. The computation procedure involved was described as optimum stratification test. It generated the optimal number of permanent monitoring plots by plantation type/counties/expected production class of plantations. The optimization either deployed the coefficients of variation obtained from the baseline study, or these coefficients were derived from an empirical function of planting density based on Giurgiu (1972). The assessment of sample size was driven by a target precision between 5 to 10 %, assuming sampling error only. It is assumed that a sampling error about  $\pm 7\%$  would mean reaching the overall error of  $\pm 10\%$ . This way, the optimization procedure calculated 184 permanent plots that are required for tree biomass carbon content assessment for the total stand area slightly over 6000 ha. As the size of permanent plot is 200 m<sup>2</sup>, the proposed sampling density is about 0.06 %.

The project plan states that the baseline study, although providing insufficient data for initial carbon stock assessment, indicated accumulation of soil carbon stock and justified its assessment in the project. Data on soil carbon stock in existing forest types

showed significantly higher values of soil carbon as compared with adjacent non-forested land. Based on this evidence, the project decided that soil compartment will be monitored to detect changes 10 years after tree planting. To determine the number of required soil monitoring plots, the key criterion was ability to detect statistically significant difference in soil carbon stock with 95% confidence.

Under project-specific circumstances, it is concluded that the required sample size for soil sampling is smaller than that for tree biomass carbon stock assessment. Hence, the number of permanent sampling plots is taken from the optimization procedure performed for carbon stock held in above-ground biomass. This means 184 permanent sampling plots (circular plot with radius of 8 m, i.e., area of 200 m<sup>2</sup>) for 6033 ha of afforested land in the project, where the initial soil carbon stock and consequently changes in the stocks of carbon in vegetation, dead organic matter and soils due to the project will be measured. The above numbers indicate a sampling density of 0.06 % as noted above, however, the actual sampling density would vary depending on forest type because of the stratification applied.

A permanent plot in the Romania Afforestation project is a circular area of 200 m<sup>2</sup> (radius of 7.98 m). The plots are localized randomly over the map of given management unit. Once located in the field according to the distance from the landmark and the azimuth, plot center is measured by GPS and permanently marked by a pole.

The project refers to its baseline study as for the initial inventory of vegetation and soil carbon. The initial soil sampling will be performed after setting-up the permanent plots. Thereafter, monitoring of vegetation and dead organic matter is proposed to be performed in 5, 10 and 15 years of the project, while soil sampling in 10 and 15 years of the project. Data from the first monitoring period will be used as input to re-parameterize the model CO2FIX in order to reproduce the actual data and predict changes in carbon stocks for the next periods. CO2FIX will be used in its default mode and then re-parameterized using local allometric equations.

The project monitoring plan contains operational details for sampling. We noted a specifically laborious procedure for identification of individual trees in the early version of the Moldova project monitoring plan. Such procedure would be unfeasible and these instructions did not appear in the latest Moldova project monitoring plan.

### 1.3.2.3. Five carbon pools

The project intends to estimate carbon held in all five pools as recommended by IPCC GPG LULUCF. The summary of the proposed methodology for particular components is shown in Table 3.

**Table 3. Carbon pools, methodology, data and monitoring frequency proposed in the Romanian project monitoring plan.**

(Széntárolók, módszertan, adatok és monitoring gyakoriság a romániai projekt monitoring módszertanból.)

<b>Carbon pool</b>	<b>Methodology, data</b>	<b>Monitoring frequency</b>
Aboveground biomass	Random stratified sampling with permanent sample plots Tree diameters and project-specific biomass functions Trees (incl. seedlings and shrub vegetation sampled)	5-year intervals
Belowground biomass	Measured randomly on selected locations outside permanent plots	5-year intervals
Deadwood	Standing trees/remnants recorded	5-year intervals
Litter	Random stratified sampling with permanent sample plots, includes organic horizons	5-year intervals
Soil	Random stratified sampling with permanent sample plots, mineral horizon only and sampling depth 30 cm	Year 10 and 15

The available documentation on the Romanian A project also includes field procedures recommended for sampling individual pools. We noted excessively laborious proposal of measurement procedures for some pools, which would not be recommended by this study. For details on the Romanian A project, consult the PCF web pages.

## 2. Afforestation in Hungary. The Hungarian test site

### 2.1. Afforestation projects in Hungary

Hungary belongs to the less forested countries of Europe. As the ratio of forests dropped to 11% after World War I, the country has been in need of timber for decades. This prompted relatively large-scale afforestation in the 20<sup>th</sup> century (Table 4). Although the afforestation rate dropped in the early 1990s, it increased again in the last few years (Table 5).

**Table 4. Change of forest area in Hungary during 1938-2004.**

(Az erdőterület változása Magyarországon 1938-2004. között.) Source/Forrás: KSH, ÁESZ Adattár.

Region	1938 forest area		1965 forest area		2004 forest area	
	thousand ha	%	thousand ha	%	thousand ha	%
West-Hungary	599,4	16,2	731,9	20	874,3	23,9
North-Hungary	318,4	22,6	329,4	24,5	378,5	28,2
East-Hungary	189,1	4,5	360,2	8,4	583,6	13,6
<b>Total</b>	<b>1 106,9</b>	<b>11,9</b>	<b>1 421,5</b>	<b>15,3</b>	<b>1836,4</b>	<b>19,7</b>

**Table 5. Afforestation rate in Hungary in the last few years.**

(Az erdősítés üteme Magyarországon az utóbbi néhány évben.)

Source/Forrás: ÁESZ Beszámoló az erdősítésekről és a fakitermelésekről, 2003.

In the afforestation season	By state- owned forestry companies	By other forestry companies	Total
	thousand hectares		
1994/1995.	0,3	3,9	4,2
1995/1996.	0,4	6,2	6,6
1996/1997.	0,4	7,9	8,3
1997/1998.	0,4	7,8	8,2
1998/1999.	0,4	8,3	8,7
1999/2000.	0,4	9,4	9,8
2000/2001.	0,3	12,8	13,1
2001/2002.	0,4	14,4	14,8
2002/2003.	0,3	11,7	12,0

## 2.2. Criteria for selecting afforestation the test site in Hungary

WP 8 of the CarboInvent (CI) Project was designed to test and develop methods at various scales, including AR JR projects. AR projects under Art. 6 of the KP can take place on several thousand or several tens of thousands of ha, depending on local conditions. In Hungary, establishing projects at both scales would be feasible, however, it is expected that projects of several thousands of ha are more realistic. There are many other conditions for establishing projects. In the CI Project, we wanted to “mimic” real situations; therefore, efforts were taken to establish an AR project site that meets certain criteria.

Before starting any research activity, criteria were developed with the help of the Kecskemet Directorate of the State Forest Service to ensure that the right site was selected. The criteria were the following:

**Size:** the total area of the afforested compartments and blocks of forests should be several thousand ha. In addition to the fact that this would likely be the characteristic size of individual afforestation projects in Hungary, the size of the project allows for keeping monitoring costs low, and meeting other requirements of efficient monitoring

**Access:** the majority of the area should be easily accessed. Since the test site is not part of a real-world project, field work is easier if the project area is easy to reach. (In addition, the area can better be used for field demonstrations if it is easily accessible.)

**Ownership:** in real-world projects, the majority of the project area would be owned by private owners. However, since the test area is not under a contract between the owners and the project, private ownership may hinder field work, whereas state owned land can more easily be monitored and destructive measurements like soil sampling and root biomass measurements are accomplished more easily. In any event, privately owned land was selected to assess the possible difficulties that may arise from private land ownership. (Fortunately, no problem was experienced; therefore, the issue of ownership is not dealt with any more in the paper.)

**Tree species:** The species must be representative of the region and must be both broadleaves and conifers. Black locust and poplar, as well as Pinus species (*nigra* and/or *silvestris*) should be used as much as possible, since they may also be among the most favourite species to be used in afforestation programs in Hungary.

**Age structure of stands:** the whole project area should mimic an afforestation project of 15-25 years. This means that several age classes of the same species under the same site conditions must be present. This allows modeling the growth of the species in each site category even during the short (3-year-long) lifetime of the Project.

**Site conditions:** site must be characteristic for the Hungarian conditions, but too compacted soil is to be avoided for convenient soil carbon assessment.

### 2.3. Test site description

Based on the above criteria, a test site was established in 2002-2003 that seemed appropriate for the project. The total size of the forest in the test site is 5226,9 ha. The test site is scattered over a larger area, which is due to the fact that, in this part of the country, agriculture is an important source of living, and croplands and forest patches together form the landscape. Also, it was an important criteria to have at least the majority of the project area in private land, and in this respect, too, the test site is very realistic, because the size of land owned by a single owner is at the order of magnitude of a few hectares, which results in a scattered project area, as it varies whether the individual land owners want to manage their lands as cropland, grazing land or as forest land.

The various parts of the test site were afforested 1-22 years ago. This, again, is realistic, because most often the whole project area is afforested over several years as was stated above. Selecting a test site that would represent such a situation, but with a shorter length of the period of afforestation, say only five years, would have been possible, but would have not enabled us to establish so called false time series, as it explained later. On the other hand, selecting a test site with ages 1 to 22 years did not hinder us to test and develop methods, which was the main aim of the Project. See also some other related considerations in section 0.

There are three species in the test site, of which almost two thirds (64.7%) are occupied by Black locust (Table 6, Figure 1). The other two species are poplars (various Hybrid poplars, *Populus x euramericana*, Figure 2, and Grey poplar, *Populus canescens*) and Black pine (*Pinus nigra*). Note that all poplars in the project area will be referred to as Grey poplar.

The yield capacity in the test area, defined as the relative height of stands at maturity<sup>5</sup>, is quite diverse (Figure 3), but the distribution of the assessed site characteristics<sup>6</sup> is quite uneven, i.e. only a few site types occur. These types include various sandy soils where the rooting depth or the humus content of the layers in the rooting depth can vary (Figure 3). However, the soil is relatively poor, which regards to both the carbon content (which is very low, see section 3.5 on soils), as well as the nutrient content. In addition, the climate of the area is continental with characteristically dry and hot summers, and annual precipitation of only around 550 mm. The sites in the test area are below the national average, which is also shown by the relatively large frequency of the occurrence in the poor and medium yield groups (Table 6, Figure 1). That the area was afforested is due to the fact that the species selected are fast-growing, making it profitable to grow them.

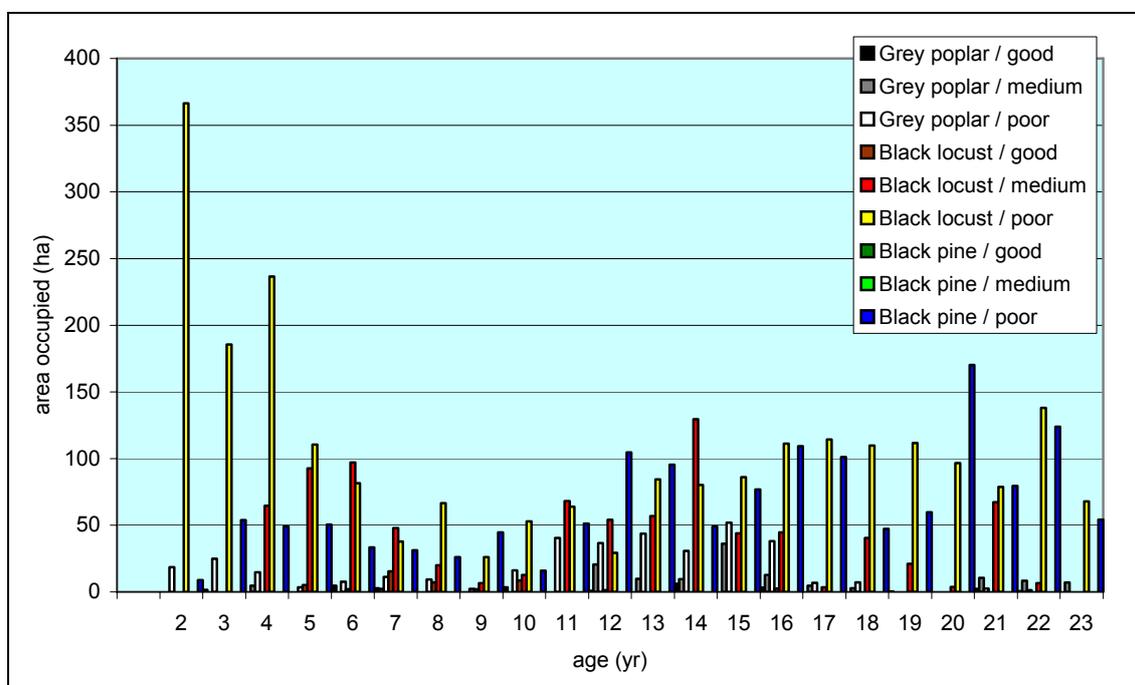
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<sup>5</sup> The yield capacity data are based on the yield class of the stand, and is taken from the local forest inventory.

<sup>6</sup> The soil characteristics data is taken from the local forest inventory.

**Table 6. Distribution of the forest area (in ha) in the test site by species and yield group.**  
(Az erdőterület (ha) megoszlása fajonként, és fatermési csoportonként. Good: 1-2. fatermési osztály;  
medium: 3-4. fatermési osztály; poor: 5-6. fatermési osztály.)

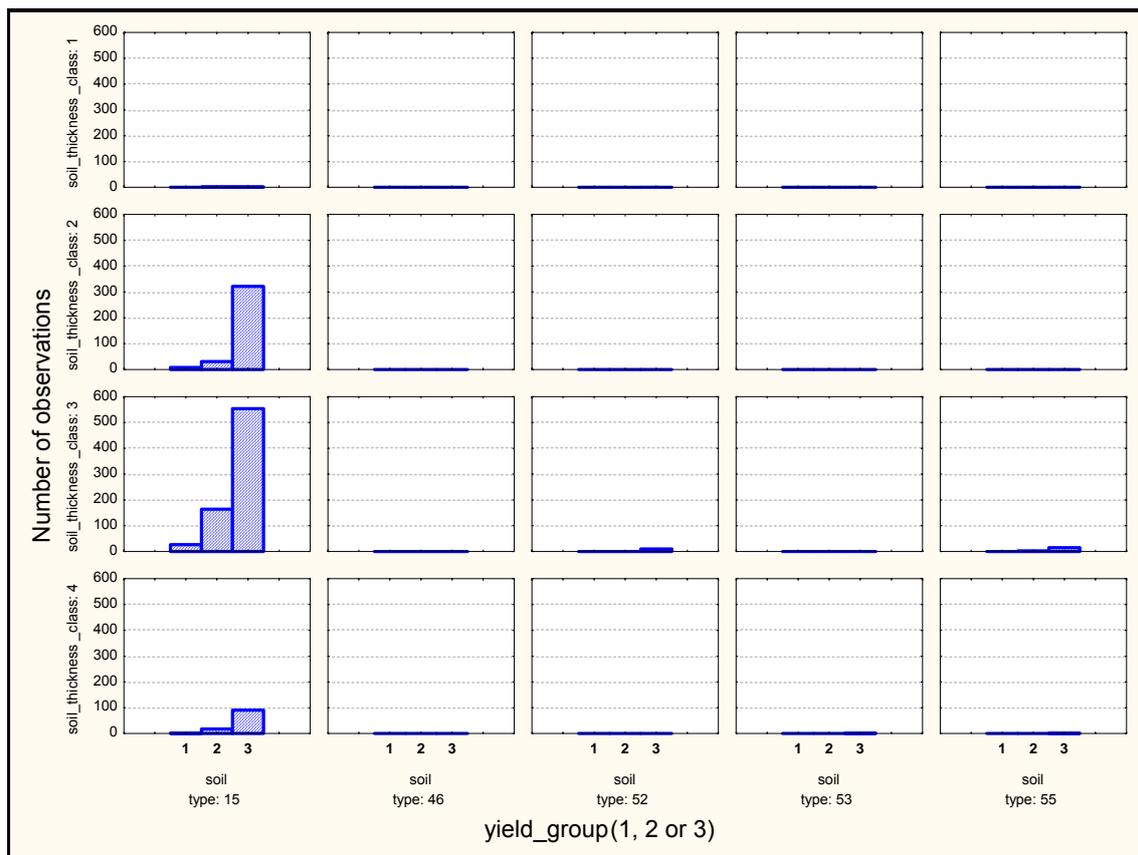
age (yr)	Grey poplar			Black locust			Black pine		
	on			on			on		
	good	medium	poor	good	medium	poor	good	medium	poor
2	0,0	0,0	18,6	0,0	0,0	366,4	0,0	0,0	8,9
3	1,6	0,0	24,9	0,0	0,0	185,6	0,0	0,0	53,9
4	0,0	4,7	14,9	0,0	64,8	236,5	0,0	0,0	49,1
5	0,0	0,0	3,6	5,2	92,6	110,6	0,0	0,0	50,6
6	4,7	0,0	7,7	2,1	97,0	81,7	0,0	0,0	33,4
7	2,9	2,4	11,3	15,5	48,1	37,8	0,0	0,0	31,3
8	0,0	0,0	9,5	7,3	20,0	66,5	0,0	0,0	26,0
9	0,0	0,0	2,3	2,0	6,7	26,2	0,0	0,0	44,8
10	3,6	0,0	16,3	8,8	12,7	53,0	0,0	0,0	15,9
11	0,0	0,0	40,5	0,0	68,3	63,9	0,0	0,0	51,3
12	1,0	20,8	36,7	1,4	54,2	29,4	0,0	0,0	104,5
13	0,0	9,8	43,8	0,0	57,0	84,4	0,0	0,0	95,5
14	6,2	9,7	30,9	0,0	129,6	80,3	0,0	0,0	49,0
15	0,0	36,2	51,9	0,0	43,9	86,2	0,0	0,0	76,8
16	3,3	12,8	38,2	2,7	44,7	111,1	0,0	0,0	109,4
17	0,0	4,7	6,8	0,0	3,6	114,3	0,0	0,0	101,2
18	0,0	2,9	7,3	0,0	40,5	109,8	0,0	0,0	47,4
19	0,5	0,0	0,0	0,0	21,1	111,7	0,0	0,0	59,7
20	0,0	0,0	0,0	0,0	3,8	96,6	0,0	0,0	170,3
21	2,3	10,5	2,7	0,0	67,2	78,9	0,0	0,0	79,5
22	0,6	8,4	1,3	0,0	6,7	138,1	0,0	0,0	123,9
23	0,0	7,0	0,0	0,0	0,0	68,1	0,0	0,0	54,2
<b>Total</b>	<b>26,6</b>	<b>130,0</b>	<b>369,3</b>	<b>45,0</b>	<b>882,5</b>	<b>2337,0</b>	<b>0,0</b>	<b>0,0</b>	<b>1436,5</b>



**Figure 1. Distribution of the forest area in the test site by species and yield group (in ha).**  
(Az erdőterület (ha) megoszlása fajonként, és fatermési csoportonként. Good: 1-2. fatermési osztály;  
medium: 3-4. fatermési osztály; poor: 5-6. fatermési osztály.)



**Figure 2. Typical marginal agricultural land, and afforested area in the region of the test site. (A teszt terület körzetében található tipikus felhagyott szántó és erdősítés.)**



**Figure 3. Distribution of the forest area (number of stands) by soil type, soil thickness and yield group. (See text for explanations.)**

(Az erdőterület megoszlása (erdőrészletek száma) talajtípusonként, a termőréteg vastagsága és a fatermési csoportok szerint. 15-ös talajtípus: humuszos homok.)

However, it must be added that real-life projects would not necessarily have this information. Rather, preliminary information or direct observations are needed to obtain auxiliary information that could relate soil fertility to stand characteristics, e.g. yield capacity of the stands. In our study, however, an attempt was made to use soil depth information to design the sampling for the estimation of emissions and removals (see section 3.4.5.2). In the test site, soil depth information was available from the National Forestry Database.

### **3. Monitoring of GHG emissions and removals in AR JI projects. Improved guidance with examples and experience from the Hungarian test site**

In this main section of the report, the carbon stock changes in the Hungarian test site will be analyzed, and related methodological issues will be discussed. Based on these, guidance is given on practicable options that any future project monitoring methodology could adopt. This guidance is given in three ways. The sections below will contain general guidance in grey text boxes (like the one a few lines below). Additionally, guidance is given on methodological issues that have not been tested in the test site, mainly because they have been regarded as standard knowledge. Finally, examples are given from the experiences in the Hungarian test site, for which a complete GHG budget has been developed.

#### **3.1. Outline of the monitoring of AR projects**

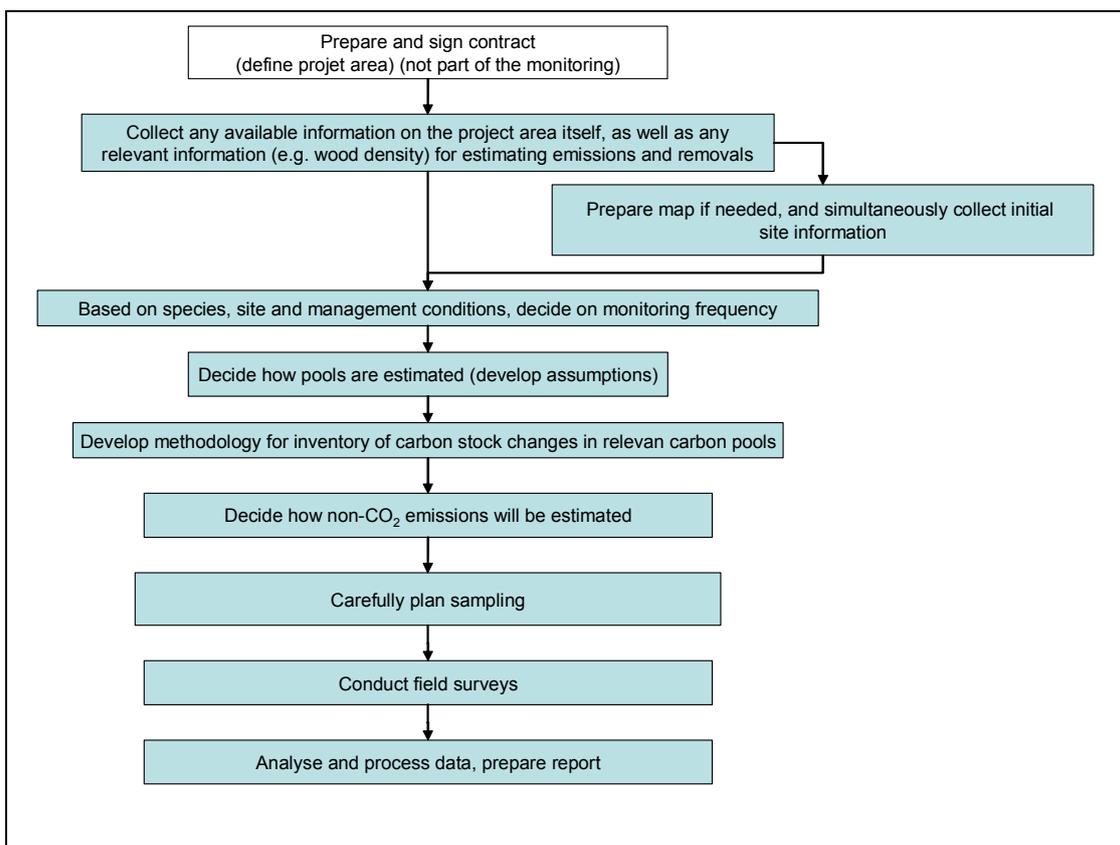
- Keep costs related to monitoring as low as possible.
- Develop and apply methods that are practicable.
- Obtain as much already available information on the project area and its history as possible.
- Collect information on stand productivity during the establishment of the project to enable stratification during monitoring (see later).

As mentioned above, the methodology of monitoring AR projects have only been discussed in a few documents. However, these documents cannot, and do not, detail all steps, procedures and methods that are eventually needed to conduct the monitoring. This is acceptable on one hand, because there are many procedures that can be regarded as standard, not requiring any further elaboration. However, there are some other ones that could be used as options, or for which certain considerations could be made with regard to the particular conditions of the AR projects.

These considerations are first of all related to the requirements that the costs of any operation in the project be low. After the establishment and early tending of the stands, one of the largest sources of costs can be monitoring costs. This is important for AR projects, as well as for CDM projects (Schlamadinger et al. 2004a, Somogyi et al. 2004). These costs should at least be balanced with the benefits, first of all those from the sequestration of carbon. Therefore, the monitoring methodology should be simple enough if it is to be cheap, while it should still be able to reasonably capture relevant emissions and removals in the project. The challenge for each monitoring program is to find this delicate balance. In trying to find this balance, various methodological options should always be considered, from using already available and accurate information to modeling and to optimized field measurements.

In any event, some terms need to be defined, or their particular definition in the monitoring of the AR projects must be specified. Where it seems justified, we provide, or cite, definitions. First of all, the term „monitoring“ itself encompasses periodic survey and comparison of forest status at subsequent points in time  $t_1$  and  $t_2$ . In contrast, the term „inventory“ is used for the assessment of forest status at a particular time point  $t$ . Other terms are also defined in the document in the relevant places.

As to the monitoring in general, it involves several types of activities and several steps (Figure 4). It is important to note that, in order that the total costs are minimized, the steps should be followed carefully. These steps, and the procedures involved are described in greater details in the specific sections below.



**Figure 4. The main activities and steps that are required in the monitoring of AR projects.**  
(Az erdősítések monitoringja során szükséges főbb tevékenységek és lépések.)

The idea of AR projects was raised with the overall goal in mind that these projects could contribute to the efforts to remove CO<sub>2</sub> from the air at a reasonable cost, while also providing additional benefits to local communities. Even if these additional benefits materialize, they cannot be claimed as CO<sub>2</sub> benefits. The investor will most likely be mainly interested in the net carbon benefits, which are the difference of total costs and the market value of the CO<sub>2</sub> sequestered.

Since monitoring costs are parts of the total costs, they must be kept as low as possible, while making it possible to conduct the monitoring at the required accuracy. To demonstrate this in an example, suppose that the market value of one tonne of CO<sub>2</sub> is €48 (4\*12). This is equivalent to a price of €176 (4\*44) of one tonne of C<sup>7</sup>, because 44/12 tonnes of CO<sub>2</sub> contain 1 tonne of C. Suppose also that the cost of 1 ha of afforestation is €1760. In this case, the sequestration of at least 10 tonnes of C is necessary to offset the establishment costs. Then monitoring costs are additional, so it is not really worth going to the forest to monitoring carbon stock changes until these 10 tonnes of C are fixed, which may take 3-5 years in the temperate zone. Even after that, only cheap, effective, yet accurate monitoring programs are required. This calls for pragmatic methods in each phase of the monitoring.

### 3.2. Mapping of the AR project area

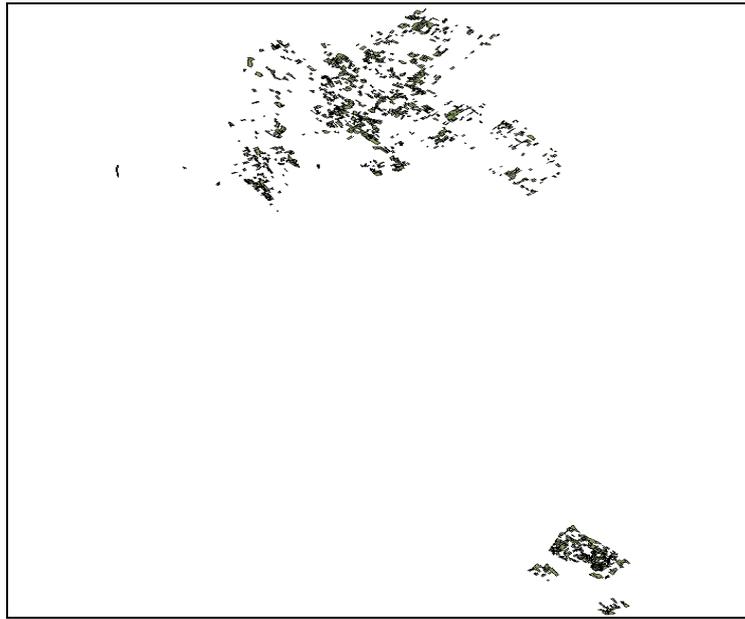
- Obtain already available information on the project area.
- If maps are available, check their quality.
- If mapping is necessary, collect information on the growth conditions for stratification simultaneously during mapping.
- Store mapping data in digital format if possible.

An exact mapping of the project area is inevitable in all projects. This mapping is most probably done for the contract of the project anyway. However, the project contract may only require the mapping of the administrative (i.e. outside) borders of the project, whereas more detailed mapping may be necessary for the monitoring (see later).

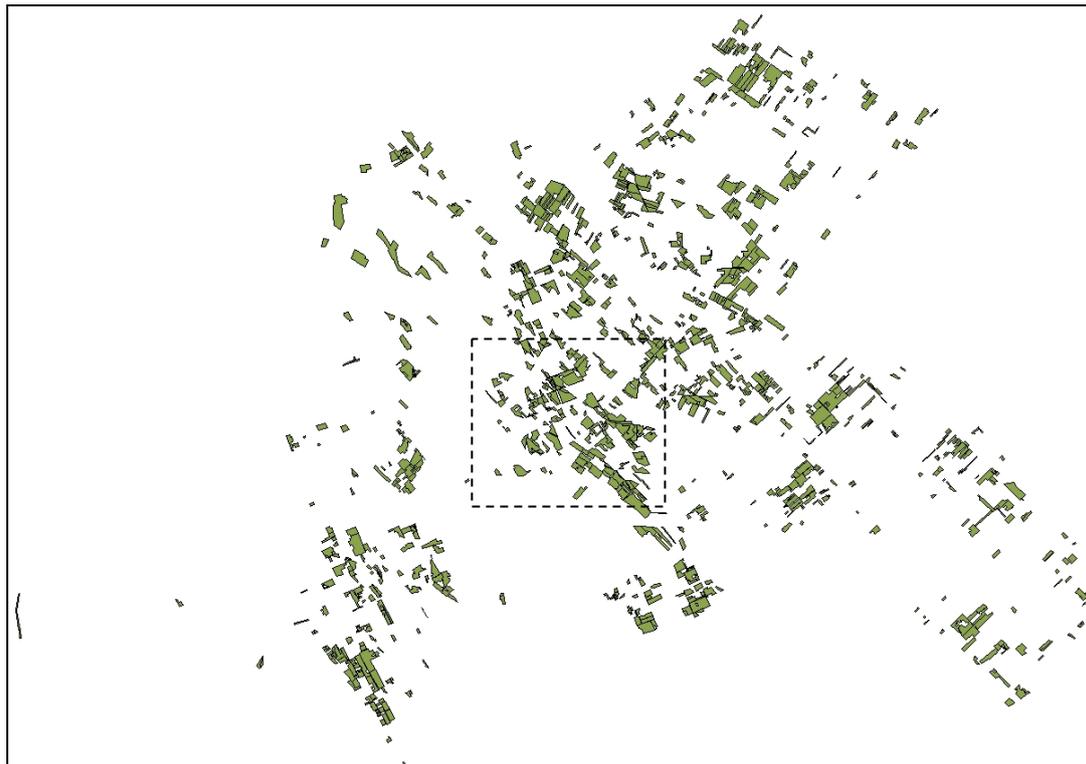
In the project test site, there are many forested blocks (i.e., the forest area is scattered in the landscape, organized around two bigger blocks, due to the diverse ownership structure, and partially due to the diverse ecological conditions, Figure 5-Figure 8). This was advantageous for the monitoring program, because the smaller and bigger individual blocks (containing one or more compartments) had to be mapped separately, which allowed also to collect that type of additional information that may be necessary for stratification.

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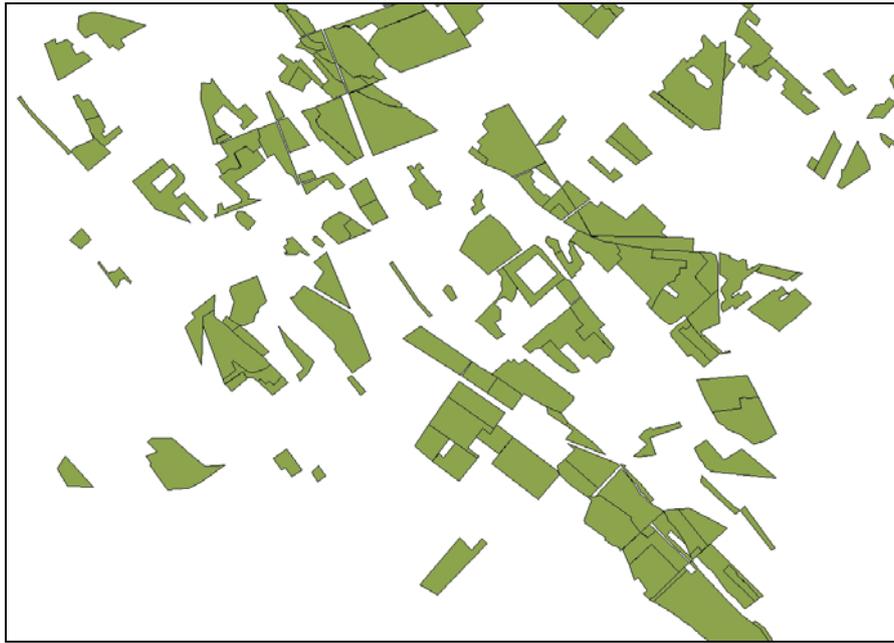
<sup>7</sup> The price of gold is 11,5 million € per tonne.



**Figure 5. Map of the total project area in two big blocks.**  
(A teljes projekt területe két nagyobb blokkban található.)

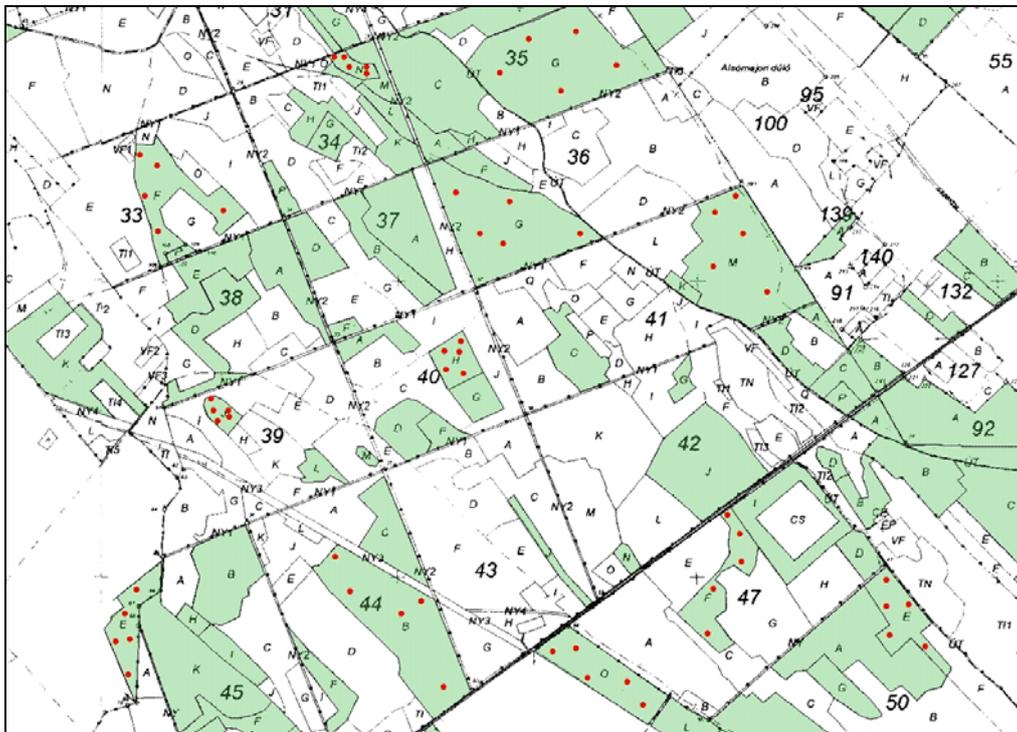


**Figure 6. Overview of a bigger block within the project area.**  
(Egy nagyobb blokk áttekinthető térképe.)



**Figure 7. Overview of a part of the above block with a smaller block, in which individual forest compartments are found. The compartments were established by considering site and stand characteristics (like species, age, site class etc.).**

(A fenti blokkból kinagyított részlet, ahol az egyes erdőtagok is láthatók.)



**Figure 8. Enlarged part of the test site. The green parts are real forest compartments of the test site; the red dots indicate the method of clustered soil sampling (see in section 3.5).**

(A teszt terület egy kinagyított része. A zöld részek a teszt terület tényleges részei; a piros pontok a csoportos talajmintavétel módszerét demonstrálják; l. a 3.5. fejezetet.)

### 3.3. General issues of monitoring the GHG emissions and removals

- Obtain and use already available information on the project area.
- Check if survey data can be taken from another organization (e.g. the national forest authorities).
- Consider using models if they can be regarded as reliable.
- Focus efforts on pools and parts of the forest area where most GHG emissions and removals are expected to happen.

Whereas mapping must be done only once in the project lifetime (if the project area does not change for whatever reason), however, the GHG emissions and removals must be estimated from time to time. Since this estimation is the most expensive, and most resource demanding part of the whole monitoring exercise, attention should be paid to accurate, but cost-effective methods. Therefore, before any field survey, an analysis is necessary concerning what to measure and how. Planning ahead always pays off.

#### 3.3.1. Considerations on sources and sinks (including carbon pools)

- Check if a pool can be assumed to be not a source.
- Assess the possible increase in a pool, and exclude pools with slow increase, because it may not be worth spending on the measurements of small, although positive, changes.
- Check operations with possible emissions, and try to avoid them, because monitoring is unavoidable if these operations are implemented.

Table 7 is prepared to summarize the above, and to add more considerations and to provide a general overview of the monitoring task in the project area. Such an overview has been found useful to organize and plan the monitoring work, and may be useful in “real-life” projects.

The monitoring of AR projects is aimed at the cost-effective, while accurate estimation of emissions and removals of both CO<sub>2</sub> and emissions of non-CO<sub>2</sub> gases. Therefore, one should avoid costly assessment of small or zero emissions and removals. This is reflected in the table prepared for our test site. In case of land-based CO<sub>2</sub> emissions and removals, the estimation on the test site focused on the estimation of carbon stock changes of the terrestrial carbon pools. No large changes were expected in the dead wood pool, because, under the Hungarian conditions, it takes decades until some deadwood is accumulated due to the relatively intensive management of the plantations. Anyway, even if there is some minor accumulation of deadwood, it only means that CO<sub>2</sub> removals are underestimated, thus, the accounting will be acceptable to the international community.

**Table 7. Overview of gases and pools covered in the test site, and also the level of Tier that was applied.**

(A teszt területen monitorozott gázok és széntárolók áttekintése, a monitorozás intenzitásának (Tier) megjelölésével.)

Carbon Pool					CO <sub>2</sub> emissions from liming	N <sub>2</sub> O emissions from fertilization
Aboveground biomass (AB)	Belowground biomass (BB)	Soil (SO)	Deadwood (DW)	Litter (LI)		
To be measured using Tier 2 or 3	To be estimated using Tier 1	To be measured using Tier 2/3	Likely to be zero, not to be measured using Tier 1	Not known, to be measured using Tier 2/3	Not occurring, therefore not to be measured	Not occurring, therefore not to be measured

In case of CO<sub>2</sub> emissions that are not related to the terrestrial carbon pools (such as emissions from liming or fertilization) and in case of non-CO<sub>2</sub> emissions, the estimation is usually based on activity data (e.g. amount of fertilizers used) and related emission factors (e.g. CO<sub>2</sub> content of lime used). It is noted here that, due to the facts that the area is calcareous and limitation to biomass growth is predominantly related to water deficit, neither liming, nor fertilizers are used in the project area. Thus, related emissions are not estimated, and assumed as zero.

Because of all the above, the monitoring of the test site was designed to focus on the needs of the monitoring of carbon stock changes.

### 3.3.2. Considerations on the time frames

- Avoid surveys as long as the stands are young.
- Adjust the number of years between two inventories to the rate of expected changes in the biomass stocks.
- In case of frequent exceptional years (repeated years of excellent growth conditions, or repeated occurrence of disturbances) increase the frequency of field surveys.

Monitoring of a project area to estimate changes obviously involves monitoring activities over many years. Quite naturally, this could not be done during the three years of the CarboInvent Project. Thus, it was not possible to directly monitor any changes in the forest area, or, more importantly, to directly measure the changes of the carbon stocks of any pools concerned. This fact made it impossible to use any time series based on measured/observed values.

To overcome this problem, two methods were used. One was, as planned, the use of so called false time series. This means that, instead of monitoring a stand over decades, we collect data on stands of similar conditions where the age of the stand is different. This

way, any required stand characteristic can be related to stand age, which is equivalent to relating the stand characteristic to time. The other method was, also as planned, to use a model for the estimation of certain stand characteristics that have been prepared using similar methods. Of the many stand characteristics, the ones that were required in this analysis, i.e. height, diameter and volume over time, were estimated using a carbon accounting model, called CASMOFOR. This model is described in more details in section 3.4.2.

It must be noted, however, that the first method (the “false time series” method) can also be used to *validate* the yield tables in the model. In case of other pools (e.g. for the soil carbon pool), the false time series *themselves* were used to estimate stock changes (also because no models exist for these pools in Hungary).

It must also be emphasized that, although an attempt was made to estimate carbon stock changes at consecutive inventory situations, i.e. at various ages of the stands, it was even theoretically impossible to carry out carbon stock changes over time during the CI project, because the measured data were only available for one time shot, i.e. when the oldest stands were 22 years old and the young ones were one year old. For earlier or later inventories, only modeling was possible. However, in “real” AR projects, the methods of estimation are similar for these earlier or later inventories. The only exceptions are when the afforestation has not been finished yet, i.e. during the first inventory. In this case, only a certain part of the project area can be inventoried, and only a partial time series can be constructed available, because the stands are still young (e.g. for the carbon stock changes in soils, see later). In these situations, sampling should only be done considering the existing stands and/or age classes, and additional sampling should be conducted as time passes.

### 3.3.3. Sampling designs

In each monitoring, sampling plays a crucial role. Although complete assessment may provide us with “complete” information, e.g. the information about each individual, in large populations such a survey is not economically or practically feasible. When the destruction methods need to be used, complete enumeration is inapplicable. As Shiver and Borders (1996) pointed out, sampling may be even more reliable than complete enumeration because more time can be taken to make careful measurements, while sampling error could be kept small.

The main sampling condition is that the selected sample represents the whole studied population. To meet this requirement different sampling designs were proposed. These designs can be applied to all carbon pools to be discussed later. Below the following sampling designs are described: simple random sampling, systematic sampling, stratified sampling, multi-stage and multi-phase sampling design.

A great number of publications devoted to sampling techniques in the literature, e.g. Cochran (1977), Zöhrer (1980), Šmelko (1985), Schreuder et al. (1993), Kish (1995), Shiver and Borders (1996), Thompson (2002), Hush et al. (2003). Thus, in the

following text we only shortly describe the main characteristics of the above mentioned sampling designs.

**Simple random sampling**, as the most basic probability sampling method (Shiver and Borders 1996), is based on the completely random selection of the sampling units. This means that each unit in the population has the same probability to be included in the sample. To apply this design, a certain frame, e.g. a list of all individuals in the population, has to be developed. This brings several difficulties in forest inventorying. For large areas, such a frame can be developed only using aerial photos or maps. The location of the selected sampling units on the ground can be difficult and very time-consuming. Another problem of random sampling design is that the selected sampling units can be clumped together, which can make the sample non-representative.

If a **systematic sampling** is applied, sampling units are located in a systematic pattern across the area of interest. This design ensures that the entire area is evenly covered with the sample plots. Another advantage over the random sampling is that no frame prior to sampling has to be developed. On the other hand, in periodic populations there is a risk that the sample obtained from systematic sampling will not represent the whole studied population. Therefore, when systematic sampling is to be used in such populations, the periodicities need to be identified a priori to structure the appropriate design that will avoid them. This is especially important in AR projects, since stands are often established as plantations with rows to specific orientation.

For heterogeneous areas it is advantageous to use the **stratified sampling**, i.e. the area of interest is divided into non-overlapping sub-units called strata that form relatively homogenous units. The strata are then sampled separately using either random or systematic sampling design. The advantage of stratification is that it reduces the standard errors of sampling, and also that it provides us with the estimates for each stratum as well as for the whole population.

**Multistage sampling** is used when inventorying large areas or populations. Within this method, the population is first broken down into primary units. Each primary unit is then broken down into secondary units, which in turn can be broken down into tertiary units etc. depending on the order of the sampling. Sampling proceeds in several steps, while their number equals the order of the sampling. If, a two-stage sampling design is applied, in the first step a sample of primary units is selected. Afterwards, within each chosen primary unit a set of secondary units is selected and measured.

Similarly to the previous design, **multiphase sampling** consists of several phases. **Double or two-phase sampling** is the most frequent one. In the first phase, large amount of information are collected using an easy, time- and cost-efficient way, e.g. the information is estimated. In the second phase, a smaller sample is selected, on which the information is collected by a more precise method. Then, the regression or the ratio between the information from the first and the second phase is calculated. This relationship is used to correct the information from the first phase. This sampling design can be efficient in the situations, where more complete and detailed knowledge than usually available is required. However, to apply this design high correlation between the first-phase and the second-phase samples is expected.

**PPS sampling** stands for the sampling design, where the probability that the unit will be included in the sample, is proportional to size (PPS=probability proportional to size). Finally, **3P sampling** is a modification of the PPS design developed for use in forestry by Grosenbaugh (1963, in Shiver and Borders 1996) meaning that the units are selected with probability proportional to the predicted value, e.g. volume.

Once the sampling design had been selected, the shape of sample plots has to be chosen. Sample plots can be of a various shape. Usually, they are square, rectangular or round. Circular sample plots are often preferred over the other two ones because it is easier to establish them and also because the amount of edge, which represents a problem whether a particular tree is inside or outside the sample plot, is minimum for a circle.

### 3.3.4. Suggested sample scheme

The sampling design that could be most often used in AR projects is based on the modern sampling techniques. In a high degree systematic sampling is applied in combination with the sampling techniques reducing the variability of the results, e.g. stratification, and the methods working with unequal probabilities, which optimize the costs and the assessment error. The proposal fulfils the general demands put on the monitoring systems. In addition, the design was developed in the way that the collected data can be used for the modeling of forest ecosystems.

Two variants of sampling design are presented with regard to the type of the inventoried area, the first variant for one large area, while the second one for the set of several smaller areas.

#### **Variant 1 – large homogenous areas**

As mentioned, variant 1 is aimed at one larger area (e.g. of size 10 thousand ha) with a high degree of homogeneity considering the assessed variable (i.e. the whole area was afforested with same or very similar species composition in a short time). In this case, biomass amount will be assessed using the systematic sampling, i.e. the required number of sample plots will be distributed in a systematic grid over the whole area to be inventoried. The number of sample plots depends on the variability of the assessed variable, and on the desired accuracy of its assessment. Assuming a variability between plots of around 30% (this biomass variability refers to variability of the biomass amount if the area to be inventoried is divided into plots of size 500m<sup>2</sup>), and a desired accuracy of biomass assessment determined of 5 %, as well as an error from the sampling assessment of the individual biomass categories within the primary sample plot (see description below, 5 %), the biomass within the primary sample plot can be estimated with a relatively high accuracy of ± 10-15% with 95% confidence. The required number of primary sample plots is obtained from the following formula:

$$n = \left( \frac{t_{\alpha/2} \cdot VK_X \%}{\sqrt{ER_X \%^2 + ER_{SP} \%^2}} \right)^2 \quad \text{[Equation 1]}$$

where:

- $n$  - number of primary sample plots
- $t_{\alpha/2}$  - critical value of Student's  $t$  distribution at desired confidence level (2)
- $VK_X\%$  - coefficient of variation of assessed variable  $X$  (e.g. 30 %)
- $ER_X\%$  - relative desired accuracy of assessed variable  $X$  (e.g. 5 %)
- $ER_{SP}\%$  - relative accuracy of assessed variable  $X$  within the primary sample plot (e.g. 5 %)

The total biomass amount within the whole inventoried area will be estimated as follows:

$$X_T = \bar{X} \cdot \frac{A_T}{a} \quad \text{[Equation 2]}$$

Where:

- $X_T$  - total biomass amount within the whole inventoried area ( $=\sum_i X_i / N$ )
- $\bar{X}$  - average biomass amount within the primary sample plot
- $A_T$  - total size (area) of the whole inventoried area
- $a$  - area of the primary sample plot

The accuracy of biomass amount estimation depends on the variance of biomass estimates, the number of primary sample plots and average accuracy of biomass estimation within one primary sample plot according to the following formula:

$$SE_X \% = \sqrt{\left(\frac{VK_X \%}{\sqrt{n}}\right)^2 + SE_{SP} \%^2} \quad \text{[Equation 3]}$$

where:

- $SE_X\%$  - relative standard error of the estimation of the assessed variable  $X$
- $VK_X\%$  - coefficient of variation of assessed variable  $X$
- $n$  - number of primary sample plots
- $SE_{SP}\%$  - relative standard error of the estimation of assessed variable  $X$  within the primary sample plot

## **Variant 2 – fragmented project area**

This variant is aimed at the biomass assessment in the case a number of smaller  $A_r$  areas are distributed across a large area. The first step is to stratify the  $A_r$  areas based on known data of the stands (e.g. age, species composition, as well as site categories) into very similar and homogeneous groups. The required number of primary sample plots will be estimated in a similar way as in Variant 1 according to following formula:

$$n = \left( \frac{t_{\alpha/2} \cdot \left( \sum_{j=1}^M w_j \cdot VK_X \%_j \right)}{\sqrt{ER_X \%^2 + ER_{SP} \%^2}} \right)^2 \quad [\text{Equation 4}]$$

where:

- $n$  - number of primary sample plots
- $M$  - number of strata
- $t_{\alpha/2}$  - critical value of Student's  $t$  distribution at desired confidence level
- $w_j$  - proportion of the  $j^{\text{th}}$  stratum
- $VK_X \%_j$  - coefficient of variation of assessed variable  $X$  in the  $j^{\text{th}}$  stratum
- $ER_X \%$  - relative desired accuracy of assessed variable  $X$
- $ER_{SP} \%$  - relative accuracy of assessed variable  $X$  within the primary sample plot

After the data acquisition in the field, weighted mean and standard deviation, as well as coefficient of variation, and standard error are calculated. The total biomass amount in the inventoried area is estimated from the following formula:

$$X_T = \left( \sum_{j=1}^M w_j \cdot \bar{X}_j \right) \cdot \frac{A_T}{a} \quad [\text{Equation 5}]$$

where:

- $X_T$  - total biomass amount in the inventoried area
- $w_j$  - relative proportion of  $j^{\text{th}}$  stratum
- $\bar{X}_j$  - average biomass amount in  $j^{\text{th}}$  stratum
- $A_T$  - total area of AF areas in the inventoried region
- $a$  - area of the primary sample plot
- $M$  - number of strata

The relative accuracy of total biomass amount estimation can be determined as follows:

$$SE_X \% = \sqrt{\left( \frac{\sqrt{\sum_{j=1}^M w_j \cdot SD_j^2}}{\sum_{j=1}^M w_j \cdot \bar{X}_j} \right)^2 + SE_{SP} \%^2} \quad [\text{Equation 6}]$$

where:

- $SE_X \%$  - relative standard error of the estimation of the assessed variable  $X$
- $w_j$  - relative proportion of  $j^{\text{th}}$  stratum
- $SD_X \%$  - standard deviation of the assessed variable  $X$
- $\bar{X}_j$  - average biomass amount in  $j^{\text{th}}$  stratum
- $M$  - number of strata
- $n$  - number of sample plots

$SE_{SP}\%$  - relative standard error of the estimation of assessed variable  $X$  within the primary sample plot

### 3.3.5. The proposed sampling design

The proposed sampling design is based on the modern sampling techniques. In a high degree systematic sampling is applied in combination with the sampling techniques reducing the variability of the results, e.g. stratification, and the methods working with unequal probabilities, which optimize the costs and the assessment error. The proposal fulfils the general demands put on the monitoring systems. In addition, the design was developed in the way that the collected data can be used for the modeling of forest ecosystems.

To assess the status or the development of biomass amount within a larger area, the afforested sites will be stratified according to their tree species composition and age structure, the information obtained from the management records. From the sites within one stratum, the sample is selected using the PPS sampling technique (Probability Proportional to size). Within the chosen sites, sampling units will be established in the systematic grid, in which the biomass amount will be estimated with terrestrial measurements.

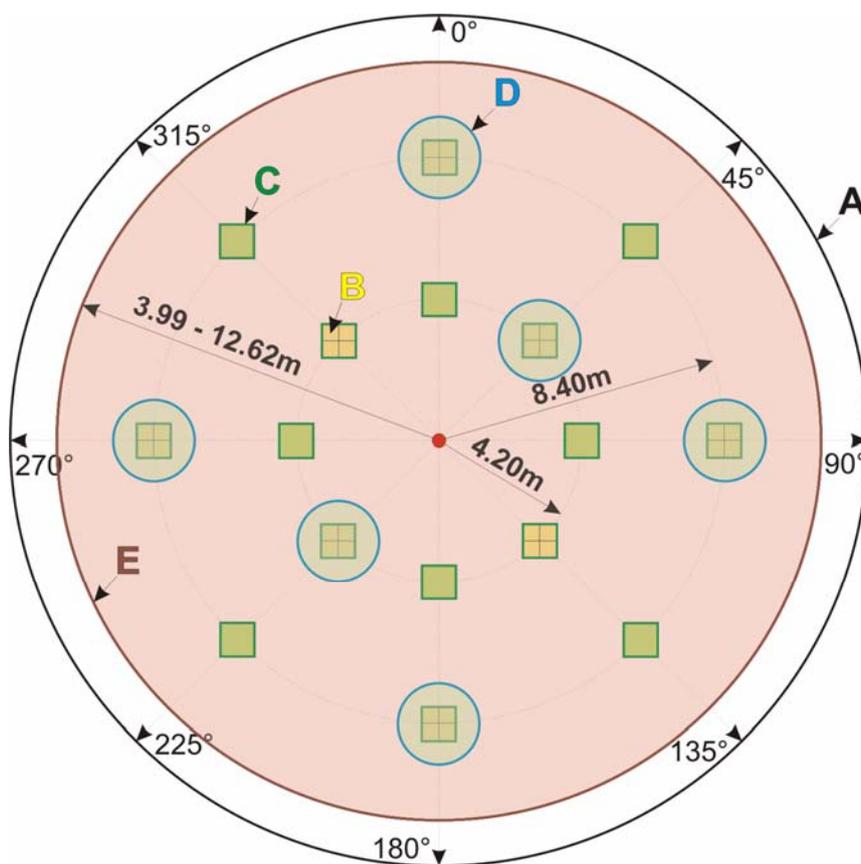
In each grid point, a sample plot is established. It is practical to use the same sample plots to obtain information for all pools, however, depending on the sampling intensity for the different pools, not all plots may be used for all pools.

The sample plot is of a circular shape and its size and, depending on the stand, can be e.g. 500m<sup>2</sup> (Figure 9). Inside the plot, the subplots and the information to be collected is described in Table 8.

**Table 8. Example for the information to be recorded in the sample plots by subplot (see also Figure 9). Note that the subplots C and D are usually not practical to establish.**

(Példa a minteterületeken belül található mikro-mintaterületek elhelyezkedésére, és a felvett adatokra (l. a **Figure 9.** ábrát is). A C és D mikro-mintaterületekre általában nincs szükség.)

Plot	Example for area [m <sup>2</sup> ]	carbon pool	Characteristics for which data is to be collected
A	500	dead wood	coarse woody debris
B	(1) 2	Soil, litter	Soil, litter
C	4	tree biomass	woody plants (shrubs and trees) with the height up to 130cm
D	18.85	tree biomass	woody plants (shrubs and trees) with the diameter at breast height $d_{1.3m}$ from 0.1cm to 7cm
E	50-500	tree biomass	woody plants (shrubs and trees) with the diameter at breast height $d_{1.3m}$ above 7cm



**Figure 9. Example of a sample plot for the assessment. For explanation of letters, see text.**  
(Példa a mintaterületek elrendezésére egy felállási pontban.)

### 3.3.6. Basic set of collected information in one sampling unit

On each sample plot, the information to be assessed is usually the same as the information collected in standard forest inventories for trees. This procedure is not detailed here. Only a few remarks are made concerning estimating soil and litter samples.

The soil and litter samples are taken, according to the approved methodology, in the sub-plots B (Figure 9) of size of 25x25 or 50x50 cm. When harvesting the samples for the laboratory analysis it is necessary to ensure that the collected material represents the sample unit.

The quantification of litter may be based on double sampling procedure. In the first phase, the amount of litter is measured on the first plot, then, in each other sub-plots, it is estimated by comparing it with the amount in the first reference sub-plot. The amount of the litter on the first reference subplot represents 100%. In the second phase, four sub-plots are selected to collect the material for the laboratory analyses for the carbon amount. The first reference sub-plot needs to be always included in this phase. From the paired values (estimation vs. measurement), a regression is calculated. The resulting equation looks as follows:

$$y = a + b \cdot x \quad \text{[Equation 7]}$$

where:

- $y$  - Measured value of the assessed parameter from the second-phase
- $a$  - Intercept
- $b$  - Regression coefficient
- $x$  - relative biomass proportion of the second-phase sample estimated in the first phase.

This regression is the used to adjust the estimated values and to refine the mean of the assessed parameter in the area of the sub-plot. The refined mean of the assessed parameter ( $\bar{y}_{COR}$ ) is obtained from the following equation (Shiver and Borders 1996):

$$\bar{y}_{COR} = \bar{y}_1 + b \cdot (\bar{x}_2 - \bar{x}_1) \quad \text{[Equation 8]}$$

where:

- $\bar{y}_1$  - arithmetic mean of the assessed parameter from the second-phase sample
- $b$  - regression coefficient from the equation [1]

$\bar{x}_1$  - arithmetic mean of the estimated relative portions from the second-phase sample

$\bar{x}_2$  - arithmetic mean of the estimated relative portions from the first-phase sample.

The standard error of the refined mean (SE) of the assessed parameter is calculated with the following formula (Shiver and Borders 1996):

$$SE = \sqrt{\frac{SD^2}{n1} \cdot \left(1 - \left(\frac{n2 - n1}{n2}\right) \cdot \rho^2\right)} \quad \text{[Equation 9]}$$

where:

$SD$  - standard deviation of the measured values from the second phase

$n1$  - number of measured samples in the second phase

$n2$  - number of estimated samples in the first phase

$\rho$  - correlation coefficient.

The real value of the assessed parameter would fall within the interval  $\bar{y}_{COR} \pm SE$ .

For the soils, this method cannot be applied, and the carbon content of all samples must be determined in the laboratory. For both litter and soil, a per hectare value is calculated, which is then used in connection with the total area of the strata to get total carbon estimates.

### 3.4. Monitoring of changes in the biomass carbon pools

#### 3.4.1. General issues

- Check if models are available for young stands. If yes, check how reliable they could be under the project conditions.
- Avoid extensive measurements of small plants.
- Get as accurate estimates for biomass as possible, because it is most likely the pool in which the carbon stock changes are largest.

Most probably, the changes of the carbon stocks in the biomass pools are the most important information in most afforestation projects, and it was expected to be the case

also in the test site, too. Therefore, it seemed appropriate that most attention was paid to the monitoring of these pools. Also, most data at the least cost, and the most accurate information can be obtained for these pools. Thus, the methodology in general should focus, and focuses on the Hungarian test site, on the estimation of carbon stock *changes* in the biomass carbon pools.

These *changes* of carbon stocks can be estimated, as suggested by the IPCC GPG, using one of two basic methods, which require different types of forest inventory. Either growth and harvest (plus any other disturbances) are estimated to account for all changes during a certain period of time (“default method”, or “process method”), or the difference is taken between stocks at two inventory occasions (“stock change method”). In the “process method” method, all processes should be separately estimated that bring about any change in the carbon stocks. Although theoretically it would be possible to measure all these processes in a project, these measurements would require a constant attention, and even then it may happen that some processes are not observed, e.g. when trees are removed illegally. Also, the accuracy of the estimation of certain processes, e.g. that of tree growth, would be low or would require costly procedures. Therefore, and for other practical reasons, it seems more practical in afforestation projects to estimate stocks at two consecutive times, i.e. to apply the stock change method.

With the stock change method, the main steps to be taken are somewhat similar to the general procedures for the whole monitoring and are the following:

1. collect all available information before planning or taking any measurements
2. decide on timing of first inventory and on monitoring frequency
3. conduct inventory at the first time
  - a. prepare sampling strategy (sampling intensity, places of sampling etc.) for field sampling
  - b. conduct field work to collect project-specific data
  - c. check and process data
  - d. analyze results including uncertainty estimates, and take additional measurements if needed
4. conduct inventory at the second time etc.

As it was mentioned before, it was not possible to have two surveys of stocks on the test site during the duration of the CarboInvent project. Therefore, modeling was needed to calculate changes of carbon stocks on the test site over age.

### 3.4.2. Using models. The CASMOFOR model

- Check model availability for the project area.
- Make sure the model contains assumptions, variables, parameters etc. that are applicable in the project area.
- Check if the model has built-in estimates, parameters etc. that could be used in the monitoring even if the model cannot be applied as a whole.

For the above mentioned modeling, a model called CASMOFOR was used. The first version of this model was developed before the beginning of the CarboInvent project. During CarboInvent, this model was developed to become a more powerful, and a user friendly tool enabling the estimation of carbon stock changes in various afforestation scenarios under the Hungarian conditions. Moreover, the model could be adapted very easily to other countries. This version 2 of the model, called CASMOFOR, was put on the web and can be accessed from there, together with its full documentation ([www.scientia.hu/casmofofor](http://www.scientia.hu/casmofofor)). Therefore, this model is not described here in greater details.

Shortly, this model takes a few pieces of information to run. This information is the afforested area by species, site type and planting year, and is needed to define any afforestation scenario. The model itself uses pre-set stand growth, allometric and other information to estimate the total amount of carbon fixed in the afforestation system. The model estimates the carbon stock changes in several pools, as all processes that may be important in a forestry system, including e.g. the amount of carbon in the harvested wood products are modeled (Figure 10). Thus, the output of the model includes carbon stock changes in several pools, and estimates of processes that should be considered in the Kyoto accounting, but it is of course possible to only consider those carbon stock changes that are relevant for the “Kyoto” afforestation projects. The procedures and results of the estimation of the carbon stock changes in the test site over time using this model are described in Chapter 3.8.

### 3.4.3. Validation of the model

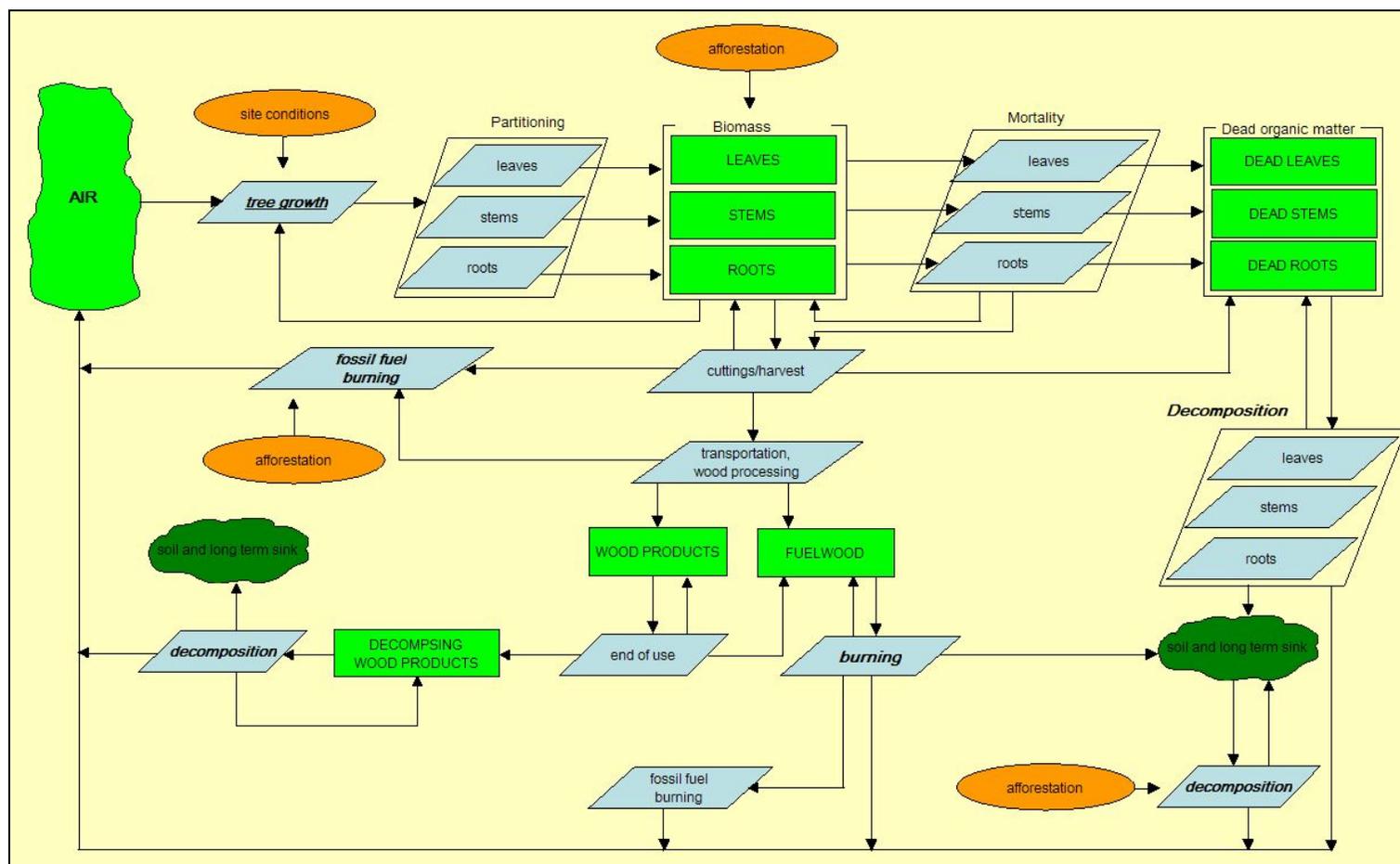
However, higher accuracy and transparency of reporting would call for the validation of at least the increment (yield) information, which is the main driver of the estimation of removals of CO<sub>2</sub> by the trees. This is because most models can only use yield table information that is usually developed for whole countries or large regions, and to apply yield tables to the project scale may involve large bias even if the yield table provides reasonable estimates at the country level. Also, growth conditions have been changing (Spiecker et al. 1996), and the rate of change in the project area can only be estimated by measurements.

One must also consider that yield level may change over the years, which may even warrant excluding growth modeling from the monitoring under certain project conditions. As to the validity of the increment in the model, the validity of the volume stock curves is demonstrated here, which play crucial role in the modeling. (The other

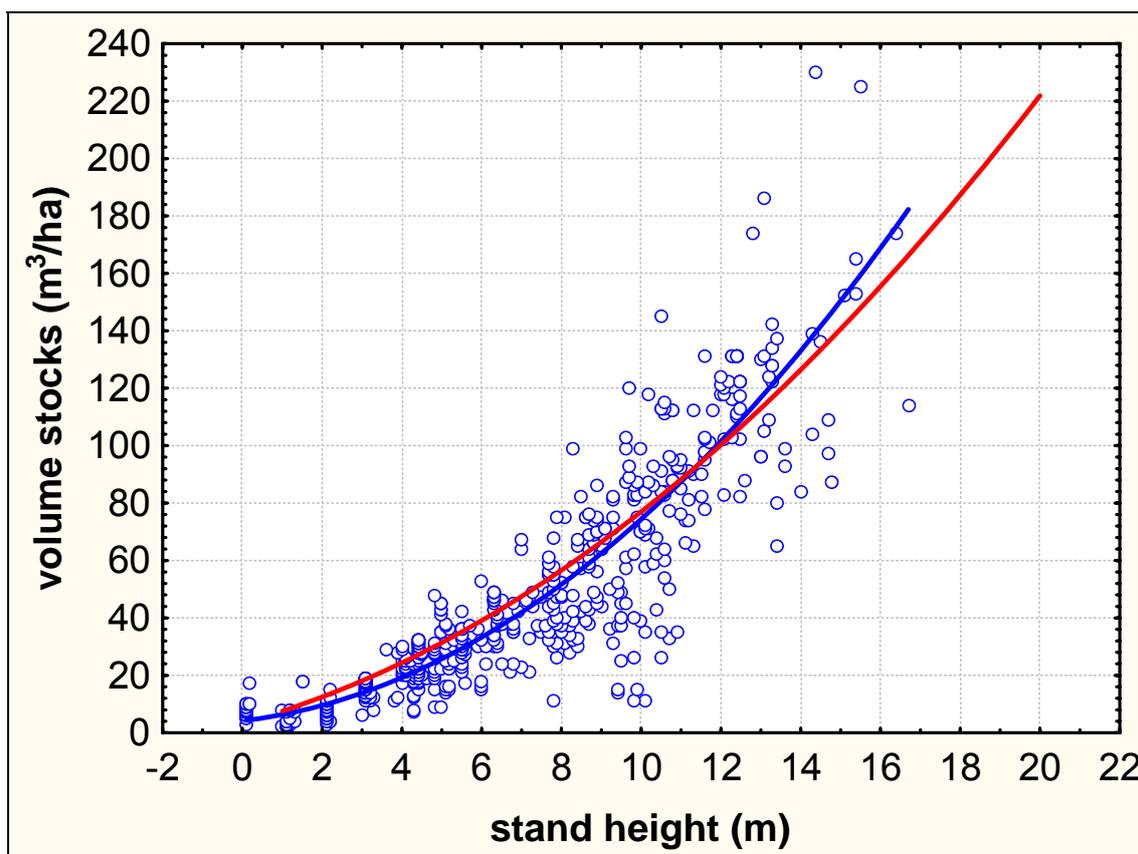
model parameters that are relevant in the biomass carbon stock change are those that discussed concerning the conversion and expansion factors and that were either developed in the test site itself, or were taken from the GPG.) Growth curves were of course not available for the test site, however, stand height and stand volume data were available from the forestry monitoring (National Forestry Database). However, as mentioned above, the standing volume information is needed for any inventory year. Therefore, to validate volume stock data is appropriate.

For Black locust, which is the most frequent species in the test site, empirical volume stocks over tree height, a standard measure of yield level, are well correlated with those of the yield table that is included in CASMOFOR (Figure 11). Thus, estimates could have been used instead of measurements. Also, it seems justified to use modeled carbon stock estimates for any two inventory years selected in this study to establish carbon stock changes in the test site (see later).

Note also that there are several other models available in the market that could be used in monitoring, or in planning, of AR projects. Two other models that have proved to be useful in different studies are the CO2FIX (Schelhaas 2004) and the GORCAM models.



**Figure 10. The flowchart of the CASMOFOR model, as it appears in its help system during running of the program, showing all relevant pools and processes that are used in modeling the carbon cycle of the afforestation system (see [www.scientia.hu/casmofor](http://www.scientia.hu/casmofor)). (A CASMOFOR model folyamat-diagramja, ahogyan megjelenik a program helpjében a program futtatásakor. Az ábra valamennyi lényeges széntárolót és folyamatot, ami az erdősítések szénkörforgalmának modellezésekor elengedhetetlen (a részleteket illetően l. [www.scientia.hu/casmofor](http://www.scientia.hu/casmofor).)**



**Figure 11. The volume stocks of the Black locust stands (blue dots) and their smoothed average (blue curve), as well as the smoothed average volume stocks in the yield model (Rédei, 1984, red curve) against stand height.**

(Az akác állományok élőkészlete – kék pont – és a rájuk illesztett kiegyenlítő függvény – kék vonal –, valamint a fatermési modell (Rédei, 1984) által alkalmazott élőkészlet – piros vonal – a fmagasság függvényében.)

#### 3.4.4. The main elements of monitoring

- Measure as few tree characteristics as possible.
- Use advanced inventory sampling techniques.
- Use simple statistics to estimate carbon stock changes and their uncertainty.
- Try to avoid bias in each step of the inventory.

In “real” projects, where costs must be considered, the modeling approach described in the previous sections may be necessary not only for planning (for which CASMOFOR was originally developed), but also to substitute data until they are not measured. However, only modeling is not acceptable. It is inevitable that the carbon stock change monitoring is based on forest inventories. However, it is important to note that, although

it may seem from the above that the “inventory” only refers to the traditional forest inventory, including the estimation of tree diameter, height and volume, the estimation of changes in biomass stocks must also include appropriate considerations concerning the conversion and expansion factors. How these factors are treated depends on the already available information, and if sampling is needed, it can be done based on the forest inventory information on the distribution of volume over species, age, site etc., and/or it can be done together with the forest inventory survey (see later).

The usual way of monitoring the carbon stock changes in the biomass pools over a large forest area (e.g. in the national GHG inventory) is to use forest inventory data on wood volume, and to convert it and, if needed, expand to biomass carbon data. Using forest inventory is also best for projects, because the methods are well established and relatively well known, and the cost of forest inventory is relatively cheap. However, the conversion and expansion to amounts of biomass are less standard, and require more attention. In any event, the monitoring must be designed in a way that the information from the forest inventory, and the conversion and expansion equations or factors collected or obtained from the literature are compatible.

This is important to note, because many tree and stand characteristics (e.g. diameter, height, volume) could be measured in a forest inventory, and, as a matter of fact, there are many types of estimation of, and conversion and expansion to biomass from these stand characteristics, but they may not necessarily be compatible. This issue is discussed in-depth in a study of Somogyi et al. (2005) that was prepared as a contribution to WP2 of CarboInvent.

For projects it is important to note that there are two basic types of procedures that could be followed. One is when reliable wood density and appropriate expansion factors are available for the given species. In this case, the required information from the forest inventory is stand volume. In the case that the wood density and other factors are not available, these should be measured in the test site. However, if measurements are needed, it may be more appropriate to develop biomass functions (see Zianis et al. 2004), instead of density and other factors. These functions most often take tree diameter, or diameter and height as input variables, thus these variables are the requested information from the forest inventory, and it is not necessary to estimate volume in the forest inventory. Depending on the stand types, biomass functions with diameter as input variable may produce reliable estimates in projects, thus, the measurements of tree height (which is also necessary to estimate volume in the first method) can be avoided. However, for a range of site conditions and extensive regions, functions utilizing also H always result in significantly improved accuracy, as D/H relationship in some way mimics site conditions.

Because of the available forest inventory information, and because of the needs of modeling for a time longer than the duration of the CarboInvent project, the method selected for the test site is composed of the following two elements: the estimation of volume stocks of stands, and the development of the required conversion and expansion factors. These elements are first discussed below separately, which is followed by the description of how the biomass carbon stock changes were estimated.

### 3.4.5. Monitoring of forest biomass

- Forest biomass is the most important pool; therefore, the monitoring should focus on the accurate estimation of this pool.
- Try to directly estimate biomass from measured tree characteristics. If this is possible, use biomass equations. Even if volume information is also needed (in inventories with additional objectives, or where a forest inventory is used to provide data for the project monitoring), try to directly estimate biomass data from the measured values.
- When estimating biomass, the variables to be used should match. For example, if  $d_{1,3}$  and  $h$  of the trees are measured, a biomass equation is needed for the species that takes these variables as input variables. If volume is estimated from these tree measures, make sure that a biomass expansion factor is used that expands this volume to total volume.

#### 3.4.5.1. Monitoring frequency

Before the first survey, the monitoring frequency basically depends on the expected changes in the carbon stocks, and the expected processes that may affect these changes. In general, the following issues must be considered: how fast the full forest area is established (e.g. in three or five years), what is the biomass or carbon yield capacity of the project (which depends on site, species and maybe management), how thinning and other harvests are done, and what is the risk of fires or other disturbances.

The information on how fast the full project is developed (and also how age, species and site is distributed during project development) is crucial in the first inventory. In contrast to most forest lands to be inventoried, forests of AR projects may only partially cover the whole future project area at the first inventory, and only young/very young stands can be found where age, species and site distribution is different from that of the full project. Also, because there are only stands of a few years old, estimation of stand characteristics may be different from that in older stands. In addition, the cost of doing an inventory in young stands may be considered too high with regard to the carbon stocks that is inevitably low in the first few years of the project.

Thus, appropriate time of monitoring may be selected based on actual project situation. The test site was special in this regard, because the establishment of the total forest area is equivalent to 22 years, thus, only a (varying) part of the total project area can be monitored at any time between project initiation (0 year) to 22 years. In a situation like this, monitoring can start later (e.g. at an age of 5-8 years), then consecutive inventories can be made at 3-5 year intervals.

### 3.4.5.2. Information available before the first field survey

- Collect as much information before the first field survey as possible.
- Validate the information available, using expert judgment if needed.

As mentioned before, conducting the inventories themselves should start with collecting information that is already available. This information may include growth information (from e.g. yield tables), site information, wood density or other conversion factor, expansion factor, biomass and volume functions etc. It is only when it is known what is available when decisions can be made as to what additional information must be collected during the inventory. Avoiding unnecessary field work can largely reduce monitoring costs.

In case of the test site, yield tables were available for all three species. This also means that volume growth functions were available, what is more, wood density values were available. Yet, to “mimic” real-life situations, and for other reasons detailed later, data collected in the test site itself was used wherever possible for both volume, as well as for biomass functions and conversion/expansion factors.

### 3.4.5.3. Estimation of the necessary tree measures

- Apply a survey scheme that requires the least amount of measurements.
- Avoid bias when using measuring instruments.
- Carefully measure tree height.
- Carefully measure all trees. Consider that the fewer trees one measures, the more important it is to have accurate measurements for each tree.

When planning an appropriate field survey to collect tree measures, any of the sampling methods described in section 3.3.3 could be used. In the Hungarian test site, we obtained volume stock data from the National Forest Database, thus, no particular sampling was necessary. However, we tested if and how stratified sampling could be done.

As mentioned earlier, real-life projects usually do not have detailed information on the possible distribution of any auxiliary variable that could be used for the stratification, at least until the first inventory. These variable, such as site characteristics, are ones that could be related to carbon stocks or tree growth. Thus, any auxiliary information may be useful that may be related to these characteristics. This information can be anything from previous crop yield data, possible soils surveys etc. If such information is not available, a general survey of the project area may be necessary, which can be done e.g. during mapping the project area.

In case of the test site, soil rooting depth information was used to assess site heterogeneity, i.e. the heterogeneity of growth conditions. This information is rather easy to collect in the test site, as the site was established in a sandy soil region where digging into the depth of the humus layer can be quickly done, and the distribution of the soil rooting depth (Figure 12) seemed to justify applying this information. Data on experiences with such auxiliary information are rather scarce at least in Hungary, especially if uncertainty estimates are concerned. Therefore, it seemed promising to apply soil rooting depth to identify strata. However, this attempt failed in the test site. This was due to the fact that, although former studies on site-yield relationships suggested a good relationship between rooting depth and yield (Járó, 1985), no such relationship was found (Figure 13) when analyzing the data that were available for the test site from the National Forestry Database.

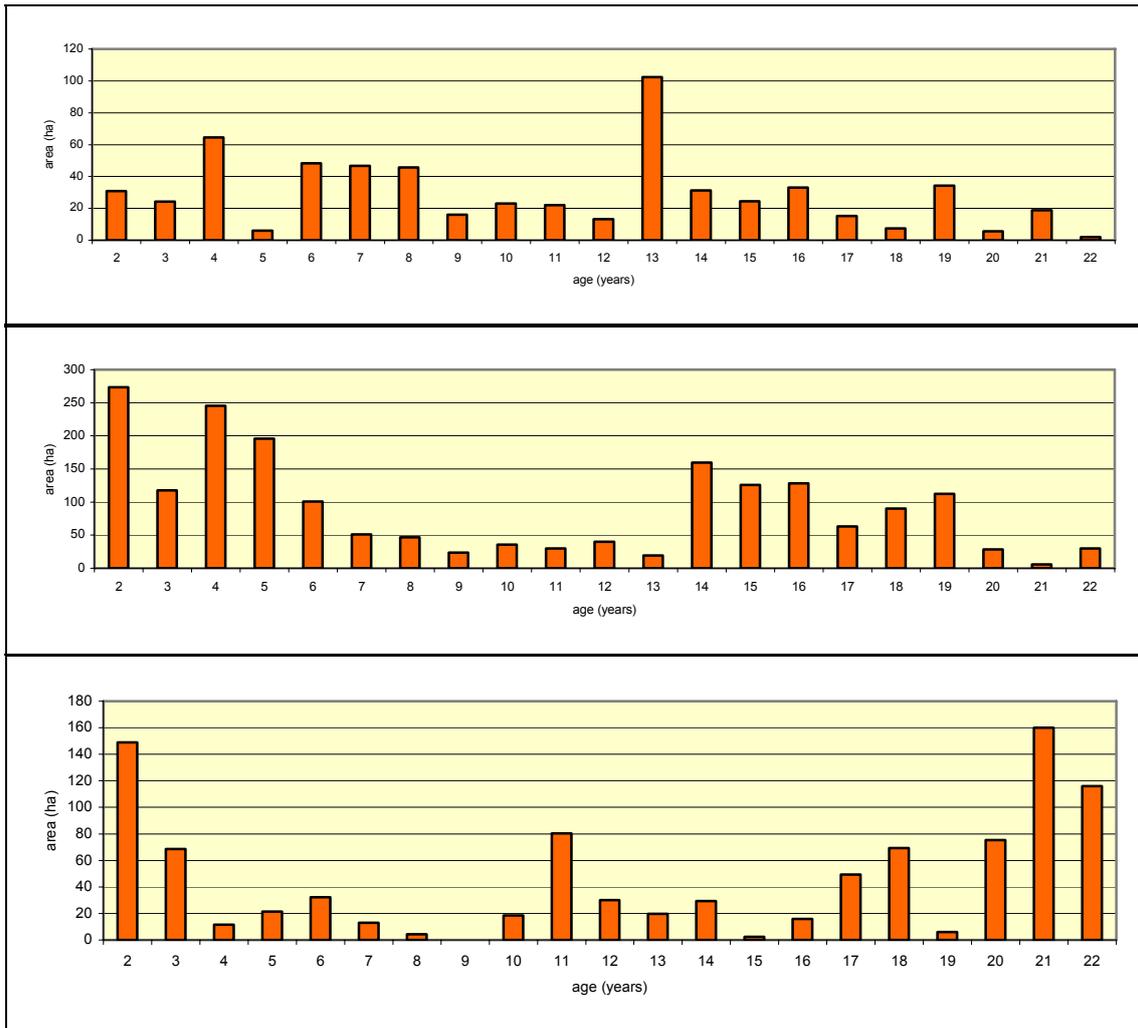
However, this would not have a profound effect on the accuracy of sampling. Sampling could be made using the area and volume data of compartments (average size: 3,82 ha). In “real” projects, these compartments could be regarded as places where sample plots are arranged.

The error of the volume data of the compartments could not be estimated in this study. However, this is of no importance here, either, because the sampling can be arranged so that the error of taking samplings within the compartment is a preset value, say 5 or 10%, thus, the sampling strategy can be arranged to stay within this preset value.

The sampling of compartments, i.e. to identify the compartments where sample plots are taken is a similar issue to consider. Here, too, a predefined accuracy can be applied, say again 5 or 10%, which would involve different sampling densities.

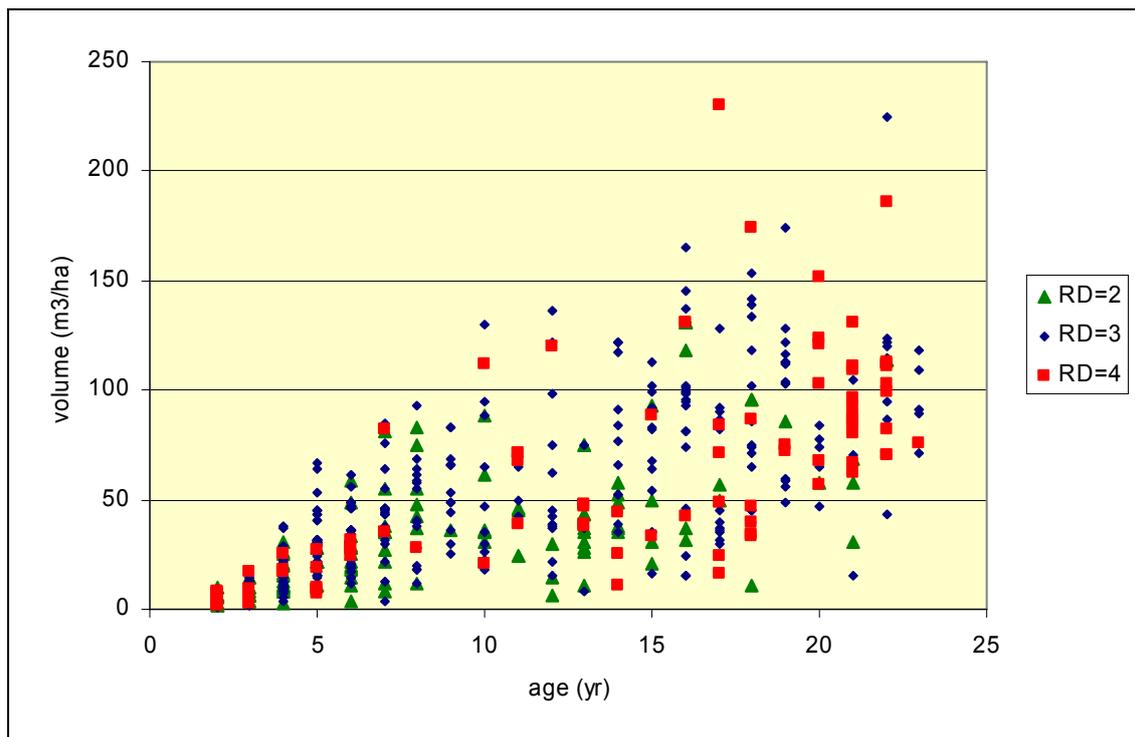
In theory, to identify sampling density, the strata must be created first. Although the use of rooting depth was not successful on the test site, we applied a sampling scheme where first three different strata were identified by species, then, within each species, different substrata were identified by rooting depth, and the accuracy requirement was set the same for all substrata.

It must be noted here that the accuracy requirements should not be developed for the biomass independently from those for other pools, because what matters is the total carbon stock changes and their accuracy, and the required accuracy for any pool should depend on the extent of the carbon stock changes for all pools, as well as the resources required to attain a certain accuracy level (see later in more details).



**Figure 12. The distribution of compartments by soil rooting depth class (RD) by age in the most frequent soil thickness classes 2 (top), 3 (middle) and 4 (bottom). (RD=2 if the rooting depth is between 20 and 40cm, RD=3 if this depth is between 40 and 80 cm, and RD=4 if it is between 80 and 120 cm.)**

(Az erdőrészek gyakorisági eloszlása a kor szerint a leggyakoribb termőréteg vastagsági kategóriákban: 2 (fent), 3 (középen), 4 (lent). A termőréteg vastagsága kategóriák az Útmutató szerint.)



**Figure 13. The dependence of volume over age as a function of the rooting depth (RD) in the test site for the Black locust stands. RD values as in the previous figure.**

(Az élőfakészlet és a termőréteg vastagsága közötti összefüggés az akácállományokban a kor függvényében. Az RD=termőréteg vastagsága kategóriák az Útmutató szerint.)

### 3.4.6. Estimating biomass equations, or conversion and expansion factors

- Use information for the country if available, but use expert judgment or measurements to verify country averages.
- Use biomass equations for the country if available, if not, expansion factors if available.
- If no equations or factors are available, take measurements to establish local biomass equations.
- Take samples for establishing the biomass equation from each diameter class that will be represented in the project area. Take representative samples. Measure weight on site, and apply water content values of fresh mass if available. If not, take sample for that and measure the samples in laboratory.

As mentioned above, available conversion and expansion factors had to be identified for the test site before the planning of the forest inventory. Although all species of the test

site are important in Hungary, and there are average values that are also used in the National Inventory Report (Somogyi 2005), we assumed that no biomass study had been conducted so far that would have resulted in published data. This was to enable the analysis of the procedures and resource requirements of the estimation of conversion and expansion factors, i.e. to “mimic” real-life projects, but also to validate the data from the literature, to study certain characteristics of the factors, and finally to develop biomass functions, we conducted an allometric study for all species. Note that all cases may occur under real project conditions.

The data collection was done in selected stands of the test site. Trees were sampled based on two main aspects. One is frequency: Black locust is the most frequent, while poplars and black pine are less common. The other aspect is that both poplars and pines were thought to have less consistent characteristics than Black locust. Thus, 30 trees were sampled for Black locust (from three stands), 50 trees for poplars (from five stands), and 20 trees for black pine (from two stands). However, sampling was done to best estimate curves between various variables while all ages and all diameters are represented that can be found on the test site.

Only aboveground compartments were measured on the trees. When measuring the trees, we separated the following compartments: total stem; thick part of the stem (up to 5 cm of top diameter); branches; thick part of branches (up to 5 cm of top diameter). For the black pine, the small branches also contain the leaves. We measured the following variables: fresh weight of all compartments on site, the volume of the thick parts on site (using standard dendrometrical methods, i.e. length, as well as bottom and top diameter of wood of 1 or 2 meters); the fresh weight of samples of the small parts; the dried (on 105 degrees C) weight of these same samples in the laboratory; and the volume and dried (at 105 degrees °C) weight of samples of the thick parts.

From all these measurements, both the volume and the dry weight of all compartments can be calculated, from which various factors and biomass functions can be developed (Somogyi et al. 2005). With regard to the factors, these are basically ratios of two measures, thus, they can be used to calculate one from the other. These are referred to here as “from what” and “to what” values. In theory, many factors can be calculated depending on which compartments are included in the “from what” value and in the “two what” value. Several of the theoretical possibilities are not practical at all, e.g. for an afforestation project it irrelevant to have “from total biomass” to “thick stem volume” ratios. On the other hand, most often it may be necessary to develop one of the following types:

- to expand from “thick stem volume (or biomass)” to total volume (or biomass)
- to expand from “thick wood volume (or biomass)” to total volume (or biomass) (in our case, “thick” means that the top diameter of the woody parts of the tree is 5 cm)
- to expand from “stem volume (or biomass)” to total volume (or biomass)
- to convert and expand from “thick stem volume” to total biomass

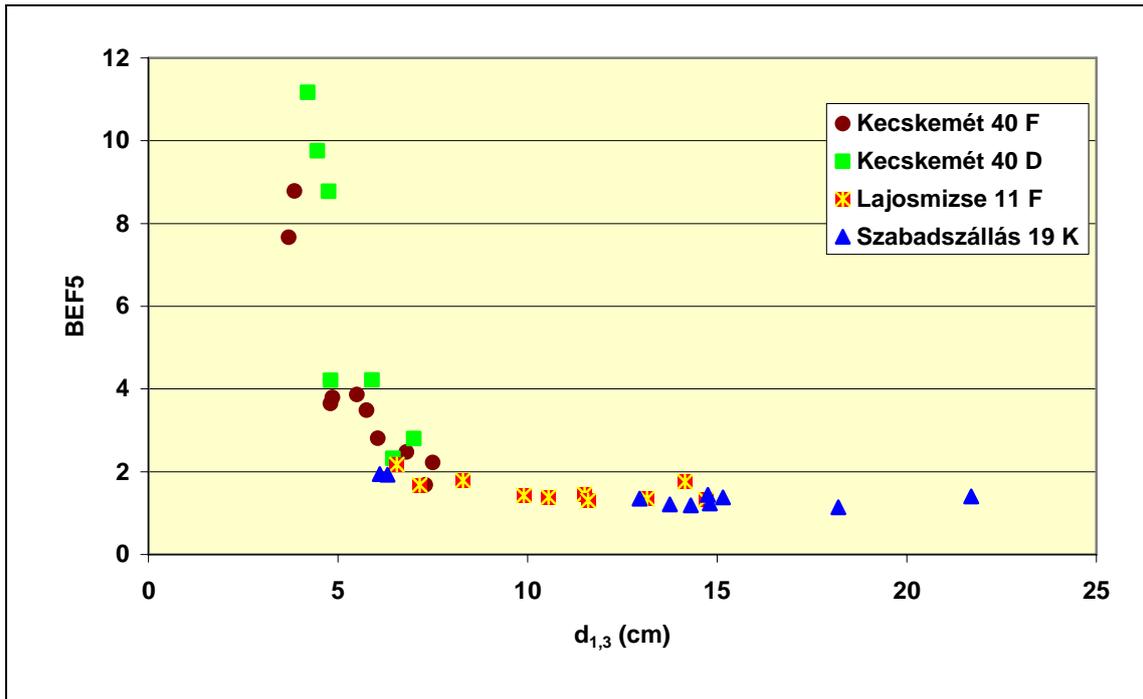
- to convert and expand from “thick wood volume” to total biomass (this combined conversion and expansion factor will be denoted by BEF5 below)
- to convert and expand from “stem volume” to total biomass.

In the first three types, all factors can be considered expansion factors (EF, dimensionless values) that expand either volume to volume or biomass to biomass (it does not really matter what we select), but the density values (D) are also needed to get biomass values. In the second three types of factors, conversion (i.e. the application of D) is combined with expansion, thus, these factors could be termed as combined conversion and expansion factors.

Quite naturally, only one type may be enough in a project. However, it may also happen that the different tree species may require different factor types. (This may especially be the case when there are certain factors for some species, but there are no such factors for other species.) In any event, what is important is that the appropriate type is used.

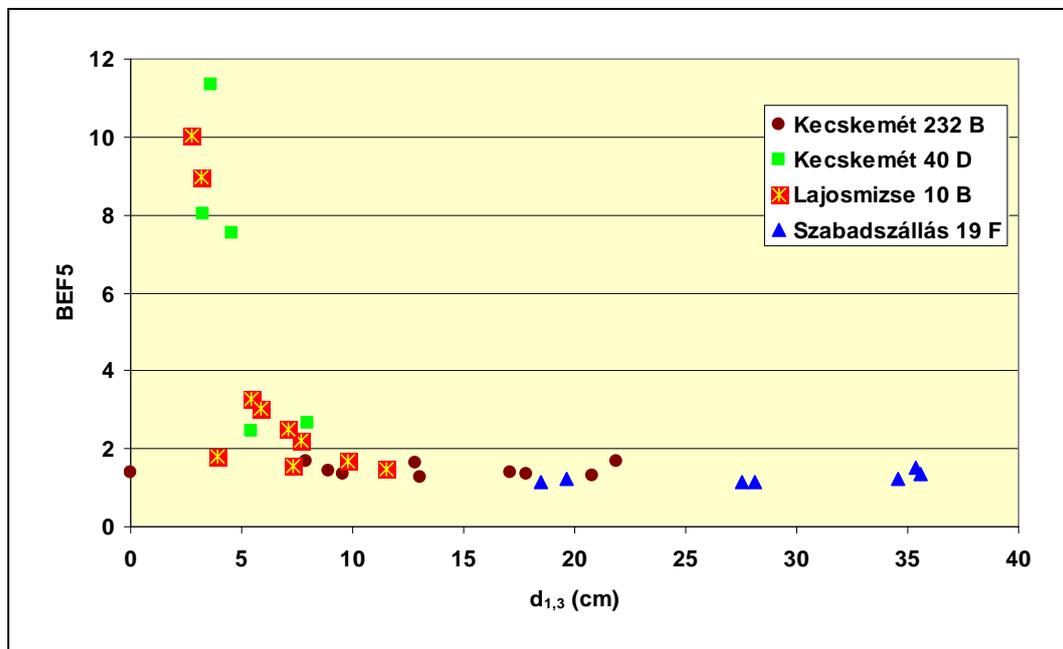
For the test site, we developed all factors for all species from the measured values to demonstrate the distribution of the measured BEF5 values over breast height diameter (Figure 14-Figure 16). BEF5 was selected just to demonstrate one type that may be used in many cases, because, most often, some sort of merchantable volume is estimated in the forest inventory (even if diameter and height of sample trees exist, only volume functions may exist to estimate volume that provide merchantable volume of trees). Also, the distribution itself may be important if, for some reasons, volume data are available by diameter, or if this volume data can be arranged by diameter after the survey. As it can be seen from the mentioned figures, BEF5 depends on diameter, especially for smaller diameters, so it is crucial to develop these variable BEF5s. For other BEFs, this dependence may not be so expressed (Figure 17).

Another variable that may be useful to develop factors is age. This is because, in some studies, dependencies were found between age and the factor, although this dependency is less expressed in other studies (e.g. Lehtonen et al. 2004). In our test site, no expressed relationship was found between another type of factor,  $B_{tot}/V_{tot}$ , which is wood density, D, and age for either the various parts of the tree (Figure 18), or the total tree (Figure 19). This is important to note here because, in the test site, total volume data was available, thus only D was needed.



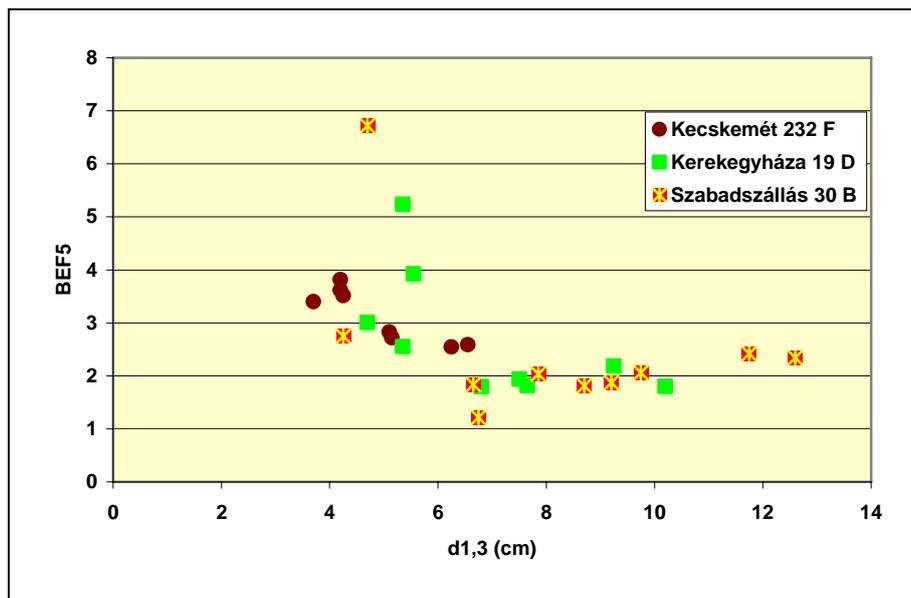
**Figure 14. BEF5 values for the sampled trees for Black locust (data collected from different stands are shown using different colours.)**

(BEF5 értékek a mintázott akác fákra a mellmagassági átmérő függvényében. A különböző erdőrészetekből származó mintafák különböző színű pontokkal vannak ábrázolva.)



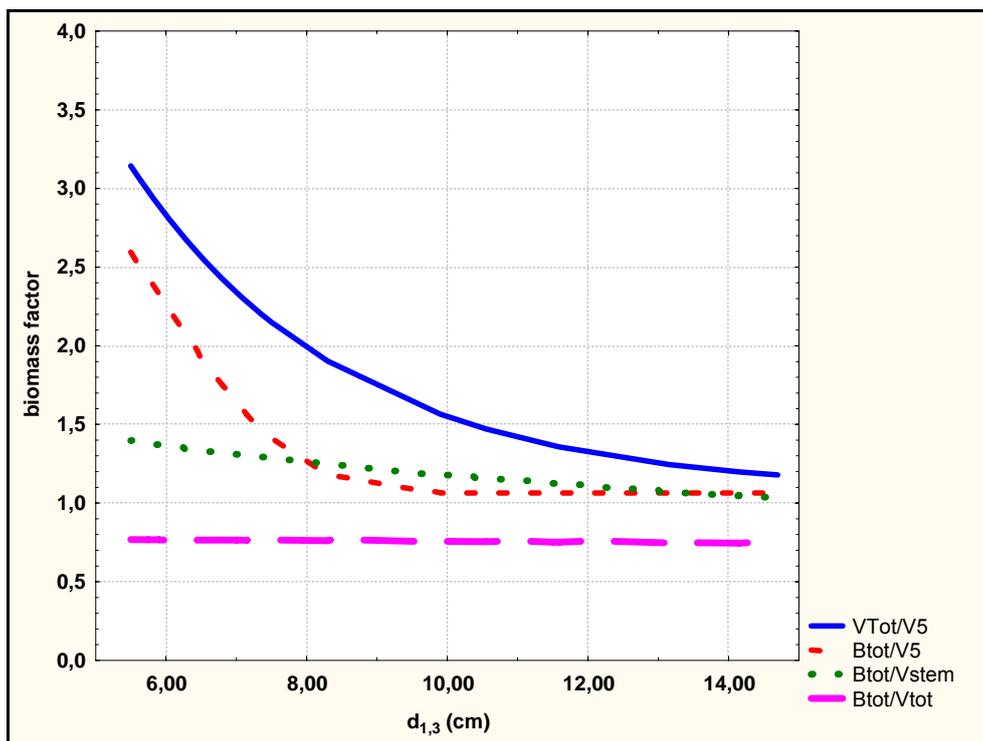
**Figure 15. BEF5 values for the sampled trees for grey poplar (data collected from different stands are shown using different colours.)**

(BEF5 értékek a mintázott szürke nyár fákra a mellmagassági átmérő függvényében. A különböző erdőrészetekből származó mintafák különböző színű pontokkal vannak ábrázolva.)



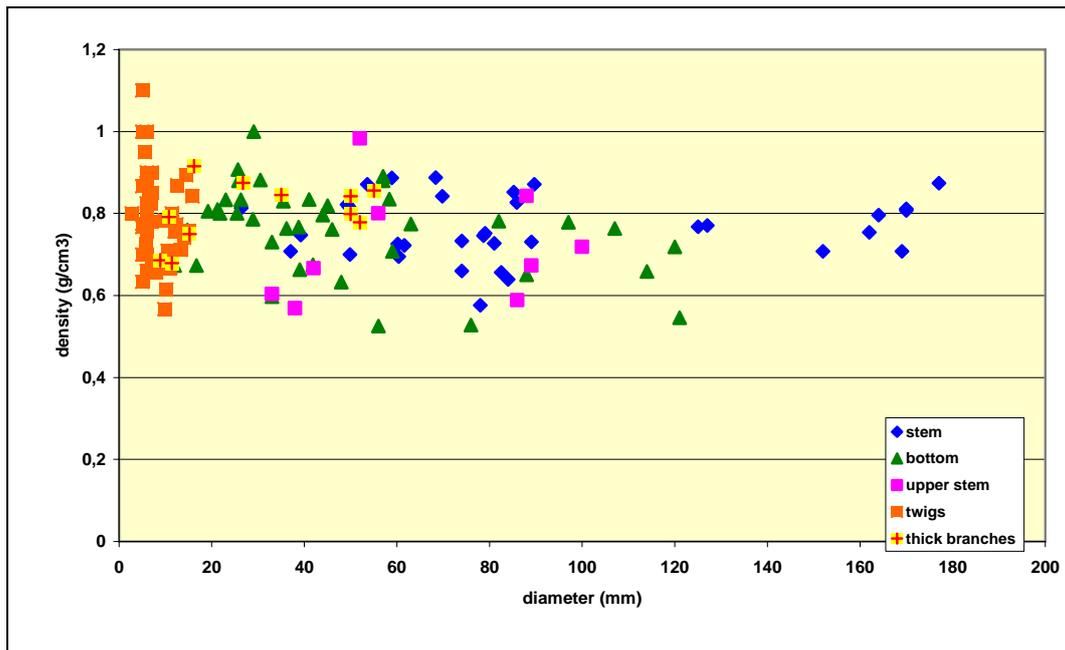
**Figure 16. BEF5 values for the sampled trees for black pine (data collected from different stands are shown using different colours.)**

(BEF5 értékek a mintázott feketefenyő fákra a mellmagassági átmérő függvényében. A különböző erdőrészekből származó mintafák különböző színű pontokkal vannak ábrázolva.)



**Figure 17. The dependence of conversion and/or expansion factors on diameter breast height for Black locust. (“V” is for volume, “B” is for biomass, “5” is for 5 cm of top diameter of stem, “stem” is for stem, and “tot” is for total.)**

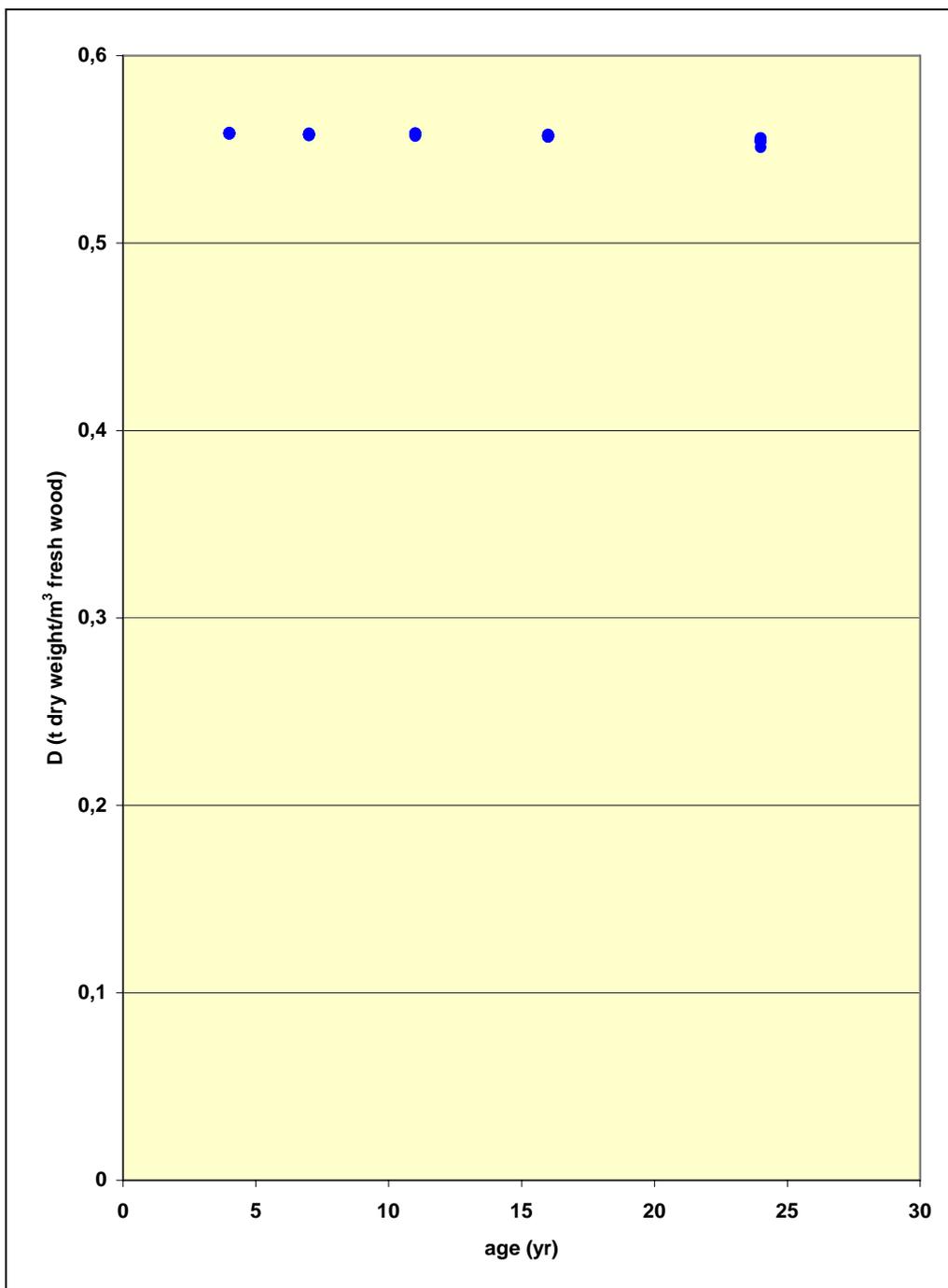
(Különböző biomassza átszámító tényezők a mellmagassági átmérő függvényében az akácra. “V” a térfogatot, “B” a biomasszát, “5” a csúcsátmérőt, “stem” a törzset, “tot” pedig a teljes fát jelenti.)



**Figure 18. The dependence of the density of the various parts of the trees on the diameter of the parts for Black locust.**

(A különböző farészek sűrűsége a farész átmérőjének függvényében az akác esetében.)

Because of all the above, only one D value was used for trees of all size and age for all species. These values, and also the default root/shoot ratios and carbon fraction (IPCC 2003), which were eventually used in our study, are summarized in Table 9.



**Figure 19. The dependence of the combined D\*BEF factor on age for whole trees. Note that the dots are the measured values. The graph is printed in this distorted way to demonstrate the low degree of dependence.**

(A kombinált biomassza átszámító tényező (=D\*BEF) összefüggése a korról az egész fákra nézve. A pontok a mért értékeket jelentik. Az ábra szándékosan ilyen torzított formájú, hogy megmutathassuk, milyen kicsi a kor hatása az átszámító tényezőre.)

**Table 9. Wood density (D), root/shoot ratio (R) and carbon fraction (CF) values as used in this study. The density values used in the national inventory report of Hungary (NIR of Hungary) are**

**included to demonstrate differences between country averages (Babos – Filló - Somkuti 1979; Kovács 1979) and locally estimated.** (A tanulmányban használt fasűrűség (D), gyökér/földfeletti biomassza arány (R) és széntartalom (CF) értékek. A Nemzeti Jelentésben használt fasűrűség értékeket is feltüntettük, hogy bemutassuk a különbséget az országos átlagok (Babos – Filló - Somkuti 1979; Kovács 1979) és a helyileg becsült értékek között.)

Factor		Species			Source
		Black locust	Grey poplar	Black pine	
D (t dry wood m <sup>-3</sup> fresh volume)	value	0,7645	0,5574	0,5685	this study
	error (%)	20%	20%	20%	
	national average value used in NIR	0,74	0,395	0,57	Babos – Filló - Somkuti 1979; Kovács 1979
R (dimensionless)	Value	0,43	0,43	0,32	IPCC 2003 (Table 3A1.8)
	error (%)	100%	100%	100%	
CF (t C of dry wood m <sup>-3</sup> fresh volume)	value	0,5	0,5	0,5	IPCC 2003
	error (%)	(not available )	(not available )	(not available )	

It is worth underlying that no major differences in the D values were found for Black locust and Black pine. However, higher density was found for Grey poplar than the national average, and if this national average had been used, carbon stock changes would have been underestimated by 29%. The cause of this difference may be that the national average regards all proveniences of grey poplar and other so called indigenous poplars (white poplar etc.), and some proveniences are found on floodplains, while others, like the ones in the test site, can be found on dry and very dry soils that obviously has an effect on wood density.

Concerning R, the values are taken from the GPG (IPCC 2003). These values may seem high, however, their use seems to be fully justified in the test site. This is because the relative amount of the roots is usually higher on poor sites than on good ones.

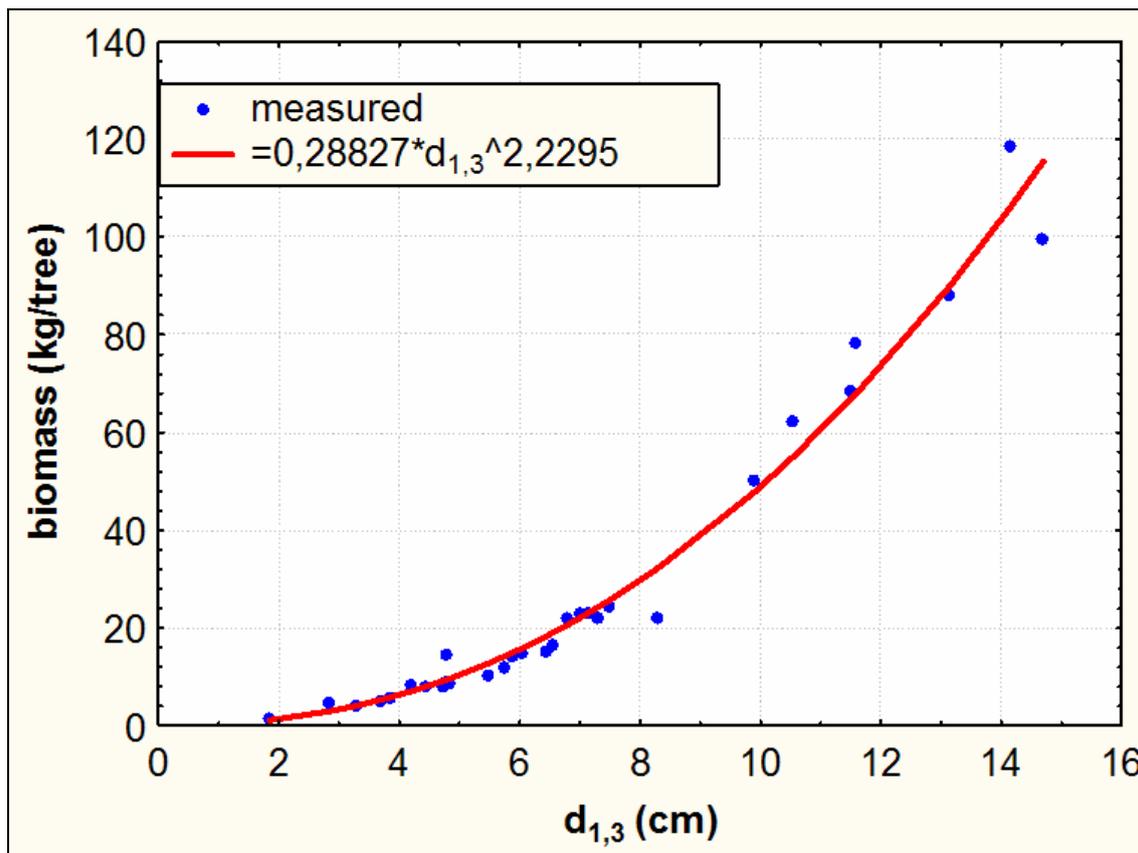
Finally, it is noted that, in many project situations, it is more practical to use biomass equations. These are simple equations that take individual tree diameter, or tree diameter and height as input variables, thus, volume estimation is not needed (Zianis et al. 2004). Such equations, too, could be developed from the data we measured at the test

site. One issue to be considered here is the format of the equation, which can be simple, like  $\text{biomass} = p_1 * d_{1,3}^{p_2}$  where  $d_{1,3}$  is diameter breast height of the tree, and  $p_1$  and  $p_2$  are the regression coefficients. This equation is easy to handle with non-linear regression offered in widely used software packages. The regression information for the equations we developed for the three species can be found in Table 10, while the original data and the developed biomass equation is demonstrated for Black locust in Figure 20.

**Table 10. Regression information for the above-ground biomass equations for the three tree species on the test site. The equation format is:  $\text{biomass} = p_1 * d_{1,3}^{p_2}$  where  $d_{1,3}$  is diameter at breast height of the tree, and  $p_1$  and  $p_2$  are the regression coefficients.**

(A regressziók adatai a három fafajra. A regressziós formula a következő:  $\text{biomassza} = p_1 * d_{1,3}^{p_2}$ , ahol  $d_{1,3}$  a mellmagassági átmérő,  $p_1$  és  $p_2$  pedig a regressziós koefficienssek.)

Regression information	Black locust	Grey poplar	Black pine
$p_1$	0,227961	0,186368	0,288263
$p_2$	2,124126	2,344395	2,229500
$R^2$	0,987	0,996	0,983
N	30	40	20
Diameter range for application (cm)	3-15(-40)	3-40	4-15(-40)



**Figure 20. Biomass equation and the measured biomass values for Black locust (for the regression information, see in Table 10).**

(Biomassza függvény akácra a mellmagassági átmérő függvényében. A regressziós adatokat l. a **Table 10. táblázatban.**)

### 3.4.7. Estimating the aboveground biomass carbon stocks and their uncertainties for two inventory years

#### 3.4.7.1. General conditions

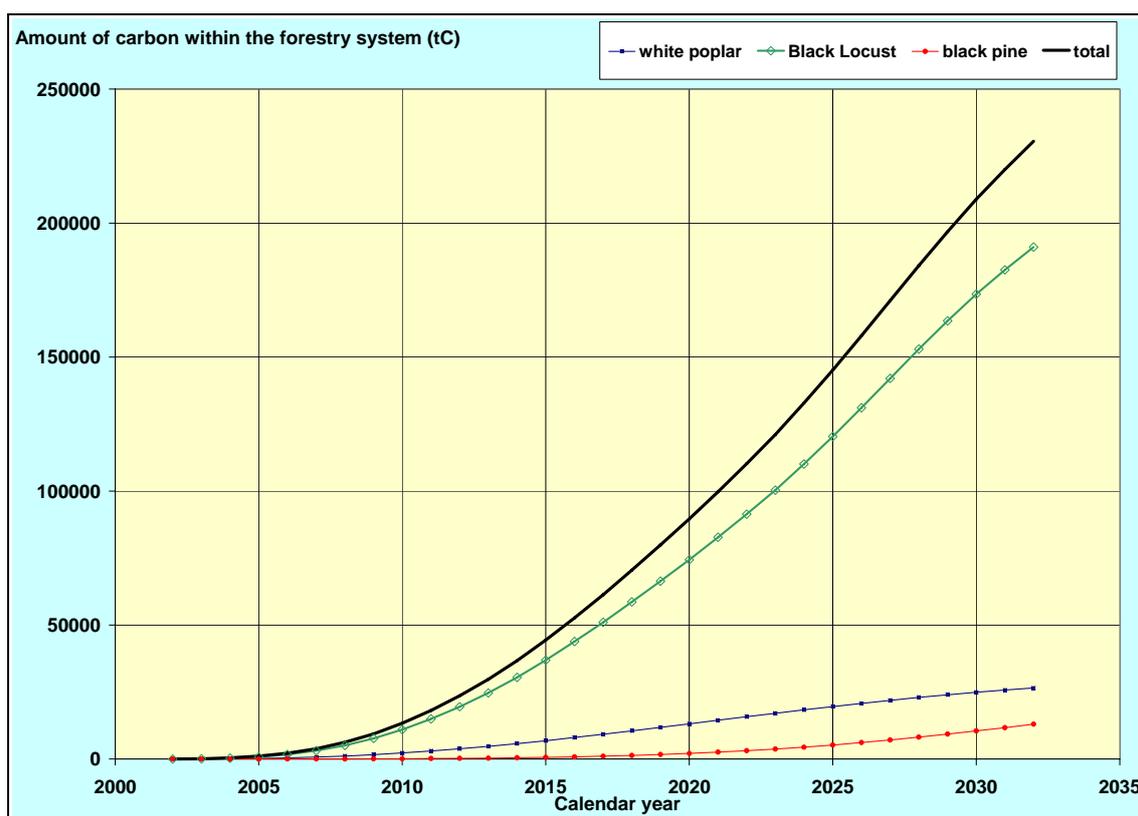
As mentioned above, modeling was needed to establish the development of biomass carbon stocks over time to obtain estimates for carbon stocks for any inventory year. For the demonstration of the carbon stock estimates, years 10 and 15 of the project development were selected, and the CASMOFOR model was used. However, to provide a more general picture, the development of the test site was modeled from project initiation until 30 years of the project. (Because CASMOFOR uses calendar years, instead of project lifetime, we “started” the project in 2002, which was the first year of CarboInvent.)

The above mentioned years were selected, because measured soil carbon stock changes were only available only until the age of 20 years, and litter data until the age of 18 years (see later), and it did not seem safe to extrapolate beyond these years.

### 3.4.7.2. Estimating the trend of the aboveground biomass carbon stocks for all ages

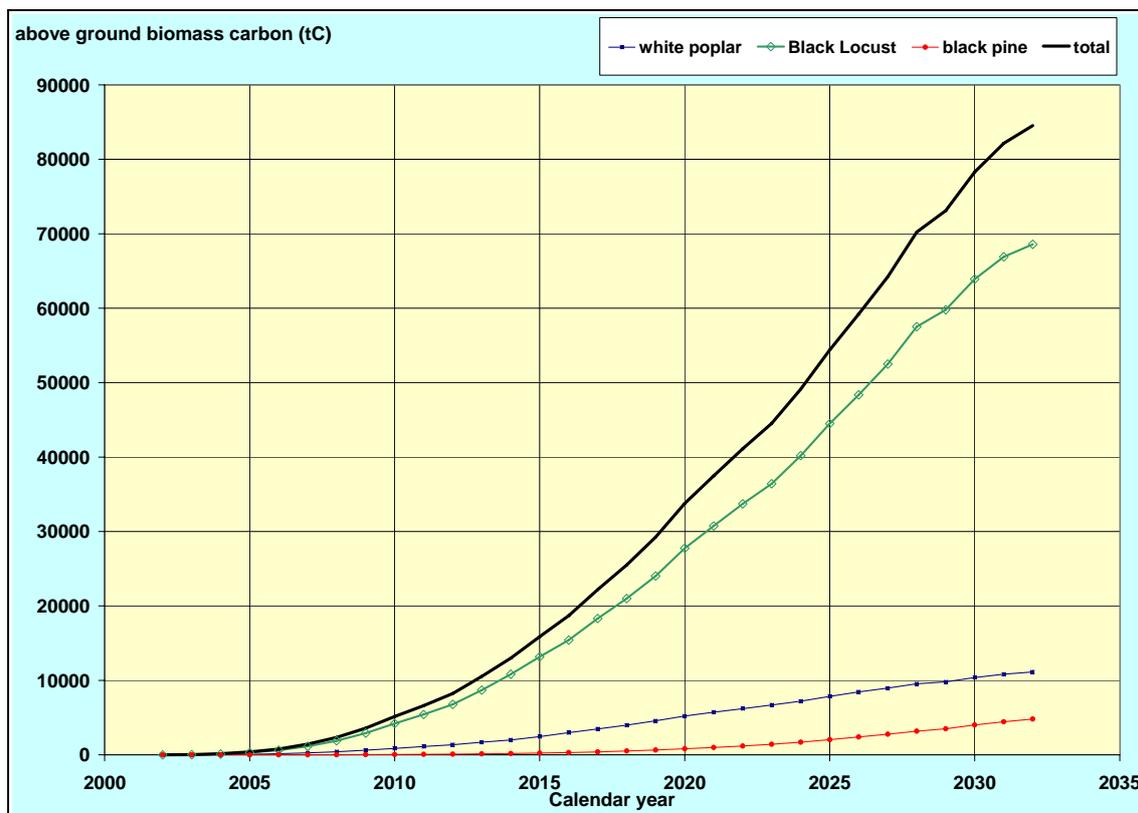
With the CASMOFOR model, the carbon stock changes of the biomass of all three species in the test site were modeled for all 23 years of the development of the project, using the conversion factors (i.e. wood density) that we developed for the test site. For this modeling, the area and the planting year were used as input variables. Concerning site, we did not use the soil rooting depth information, because it was known from the above that it has no real correlation to the site class. Rather, we used tree height, available from the forest inventory, to classify stands into good, medium and poor site classes, and the pre-set growth curves (yield table curves) were applied for these classes.

First, the main output of CASMOFOR is demonstrated (Figure 21) showing the total carbon content of the forestry system. By this “forestry system” all carbon pools are meant where carbon can be found after it is sequestered by the trees: above- and belowground biomass, soil, deadwood, and even harvested wood products. This is important to show because, as the comparison with the next graph (Figure 22) reveals, the total amount of carbon is more than double of that contained in the above ground biomass.



**Figure 21. The total amount of carbon within the forestry system of the test site as projected by CASMOFOR (see details in text).**

(Az összes szénmennyiség az erdészeti rendszerben, a CASMOFOR model becslése szerint; további részleteket l. a szövegben.)



**Figure 22. The total amount of carbon in the above ground biomass in the test site as projected by CASMOFOR.**

(A teljes szénmennyiség a földfeletti biomasszában a CASMOFOR modell becslése szerint.)

Also, it is worth noting that the growth curves, for any species, sum up the effects of the following information up to any specified point in time:

- the area of the species, stratified by site type (i.e. good, medium, poor) planted each year before the specified point in time;
- the growth curves of volume per unit area by site type;
- any thinning (the thinning regime is designed for each site type, and thinning is always done at specific age).

Because of all this, the total biomass carbon curves are not as smoothed as what could be expected from the application of yield tables that are built in the model.

### 3.4.8. Estimating the carbon stocks in the belowground biomass

- Belowground biomass is very expensive to measure, therefore, use data from other sources.
- Use national data if available.
- Use expert judgment and reasoning to consider the local conditions and their possible effects on the difference between local values and the data taken from other studies.
- Only use acceptable values, or conservative estimates, otherwise consider not to report carbon stock changes in the belowground biomass pool.

### 3.4.9. Carbon stock changes of the biomass compartments between two inventory years

Under real project conditions, the objective of the monitoring is to estimate carbon stock changes over time. This can easily be done by taking two inventories, then to take the difference between the two estimates.

In the test site, only the modeling approach was possible as discussed above. An important feature of CASMOFOR is that it also provides output data in a tabular format. From these output tables, carbon stock changes between any two years can easily be calculated (Table 11). These carbon stock changes for the aboveground biomass between year 20 and 15 of the project lifetime amount to 14253,1 tC, and 6128,8 tC for the belowground biomass.

**Table 11. Carbon stocks in two inventory years and their changes for the aboveground biomass for test site, as projected by the CASMOFOR model.**

(A széntárolókban tárolt szén mennyisége a két egymásutáni leltár alkalmával, a CASMOFOR becslése alapján.)

tree species	biomass compartment	carbon stocks (tC) in inventory year		carbon stock changes (tC)
		10	15	
grey poplar	AB	1181,5	3340,6	2159,1
	BB	508,0	1436,5	928,4
Black Locust	AB	5852,1	17630,6	11778,4
	BB	2516,4	7581,1	5064,7
black pine	AB	79,8	395,4	315,5
	BB	25,5	126,5	101,0
total	AB	7113,4	21366,5	<b>14253,1</b>
	BB	3058,8	9187,6	<b>6128,8</b>

#### 3.4.10. Uncertainty of biomass carbon stock change estimates

The uncertainty estimation should in principle include all elements of the estimation. These elements are those that have been discussed above: sampling for tree measures, taking the tree measures, applying biomass functions or conversion and/or expansion factors, and the estimation of the forest area. This is because all these elements may be sources of errors: either those of statistical nature, or bias. While it may be easier to estimate, and also control, the first type, it may be difficult or impossible to estimate the second one. Therefore, it is of utmost importance to avoid any under- or overestimation.

In any event, an estimate is needed for the uncertainty of each elements of the estimation, and then error propagation methods could be used to obtain combined uncertainties. These are discussed in section 3.9. We only note here that sampling error could be kept small, or at least in a certain range (say 5 or 10 %), by changing sampling density, as discussed in 3.3.3. Applying equations or factors usually involves a higher uncertainty, which is also more difficult to estimate. However, if the data to derive these equations or factors are measured in the inventory, then it may be possible to estimate the associated uncertainties. Otherwise, estimates from the original data source, or expert judgment could be used.

In the test site study, all of the above situations have occurred. See section 3.9 for the detailed estimates, and the combined uncertainties.

### 3.5. Monitoring of soil carbon stock changes

- Define soil and litter using a practical definition. For example, litter includes all dead organic matter (with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. In terms of layers, litter includes the fomic and humic layers. Also, live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically. Soils on the other hand include everything below the litter layer. This is practical in projects, because litter is thus relatively easy to separate from the soil layers.
- If there no emissions are expected from the soils, consider avoiding measuring the carbon stock changes, because of its cost-ineffectiveness.
- If emissions are expected from the soil, consider the estimation, if it is not too expensive.
- Apply relatively cheap humus% measurements to demonstrate that the soil is not a source
- If it seems worth measuring removals, consider estimating changes only in the uppermost layers (e.g. 0-10 and 10-20 cm).

### 3.5.1. General issues

It is well known that it is much more difficult, and much more resource intensive, to monitor soil characteristics than to monitor biomass characteristics. Therefore, it is especially important to find methods that are cheap, while producing reasonable results. The Marrakesh Accords even allow not to report on carbon stock changes in a pool if verifiable information can be used to demonstrate that the pool is not a source. As it was argued earlier, we assume, using this option, that the carbon stock changes of the dead organic matter pool are not to be monitored, because that pool is obviously not a source, and that it is not worth the resources to estimate the very little increases, at least in the first few decades, in that pool.

With soils, it could be argued in a similar fashion, or using other ways of arguing. It is to be noted that, in Chapter 4.2 of the GPG (Schlamadinger et al. 2004b), several ways are identified as good practice. These are the following:

- *“Representative and verifiable sampling and analysis to show that the pool has not decreased. It is good practice under this approach to measure the pool at enough sites, within regions, to provide statistical confidence, and to document the sampling and research methods;*
- *Reasoning based on sound knowledge of likely system responses. For instance, if cropland is converted to forest land by afforestation or reforestation, the dead wood pool cannot decrease, because there is typically no deadwood in a cropland (if it does not contain trees, e.g., if it does not contain any shelterbelts, was no orchard, and was no other agroforestry system);*
- *Surveys of peer-reviewed literature for the activity, ecosystem type, region and pool in question (for example, showing that in the climatic situation and with the soil types of the region, afforestation or reforestation of cropland leads to increases in soil organic carbon stocks); or*
- *Combined methods.”*

The first method itself could have been used, but, in the case of projects, it is basically equivalent to measuring carbon stock changes. The second argument was used for deadwood, and, like the third one, it can be used for soils, thus, the fourth method, as well. In Hungary, there are very few studies on the carbon stock changes in the soils. Kovács et al. 2005 showed that the carbon stocks increase in the soil and litter carbon pools after afforestation, with an increase of some 0,2 tC/ha in the soils in the first 20 years, and an increase of 0,3 tC/ha in the litter layer in the same period. However, this study included only a few samples from the country, and used different tree species under different site conditions from the test site.

Therefore, a survey was designed for collecting soil, as well as litter, carbon information. Note that, using the first argument above, the results of this study could in theory be used in other situations of similar conditions, e.g. in a “real life” project, as suggested by the third argumentation method above.

In a “real” project, carbon stock changes could be established by taking the difference of carbon stocks at two consecutive times. As for biomass, it was not possible to apply this approach this in the test site, at least by using two measured values. This method would have been even more difficult to apply in the test site for soils, because, for soils, a longer period seems necessary to identify the same rate of changes with the same accuracy than for biomass. This is due to three factors. One is that the increase of carbon stock changes is usually much slower in soils than in the biomass pools. If, however, carbon is lost from the soil, this loss could be very fast, making it of course easier, and more necessary, to measure the loss. The second factor is that the carbon content of the soil is highly variable, much more variable than the stand biomass, which would require high sampling intensity. Finally, the costs of measuring the carbon content of the soil is expensive and requires a certified laboratory, which makes it difficult to involve these types of measurements in projects.

Because of all the above, instead of taking a full inventory of the carbon stocks at one time, we tried to find relationships between stand age and the carbon content of the soil. By doing this, we expected to establish two relationships. One was the increase of the soil carbon stocks by stand age, which was expected to enable us to estimate the carbon stocks at any two point of time, and then to take the difference between these two estimates, which is what needs to be known in general. However, we also wanted to know if there was any carbon loss due to the soil preparations during the afforestation. For both analyses, the same false time series analysis was used as it is detailed in the next section.

### 3.5.2. Methods of estimating the soil carbon stocks

Because of the requirements for resources, we only studied the soils that were afforested by Black locust (this species occupies two thirds of the test site). We sampled altogether 12 areas on a random basis from a spatial point of view. Ten of these were stands of different age, and the rest were control areas, i.e. areas that were not afforested, rather, used as croplands or fallow, and that were next to afforested stands, seemingly having similar site conditions to the adjacent stands. (The reason that they have not been afforested yet may mean that the site conditions may be better there, which may involve that the soil carbon content is not lower, or possibly larger, than in the stands themselves.) By setting the age of these control areas to zero, a complete false time series could be established from the age of zero to 20 years.

Within each sampled stand, and in each control areas, five randomly selected places were established where soil samples were taken (see also Figure 9). Because of the high variation of soil characteristics, a soil pit was made at each place where samples were taken from four layers by each quarter. Thus, the total number of soil samples was  $12 * 5 * 4 * 4 = 960$ .

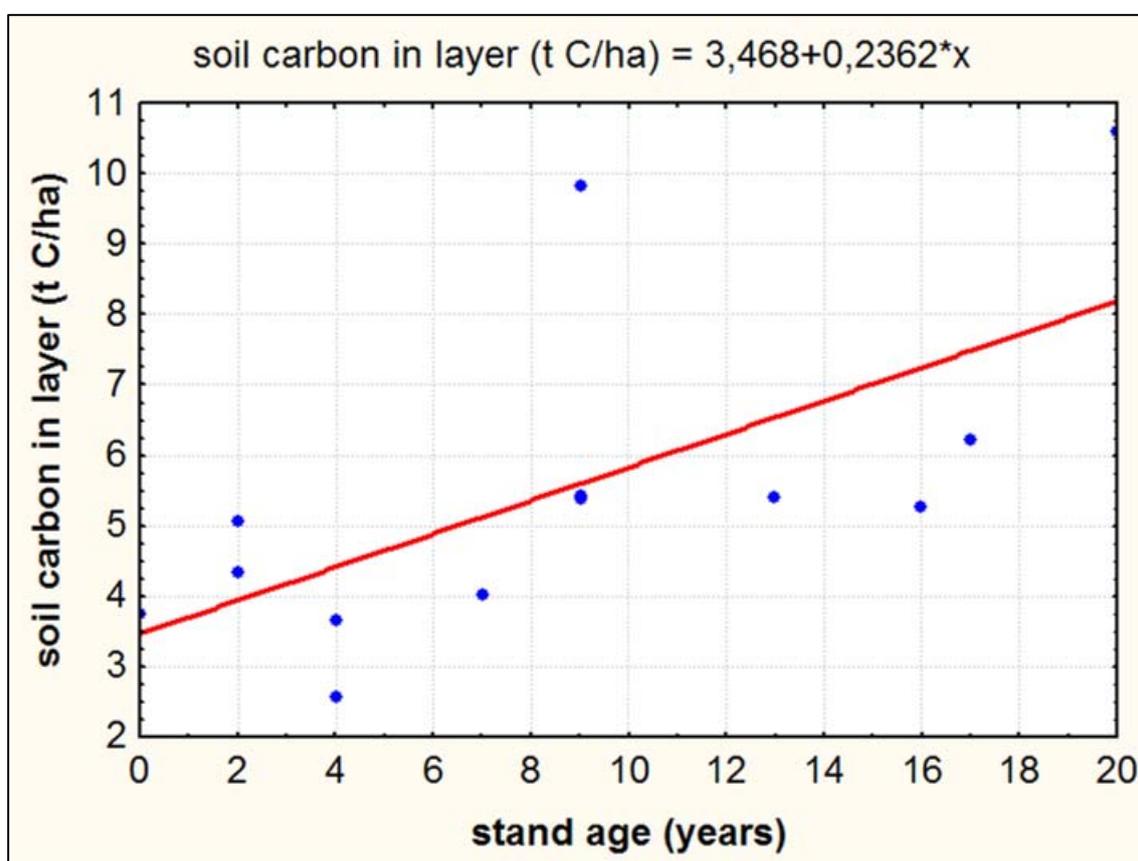
Note that the same amount of samples could have been taken using other sampling schemes. In our study, the principle aspect was to have a rather comprehensive (false) time series. If carbon stocks are to be estimated for any one inventory year in a “real” monitoring, the same amount of samples may be taken from more stands, because the variation of the soil C content would be smaller across the project area.

Concerning the layers, the samples were taken from the 0-5 cm, 5-10, 10-20 and 20-30 cm layers. (Note that According to the GPG (IPCC 2003), it is enough to take soils samples down to the depth of 30 cm. It also seemed unnecessary to measure carbon stock changes in lower depth because of the relatively young age of the stands.

From each soil sample, C and N-content was measured (in the lab of the University of West Hungary) using an Elementar Vario EL CN instrument.

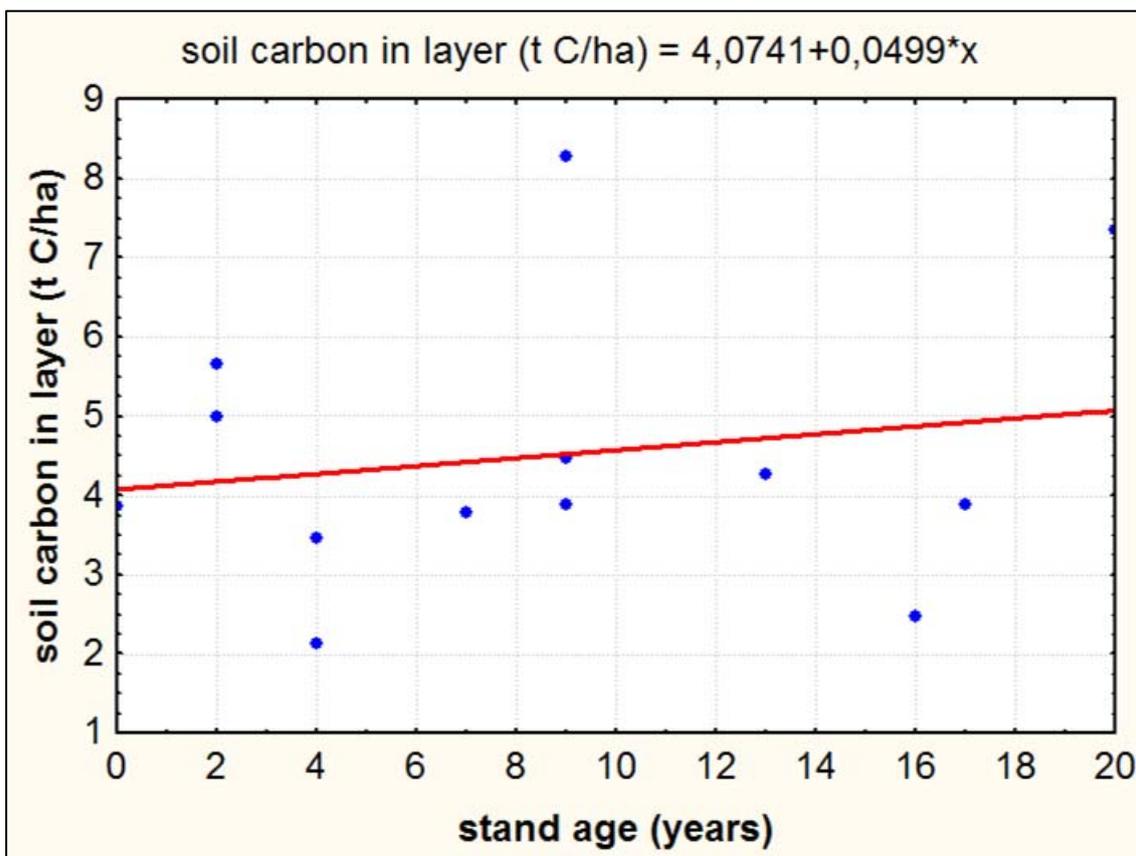
### 3.5.3. Results

The results are first demonstrated by soil layers (Figure 23 to Figure 26).



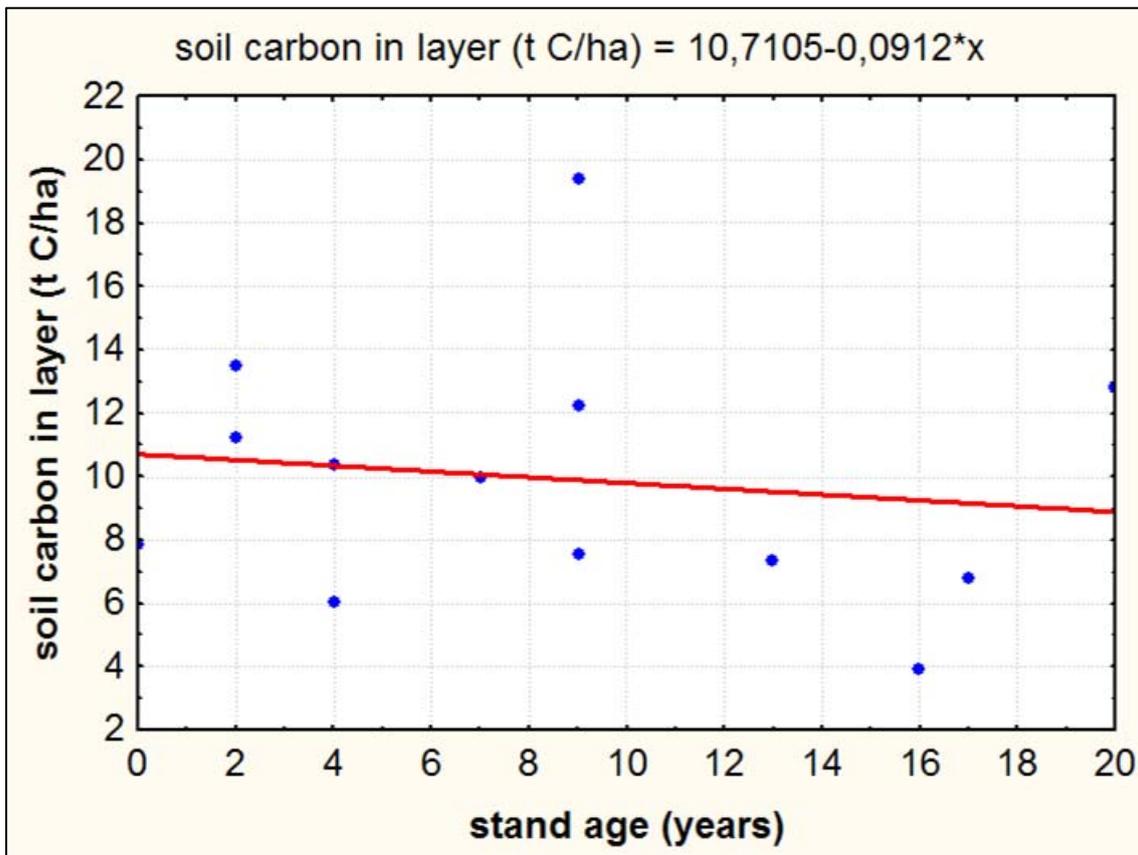
**Figure 23. The change of the carbon content of the soil in the 0-5 cm layer in the test sites plotted against stand age (false time series, see text): the symbols are the means of the measured values at each stand and the red line is the linear regression fitted to these mean values.**

(A széntartalom változása a talaj 0-5 cm-es rétegében a teszt területen. A kis négyzetek a mintavételi helyeken mért értékek átlaga, fölöttük és alattuk a mért értékek 95%-os szignifikanciaszinten vett konfidencia-határai, a piros vonal pedig az átlagokra illesztett regressziós egyenes.)



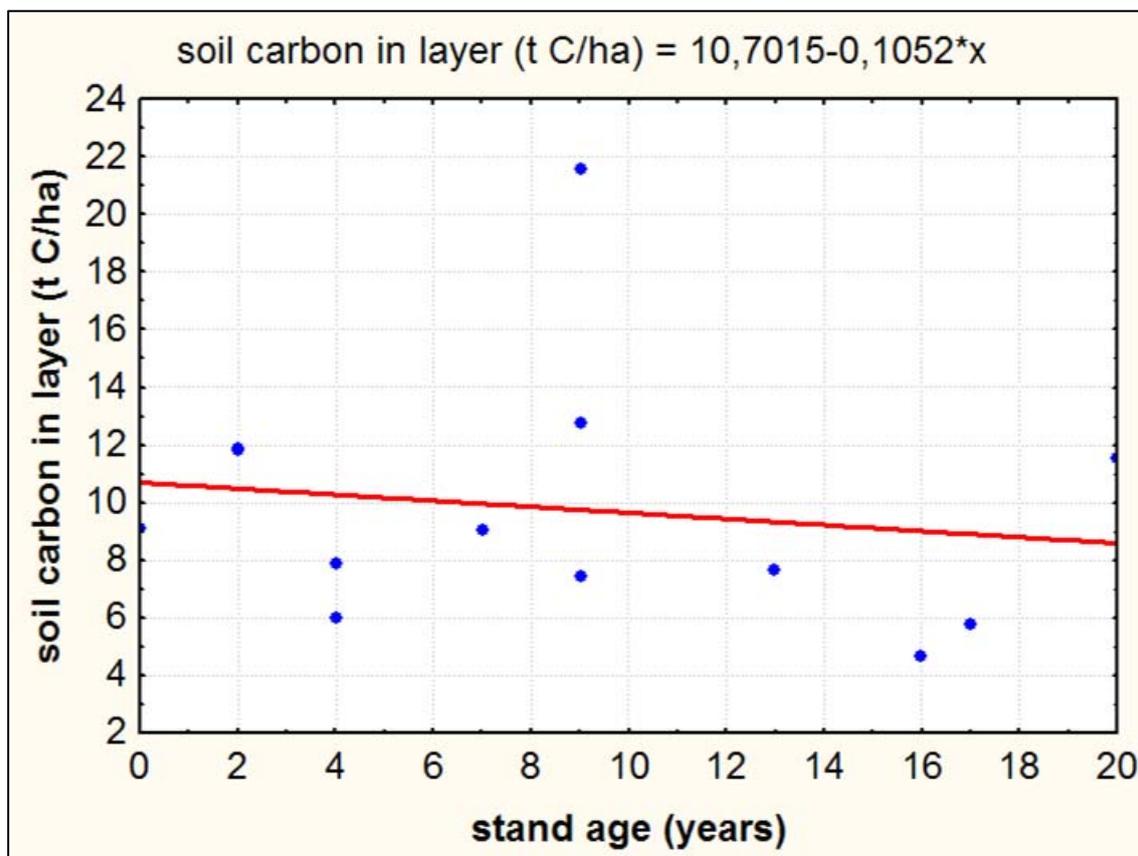
**Figure 24. The change of the carbon content of the soil in the 5-10 cm layer in the test sites plotted against stand age (false time series, see text): the symbols are the means of the measured values at each site and the red line is the linear regression fitted to these mean values.**

(A széntartalom változása a talaj 5-10 cm-es rétegében a teszt területen. A kis négyzetek a mintavételi helyeken mért értékek átlaga, fölöttük és alattuk a mért értékek 95%-os szignifikanciaszinten vett konfidencia-határai, a piros vonal pedig az átlagokra illesztett regressziós egyenes.)



**Figure 25. The change of the carbon content of the soil in the 10-20 cm layer in the test sites plotted against stand age (false time series, see text): the symbols are the means of the measured values at each site and the red line is the linear regression fitted to these mean values.**

(A széntartalom változása a talaj 10-20 cm-es rétegében a teszt területen. A kis négyzetek a mintavételi helyeken mért értékek átlaga, fölöttük és alattuk a mért értékek 95%-os szignifikanciaszinten vett konfidencia-határai, a piros vonal pedig az átlagokra illesztett regressziós egyenes.)



**Figure 26. The change of the carbon content of the soil in the 20-30 cm layer in the test sites plotted against stand age (false time series, see text): the symbols are the means of the measured values at each site and the red line is the linear regression fitted to these mean values.**

(A széntartalom változása a talaj 20-30 cm-es rétegében a teszt területen. A kis négyzetek a mintavételi helyeken mért értékek átlaga, fölöttük és alattuk a mért értékek 95%-os szignifikanciaszinten vett konfidencia-határai, a piros vonal pedig az átlagokra illesztett regressziós egyenes.)

The graphs demonstrate that:

- The variation of the data is rather high, as it was expected.
- Yet, it seems that characteristic trends can be identified for each layer.
- It is only the uppermost layer (0-5 cm), and maybe the layer below it (5-10 cm) where soil carbon content seems to be age-dependent.
- In the two lower other layers, the amount of the carbon stored in the layer is more or less age-independent.

In order to answer the second question that was put with regard to the soil carbon stock changes (see section 3.5), the means and the variations of only the measured values in the first few years are useful. Based on the data it can be affirmed with a rather high certainty that the carbon stocks did not change substantially after the establishment of the stands even in the uppermost layer that is the most prone to carbon loss. However, it must be added that the soil in the test site contained very little carbon even in the

control areas, i.e. before the afforestation, which may be one explanation for this finding, and that some insignificant loss could still have occurred, and/or the rate of carbon accumulation was slow in the first few years.

Notwithstanding the causes, the results could be used at least in two ways. One is of course that we calculate the changes between the estimates taken from all fitted function for any two inventory years. The other way is that we accept the assumption that carbon stock changes can only be expected, thus, to be measured, in the uppermost 0-5 and 5-10 cm layers. This would make the monitoring significantly cheaper, or the total number of samples could be better used to get a more reliable estimate for the carbon stock changes.

Quite naturally, it is not possible from our one-time survey to estimate carbon stock changes between two inventory years using the measured values only. However, we can use the predictions from the regression curves. In this case, however, the error of any cannot be estimated, because the variation of data from sampling stands of similar ages is obviously smaller than that from stands of varying age.

#### 3.5.4. The uncertainty of the soil carbon stock change estimates

The error of the survey results from two main groups of sources of error: one that is related to the measurements, sample handling, data recording and data processing, and the other is that is related to the errors of sampling, including the possible assumption, which we apply in the test site, that carbon stock changes in the soils are independent of the tree species. We applied this assumption in the test because, as it was shown above, the majority of the forest area is occupied by Black locust, and it was not possible to sample all areas occupied by all species.

Of these many possible sources of errors, we assume that, for the sake of a practical inventory, and by assuming high quality work, those in the first group could be avoided. In any event, it is mainly the high variability of the soil characteristics that has by way the highest effect on the total error of the survey. Variability between stands per ha carbon content of the soil (expressed here in percent relative standard error) was higher than the variability within a stand. The overall relative standard error of all the samples was for the various layers (starting from above) was 21,6, 9,4, 19,4 and 11,3 %, respectively. However, for any one inventory in a “real” project would be much smaller than this, thus, expert judgment was used to obtain uncertainty estimates for the error budget (see Table 15).

Unlike with biomass, it must be considered with soils whether any significant change can be detected between two surveys. The issue of “minimum detectable change”, or “minimum detectable difference”, or “reliable minimum estimate” of differences of soil carbon contents between two surveys has been extensively discussed in the literature (e.g. Ellert et al. 2002, Brown et al. 2003, Conant et al. 2003, Smith 2004). This change can of course only be established between measurements at any two time points, when the variances of the sample values are known. In our case this was not possible as shown above. However, it can be stated that, in the test site, the total carbon stock changes in all layers studied amounted to only some 0,09 tC/ha annually. This is the

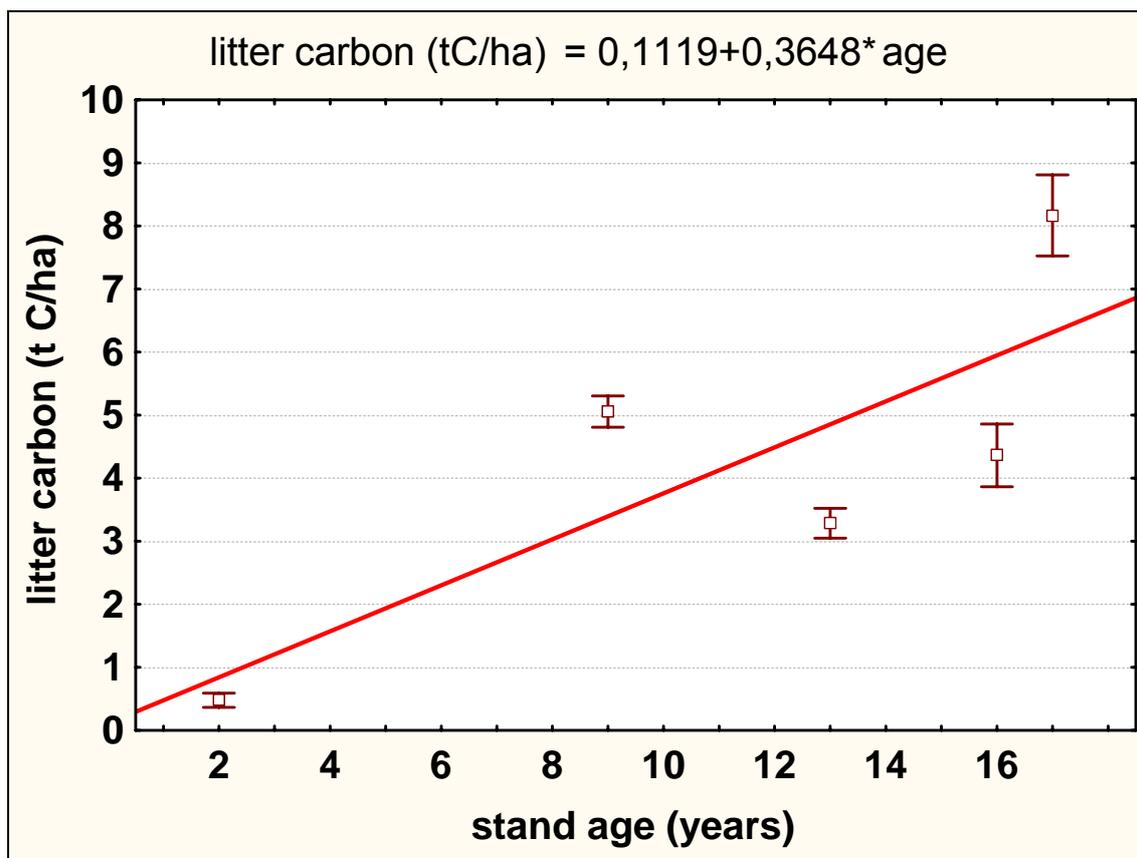
resultant of increase in two layers (0-5 and 5-10 cm), and decrease in the other two layers (10-20 cm, and 20-30 cm). It must also be added that it is only the increase in the 0-5 cm layer (0,2362 tC/ha annually) that can be regarded as significant at the 95% probability level ( $p=0,0167$ ); the changes in the three other layers are not significant ( $p>0,5$ ). Finally, the carbon stock changes can be zero or even negative in the first decade. The values may suggest this in each layer; however, there are not enough samples to have significant results.

### 3.6. Litter

- Define litter according to the GPG (see above, under soils).
- Try to measure carbon stock changes in the litter pool, because these changes may be relatively large, and because it is relatively easy to estimate litter carbon.
- Use appropriate and cost-effective sampling (e.g. stratified by species, site types etc.)

Carbon stock changes in the litter layer was also expected to play an important role in the total carbon budget, therefore, an attempt was also made to obtain reliable estimates. The estimation was based on a sampling that was made together with soil sampling. Thus, the principles of the sampling are similar to those for soils. For litter, a sub-sample of the stands selected randomly for soil sampling was used, and the same five places in the stands were used that were established to take the soil samples. Before taking these soils samples, a 50 \* 50 cm area was laid out and all litter from that micro-plot was collected down to the surface of the uppermost 0-5 cm soil layer. The litter sample was later oven-dried and its weight was measured. To obtain the amount of carbon in the litter, the default carbon fraction of the litter of 0.37 was used (this fraction was suggested by Smith and Heath, 2002, as cited and approved in the GPG (IPCC 2003, p. 3.35).

As with soils, there was no possibility to sample the amount of litter twice, but we could establish a relationship between litter carbon stocks and stand age (Figure 27). In addition to the obvious variability that can be observed here, it seems that the increase of the amount of litter is significantly correlated with stand age (Table 12). To quantify trends over age, a linear relationship between litter carbon and stand age was assumed. This was only done considering the relatively little number of samples, and the short length of age range. As with soils, the increase between two inventory years can be calculated using readings from the curve and the area distribution in the two inventories. Also similar to soils, the relative standard error for one inventory for the uncertainty estimate of the monitoring was inferred from the overall relative standard error of the samples, which was 51,8%.



**Figure 27. The amount of litter carbon by stand age. The blue dots are measured values, and the continuous red curve is the fitted regression line. The squares are the means of the measured values, above and below them the confidence intervals at 95% level, and the red line is the linear regression fitted to the mean values.**

(Az avarban található szén mennyisége az állomány korának függvényében a teszt területen. A kis négyzetek a mintavételi helyeken mért értékek átlaga, fölöttük és alattuk a mért értékek 95%-os szignifikanciaszinten vett konfidencia-határai, a piros vonal pedig az átlagokra illesztett regressziós egyenes.)

**Table 12. The results of the one-way analysis of variance to test if stand age has a significant effect on the amount of litter carbon. The low value of p indicates higher than 95% of significance.**

(A variancia-analízis eredménye annak tesztelésére, hogy vajon a kor szignifikáns hatással van-e az avar széntartalmának növekedésére. A kis p érték azt bizonyítja, hogy a hatás szignifikáns a 95 %-os valószínűségi szinten.)

Variable	Analysis of Variance (litter tC per ha for each sample)							
	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
litter carbon (tC/ha)	489,6503	4	122,4126	226,8019	103	2,2020	55,5925	0,0000

### 3.7. Estimation of the baseline carbon stock changes

By baseline the theoretical scenario is meant that would have happened if the project would have not taken place. In our case this theoretical scenario is that the land would have remained under fallow, or under low-intensity agriculture. In both cases the assumption is that carbon stock changes would be zero in the long run. For the fallow, very slow revegetation would be possible, but this revegetation would really be very slow, and if one disregards the increase of carbon stocks the error of excluding this increase is negligible. Even more negligible is the error for lands that would have gone under agriculture, because the low intensity of land management would guarantee that no loss from the soil happens.

Note that “baseline” only refers to any land that has entered the project. Therefore, when talking about baseline for any year in the project lifetime, only those pieces of land, and their carbon stocks, are considered that have actually entered the project until that year.

Note also that, since the baseline options do not include forest, thus, they do not involve any need for a methodology that could be the interest of CarboInvent. Therefore, no attempt was planned and made to estimate the baseline in a more detailed way.

### 3.8. Total carbon budget

- Use the total carbon budget to analyze key pools with relatively carbon stock changes.
- Reconsider the distribution of resources in the next inventory.

The total carbon budget of the test site is demonstrated below in two ways. One is of course the way it should be developed under “normal” project conditions. The first step in this case is to have an estimate at time one and another at time two, and then to take the difference to get the carbon stock changes in the project area (Table 13). However, the carbon stock changes in the “baseline” scenario must be deducted from these changes in the second step to get those carbon stock changes that are due to the project activities (Table 14).

**Table 13. The carbon stocks and their changes (tC) in the test site. Note that the numbers always only include those areas that have already been afforested (2474 and 3429 ha for 10 and 15 years after project initiation, respectively).**

(A szénkészletek nagysága és azok változása (tC) a teszt területen. A számok a teljes projekt területnek mindig csak arra a részére vonatkoznak, amelyeken már megtörtént az erdőítés: a projekt 10 éves korában 2474 ha, 15 éves korában pedig 3429 ha.)

Carbon pools	Grey poplar		Black locust		Black pine		Total		Carbon stock changes in the project area
	in year after project initiation								
	10	15	10	15	10	15	10	15	
AB	1182	3341	5852	17631	80	395	7114	21367	14253
BB	508	1436	2516	7581	26	127	3050	9144	6094
SO	7138	12370	39948	54250	25675	35198	72760	101818	29058
LI	282	970	2488	5560	1830	3830	4599	10360	5760
DW	0	0	0	0	0	0	0	0	0
Total	2855	6852	14917	35329	4061	7298	21833	49479	27646

**Table 14. Carbon stock changes (tC) in the project area relative to baseline.**

(A referencia szcenárióhoz viszonyított szénkészlet-változások, tC.)

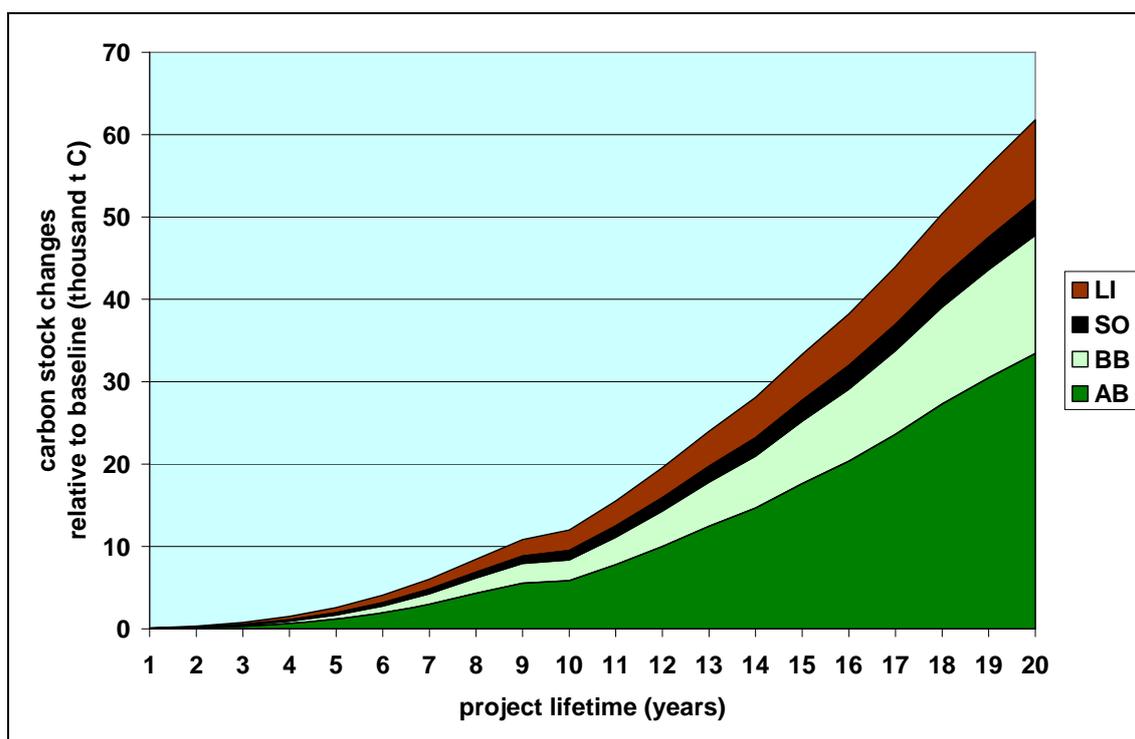
Carbon pools	Carbon stock changes between years 10 and 15			
	in the project area	in the baseline	due to the project activities	
	(tC)	(tC)	(tC)	(%)
AB	14253	0	<b>14253</b>	<b>51,8</b>
BB	6094	0	<b>6094</b>	<b>22,1</b>
SO	29058	27642	<b>1416</b>	<b>5,1</b>
LI	5760		<b>5760</b>	<b>20,9</b>
DW	0	0	<b>0</b>	<b>0,0</b>
Total	55166	27642	<b>27524</b>	<b>100,0</b>

This summary table represents the principle estimates for the project. It can be seen that more than the half of the gains come from the increase of the aboveground biomass carbon. However, about one-fourth of the gains come from the belowground biomass, and some one-fifth comes from the increase of the amount of the litter. This is important to underline because, as it will be shown in the next section, the uncertainty of the estimates is very different for the various pools. The results therefore also demonstrate that, overall, less effort should be paid to the inventory of the soils, and more to that of the litter. This is especially important to note because it is rather easy to collect litter samples, and it is rather easy to process them in a simple lab to get reliable estimates for the litter pool. Also, because the analysis of the litter is relatively cheap, it is worth increasing the sample size (i.e. the number of samples) to decrease the sampling error.

Quite naturally, however, it is also important to bear in mind that, with any piece of land entering the project, a relatively large carbon pool, i.e. the soil carbon pool, also enters the project. It is of course the responsibility of the project managers to maintain

this large pool, and to monitor any decreases in it. Therefore, even if direct soil carbon measurements are avoided, in order to save on the monitoring costs, it must be made sure that places with carbon losses are identified, and if carbon losses are suspected, the carbon stock changes in the soils are also estimated.

The other way of representing the results of the monitoring of the test site is to demonstrate the development of the amount of carbon fixed in each pool over time (Figure 28). The amount of total carbon in all pools in the project area increases due to two effects: one is that, when a certain piece of land enters the project, its soil carbon enters the carbon budget, too, and the second is the increase of carbon stocks due to the project activity. Quite naturally, only the latter increase matters.



**Figure 28. The amount of carbon stocks in the project by pool over the project lifetime using the modeling technique. The soil values include all the carbon stocks that are present in the soils when the area becomes part of the project. With all other pools, the carbon stocks are always zero on all areas that become part of the project.**

(A szénkészletek alakulása az egyes széntárolókban a projektben az idő függvényében, a modellel becsülve. A talajértékek tartalmazzák azt a szénkészletet, ami a talajban található akkor, amikor egy adott terület a projekt részévé válik. A többi széntároló esetében a szénkészlet nulla akkor, amikor a terület a projekt részévé válik.)

### 3.9. Summary of uncertainties

- For all measurements that are taken in the monitoring, estimate uncertainty.
- For data taken from any literature, use the uncertainty estimate provided, or use expert judgment.
- Consider sample size: in case of „small” samples, where the number of the sampled observations (n) is less than 30, the t value for the calculation of the confidence interval should be taken from the t-distribution as a function of n.

Uncertainty refers to the lack of knowledge with regard to the true value of the estimate. Although it is obvious that lack of knowledge is imminent in the monitoring of projects, too, no special consideration was made in Chapter 4.3 of the GPG (IPCC 2003) concerning the uncertainties. The uncertainty estimation can be regarded as unnecessary, as the emission and removal estimates are “point estimates”, i.e. credits and debits are accounted based on totals (which is equivalent to accounting mean values). However, the uncertainty estimation can help the inventory agency in several ways. The objective of the uncertainty estimation in projects, as in the national GHG inventories, can be to identify areas where improvements in the methodology can be planned for subsequent inventories. Also, considering the absolute values of carbon stock changes and their uncertainties, decisions could be taken e.g. whether a certain pool is to be estimated or not.

The uncertainty can be expressed as an interval around the estimate, i.e. the estimate minus the width of the interval and the estimate plus the width of the interval. The width of the interval can be different on the minus and the plus sign, but is equal if the normal distribution can be assumed. (For practical reasons, this can be applied in projects if the distribution cannot be assessed from the data.)

Even if the methodology to obtain an estimate is correct, the sources of the uncertainties are manifold. The uncertainty may arise from statistical random sampling errors to lack of representativity of sampling, to measurement errors, to recording and processing errors, to missing data, and to modeling errors. Many errors are difficult or impossible to quantify. Easiest is to quantify sampling error. The uncertainty in the mean can often be estimated as plus or minus t times the standard error, where the standard error is the sample standard deviation divided by the square root of the sample size. If the number of sampled observations (n) is greater than 30 (=“large sample”), t can be taken as 1,96, however, if n is 30 or less, t is obtained from the student’s t-distribution as a function of n. The uncertainty can also be expressed as a percent value of the absolute value of the emission and removal estimate.

In Table 15 relative uncertainties are summarized by pool for one inventory. This means that if the inventory is made e.g. ten years after the project started, the uncertainties in the table can be assumed.

**Table 15. Uncertainties of the carbon stock change estimate by pool in the test site. The combined uncertainties are calculated using the error propagation formulas that can be found in GPG. (A szénkészlet változások becslési hibája az egyes széntárolókban és összesen a teszt területre vonatkozóan. A kombinált hibát a GPG hibaterjedési formuláinak felhasználásával számoltuk.)**

Pool	Variable	Source of error	Relative uncertainty (U) at 95% probability (=half of the confidence interval ≈ two times the standard error in percent of the estimate)
<b>Biomass</b>	Total tree volume per ha, V	Forest inventory (sampling, as well as measurement of d and h at the tree level)	2*5% (a-priori requirement)
	Conversion and expansion factors (above ground), CBEF <sub>ABOVE</sub>	Conversion and expansion from measured tree values (e.g. d, h, N) to total aboveground biomass per ha (including estimation of tree volume using volume equation)	2*10% (this study; expert judgment)
	Total project area, A	Expansion to the total project area (=error of area determination)	2*1% (expert judgment)
	<b>Combined uncertainty for above ground biomass, U<sub>BIAG</sub> = <math>\text{SQRT}(U_V^2 + U_{\text{CBEFABOVE}}^2 + U_A^2)</math></b>		<b>22,4%</b>
	Expansion factor (below ground), CBEF <sub>BELOW</sub>	Expansion to the belowground biomass	2*30% (30% for Black locust and grey poplar, 20% for black pine, as inferred from Table 3A.1.8 of IPCC 2003)
	<b>Combined uncertainty for below ground biomass, U<sub>BIBG</sub></b>		<b>60%</b>
<b>Combined uncertainty for biomass, U<sub>BI</sub> = <math>\text{SQRT}((\text{BI}_{\text{AG}} * U_{\text{BIAG}}^2) + (\text{BI}_{\text{BG}} * U_{\text{BIBG}}^2)) / \text{ABS}(\text{BI}_{\text{AG}} + \text{BI}_{\text{BG}})</math></b>		<b>37,8%</b>	
<b>Deadwood</b>	Total deadwood estimate (DW)	Assumption: no changes	<i>Unknown, but negligible</i>

**Table 15, cont.**

<b>Pool</b>	<b>Variable</b>	<b>Source of error</b>	<b>Relative uncertainty (U) at 95% probability (=half of the confidence interval ≈ two times the standard error in percent of the estimate)</b>
<b>Soil</b>	Soil carbon content per ha (S <sub>Operha</sub> )	Sampling	2*20% (this study, with expert judgment)
	(M <sub>SOIL</sub> )	Mistakes in laboratory, lab measurements	2*1% (expert judgment)
	Total project area (A)	Expansion to the total project area (=error of area determination)	2*1% (expert judgment)
	<b>Combined uncertainty for soil, U<sub>SO</sub> = SQRT(U<sub>SOperha</sub><sup>2</sup> + U<sub>MLITTER</sub><sup>2</sup> + U<sub>A</sub><sup>2</sup>)</b>		<b>20.2%</b>
<b>Litter</b>	Amount of litter per ha, L <sub>iperha</sub>	Sampling	2*25% (this study, with expert judgment)
	Conversion factor, CF <sub>LITTER</sub>	Converting to get the amount of carbon in litter per ha	10% (not provided by IPCC 2003; expert judgment)
	Measurements, M <sub>LITTER</sub>	Mistakes in laboratory, lab measurements	2*1% (expert judgment)
	Total project area, A	Expansion to the total project area (=error of area determination)	2*1% (expert judgment)
	<b>Combined uncertainty for litter, U<sub>LI</sub> = SQRT(U<sub>Liperha</sub><sup>2</sup> + U<sub>CFLITTER</sub><sup>2</sup> + U<sub>MLITTER</sub><sup>2</sup> + U<sub>A</sub><sup>2</sup>)</b>		<b>51,1%</b>
<b>Total</b>	<b>All errors combined using simple error propagation (for information only):  U = sqrt((BI<sub>ABOVE</sub>*U<sub>BIABOVE</sub>)<sup>2</sup> + (BI<sub>BELOW</sub>*U<sub>BELOW</sub>)<sup>2</sup> + (SO*U<sub>SO</sub>)<sup>2</sup> + (LI*U<sub>LI</sub>)<sup>2</sup>)/ABS(BI<sub>ABOVE</sub> + BI<sub>BELOW</sub> + SO + LI)</b>		<b><u>35,4%</u></b>

Concerning the combined uncertainties, Approach 1 of the GPG is suggested for projects. In this approach, uncertainty in emissions or removals can be propagated from uncertainties in the activity data, emission factor and other estimation parameters

through the error propagation equation (Table 15, Mandel, 1984, Bevington and Robinson, 1992, IPCC 2003). Theoretically, approach 1 also requires that the standard deviation divided by the mean value is less than 0.3. In practice the approach will give informative results even if this criterion is not strictly met.

Finally, when carbon stock changes are concerned, then covariance between the two inventory samples should also be considered, and the above error propagation equation cannot be used in a strict sense. This is because the estimates of the two inventories are correlated, and taking their difference removes much of the individual error. However, no correlation data is available for the test site, because it was not possible to obtain two inventory estimates. Therefore, the uncertainty of the carbon stock change estimates could not be computed. However, the uncertainty data of the inventory estimates is informative enough, especially if the various pools are compared by taking the relative values of uncertainties. It is obvious that the belowground biomass estimate is the most uncertain. It is followed by the litter estimate, however, it must be added that the number of the litter samples was low, and if litter samples are taken from all sample plots where soil samples are taken (i.e. more than 200 sites) then the uncertainty of the litter samples is also reduced substantially. In this case, the overall uncertainty also decreases, and a reasonable overall estimate can be obtained for the whole project area.

### **3.10. Conclusions. Possible improvements of the methodologies of monitoring the carbon stock changes in AR projects**

Both the total carbon budget, as well as the summary of the uncertainties demonstrate that we could achieve all aims of the CI research project: to implement and analyze the methodologies that are supposed to be used in AR projects. This also means that these methodologies are ready for application. However, the experiences also show that, in order to be practical, cost-effective, and yet accurate, one always has to apply common sense and adapt the methodologies to local conditions. No general guidance can be given for the myriads of forest situations that may occur in AR projects. This guidance will always stay too general. However, we managed to translate our experience into a more extended guidance, which was the aim of this module of the CI project.

It must be noted that, since the idea of the CI project was formulated, the international landscape has changed, and it seems that it is going to be the so called CDM projects that will play a more important role in implementing the commitments under the Kyoto Protocol. With respect to the monitoring methodologies, this does not mean at all that the guidance in this report cannot be fully utilized: on the contrary, the guidance and methodology can be fully adapted in the CDM projects, where the rules for the monitoring will not be significantly different. Therefore, this report will be useful for CDM project developers, and teams that will conduct the greenhouse gas monitoring.

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