UNCERTAINTY ANALYSIS
BY ERROR PROPAGATION

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1 Uncertainty analysis of carbon stock changes in the biomass

To understand the methods of uncertainty analyses, data of the Hungarian National Forest Database (NFD) must be known (for a detailed description see the document entitled *Forestry-related Databases of the Hungarian Forestry Directorate* available online at: http://www.mgszh.gov.hu/szakteruletek/szakteruletek/erdeszeti_igazgatosag/supplementary_inf_ERT/forest-db.html). NFD data are gathered by forest planning and forestry inspection activities. As a part of forest planning tree stand of every forest subcompartment is sampled in 10-year-long cycles which means that a given stand is sampled once in every 10 years. Sampling method is chosen by the planner considering tree stand structure and site conditions. Forest inspectors update the data every year according to changes caused by afforestations, reforestations, harvesting operations, forest fires or others.

From the uncertainty point of view it is important to know that NFD stores various mean data of subcompartments of 4 ha in average (ranging from 0.1 to 100 ha). Consequently, no information is available about the spatial diversity of the tree stand. However, uncertainty analyses would require such information (i.e. raw sampling data) because that is needed for confidence interval calculation.

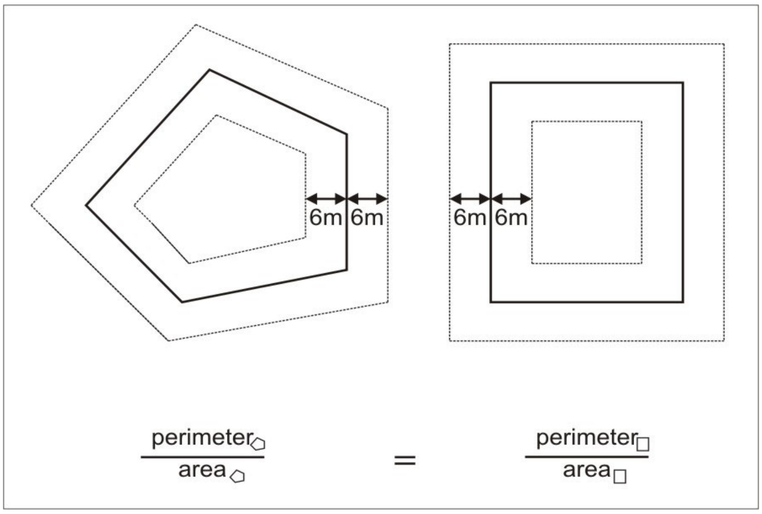

Figure 1 Uncertainty of subcompartment area assuming +/ 6 m random error in location of the border lines. According to a pilot study, random errors of subcompartment areas are approximately identical if rectangular shapes are assumed instead of the real shapes. For further explanation see the text.

Data collected by forest planning and inspection and imported in NFD include stand age, diameter as well as height. From these data *per hectare volume* is calculated by internal algorithms using yield tables. If a stand is sampled in a given year, its volume is calculated from the sampling data. If a stand is not sampled in a given year one year increment is added to its volume in the previous year. Increments are determined by internal algorithms again from yield tables.

To calculate the uncertainty of the standing volume bottom-up by error propagation, the following uncertainties must be known:

- Sampling errors of forest planning activities.
- Error of per hectare standing volumes of yield tables. Error of increments published in yield tables.
- Error of updating the NFD data by forestry inspection.
- Error of subcompartment areas.

The errors listed are complex and may be splitted into “sub-errors” originated from various sources at lower levels.

Raw sampling data would be necessary for estimation of sampling errors of forest planning. However, such data are not available yet, though a country-level study is planned in this topic.

Errors occurring in volume and increment data of the yield table cannot be identified, either, based on the available data. The explanation of this is the fact that uncertainty of the data was rarely published along with the yield tables (created in the 1970’s) currently used in the NFD. Consequently, uncertainty of the yield table data can be calculated only if the raw sampling data from which they were calculated are known. However, on the one hand these data are not accessible or on the other hand procession of these data would need unduly high efforts (because data are stored mainly on papers).

It is difficult to quantify the error of updating. If forest manager carries out harvesting operation in accordance with the forest management plan then forest inspector updates NFD data without any in-situ investigation. In this case, an error occurs if the forest manager does not follow prescribes of the forest management plant precisely. However, based on the available data, this type of error cannot be quantified directly.

Error of subcompartment areas can be modelled easily from prescriptions related to mapping precision. That is, a maximum error of 6 m, relative to the “true” location, of any point of the border of the subcompartment has been allowed until recently. It means that the difference between the true and the mapped location of the boarder lines of a given subcompartment can be maximum 6 m (Figure 1). It must be emphasized that this maximum distance is clearly an overestimation of the real precision of mapping practice according to expert judgments. Still, an error of 6 m was supposed when calculating area uncertainty for the shake of conservativeness.

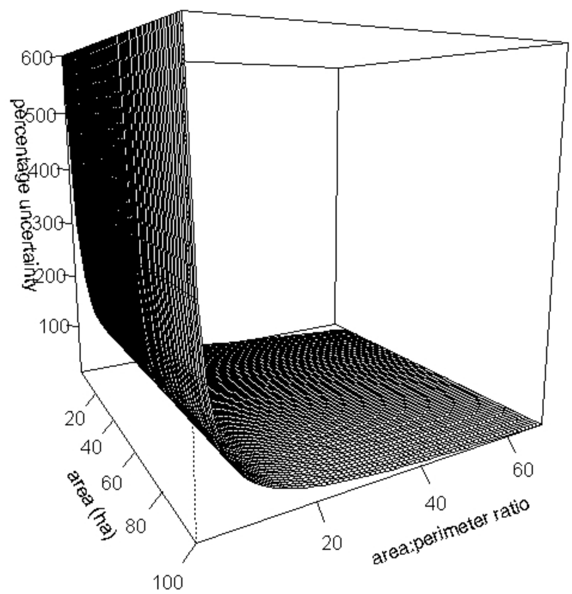

Figure 2 Percentage uncertainty of forest subcompartment area as a function of the size of the area and the area:perimeter ratio supposing a 6 m error in the location of the border lines.

Assuming that all subcompartments are rectangular and error of their area is random it is easy to calculate the maximum positive or negative difference between the true and the mapped areas (i.e. the range of the area; Figures 2-3). Note that application of range instead of confidence interval is a clear overestimation of random error. However, as GL for LULUCF 2006 suggests on page 3.21 when the only available information about uncertainty is the range it can be treated as a confidence interval (with 95 % confidence level). Thus, the percentage differences between the possible maximum and the possible minimum size of the mapped areas were applied as uncertainty values. Using error propagation (Equation 3.1 in GL for LULUCF 2006) the error of total area of forested land is 0.03 % on country-level even by this highly conservative approach. According to a pilot study carried out by an expert modelling the shape of the subcompartments by rectangles gives reliable results that do not differ considerably from those when the real shapes are used with 12 m-wide (i.e. +/- 6 m) buffer zones for calculation of the possible highest differences between the true and the mapped areas (Figure 1). Thus, due to practical reasons the above-mentioned assumption of rectangular shape was applied.

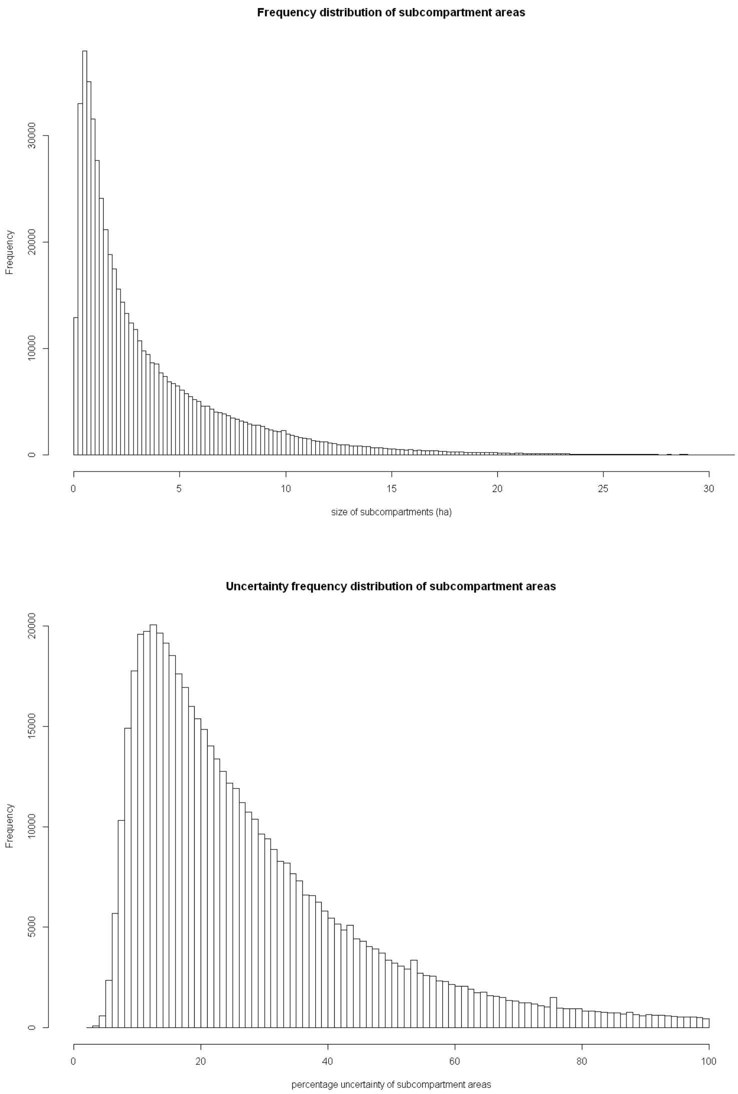

Figure 3 Frequency distributions of subcompartment areas and their uncertainties.

1.1 Uncertainty estimation methods of NFD per hectare volume data

Uncertainty of NFD per hectare volume data can be estimated only indirectly since no information is available about sampling error of forest planning and uncertainty of yield table data. Besides NFD, there is another forest inventory that is the database of the so-called

Forest Growth Monitoring System (hereinafter abbreviated by FGM). Data of FGM are collected by a countrywide systematic sampling.

The entire area of the country is covered by a grid of 2.8 km x 2.8 km. In each grid point sampling is carried out every 5 years. The sampling units (plots) are circle-shaped. The radius of the circles depends on tree stand structure. In young stands or in stands of smaller trees it is shorter while in older stands or in stands of larger trees it is longer. The aim of the variable sizes was to fix the number of trees sampled in each plot. Thus, sample size of each plot was approximately identical, 15-20 individuals. Diameter and height of each sample tree were measured, except for trees which had broken crowns or non-visible tops. Height of such trees was determined by diameter-height curves. From the obtained data, standing volume was calculated applying country-specific volume functions. Data of the first three 5-year-long cycles of FGM were used for uncertainty analyses purposes. Note that in this type of analysis temporally dependent data could be applied since no significance tests were carried out, consequently pseudoreplication was not a problem.

On the subcompartment-level, various random errors obviously occur in FGM standing volume data. The main sources of them are the following:

- Sampling error. The source of this type of uncertainty is that FGM plots may be unrepresentative of the tree stand of the entire subcompartment. This means that standing volume of the plot may differ from the average standing volume of the subcompartment. However, this error type cannot be quantified.
- Measurement errors.
- Error of diameter-height curves (when applied).
- Error of volume functions.
- Error of the area of the sampling plots.

By applying appropriate assumptions, FGM data are suitable for uncertainty analysis of NFD data. However, the resulted uncertainty values are rather of an informative character and may not be an accurate estimation because of the errors inherent in the FGM estimates.

For analyzing the uncertainty of the per hectare volume data of NFD, those FGM plots were chosen which fulfilled the following requirements:

- The dominant tree species and its age were identical with those stored in the NFD.
- The FGM plot is located in a subcompartment of approximately homogeneous tree stand. Approximately homogeneous means that ratio of the dominant tree species is minimum 80 % whereas the closure (vertical crown projection) of the dominant tree species is minimum 70 %. In this way, a random error type of FGM data caused by the fact that FGM plot may be unrepresentative of the entire forest subcompartment was reduced. Note that application of higher threshold values of species ratio and closure was not possible due to the related low sample sizes (see Table 1).

Differences between NFD and FGM per hectare standing volume data of the dominant tree species were calculated. Uncertainties of NFD data relative to FGM estimates were assessed by species groups from the distributions of these differences.

Tree species were grouped before data processing. The groups were the same as those used for assessment of carbon stock change in the biomass (NIR, Table 7.8). However, uncertainty analyses were performed only if the sample size was reasonably large (Table 1). Thus, not all of the species groups could be involved in this investigation.

Uncertainty of the FGM data was disregarded when assessing errors of NFD data. Theoretically, uncertainties of FGM data should be taken into consideration when per hectare volume data of NFD and FGM are compared. However, the aim of the uncertainty analysis was to make an *order of magnitude estimation* of random errors of the NFD data because it is impossible to give an accurate assessment due to the strongly different methods of data collection and processing of NFD and FGM data. Disregarding subcompartment level-errors of FGM data leads to a conservative estimation of uncertainty of NFD per hectare volume values. In other words, due to the systematic sampling design of FGM plots it can assumed that the subcompartment-level errors of the FGM data are random since the FGM plots are placed independently from the tree stand structure. Consequently, FGM plots may have higher or lower standing volume than the average standing volume of the subcompartment with equal probability.

According to the background model, differences between the NFD and FGM data are caused by errors of the former ones. This assumption is supported by the following facts:

1. In the FGM plots diameter and height of all trees are measured (the only exceptions are the trees height of which cannot be measured directly due to various reasons) whereas in the case of NFD there are much fewer directly measured data because of high costs. Actually, in most cases standing volume is estimated from yield tables based on stand age, height (as estimated from data of only a few trees) and species ratio (calculated from basal areas which are estimated visually or measured by Bitterlich relascope). FGM data are much more reliable due to the much more measured data.
2. FGM standing volume values are calculated by the Király 2 volume functions (Sopp and Kolozs, 2009) on individual level. By contrast, NFD standing volume values are assessed (predicted) on stand level and from yield tables which were created from countrywide data and consequently may not be representative of the local conditions. The latter method gives less precise estimation because uncertainty of the yield tables is incorporated in that of the standing volume. It should be noted that uncertainty of the yield tables originates from various sources such as error of volume functions. According to expert judgment, uncertainty of these functions is larger than that of the Király 2 functions used in the case of FGM. There is another error related to the application of yield tables which cannot be quantified based on the available data. Namely, that standing volume of a given forest subcompartment may differ more or less from the country-level "average" as represented by the yield table for stands of the same characteristics (i.e., species, age and mean height) as those of the subcompartment.

However, it can be assumed that the approximation of the uncertainty of NFD data from the distribution of differences between FGM and NFD per hectare standing volume values gives an overestimation of the true random error because the distinct sampling methods may increase these differences. Advantages of the applied assessment method include conservativeness, possibility of quantifying uncertainties from probability density functions created from measured data and further development.

According to the applied model percentage uncertainty of the per hectare NFD data of the studied species groups were assumed to be independent from the species, age, site conditions as well as sampling errors of forest planning. Obviously, these assumptions allow only a rough estimation. However, it was not possible to make a more sophisticated assessment (e.g. by species, age groups or site types) because of the low (less than 100 independent sampling plots) number of the suitable FGM plots that have more or less homogeneous tree stand structure.

The comparisons of NFD and FGM per hectare volume data give uncertainty estimations of the former ones on an aggregated level that includes the above-mentioned error sources.

According to the background model, percentage confidence intervals of NFD m^3/ha values (i.e. average values of the given subcompartments) can be calculated from probability density functions of the differences between NFD and FGM data. It is important to understand that the shape of the curves of the probability density functions of these differences is identical with that of the hypothetical distribution of NFD m^3/ha values which is approximated by distributions of FGM data (Figure 4). However, distributions of the differences are shifted in the origo (which means that the means of the distributions are zero). That is the reason why probability density functions of the differences can be used for calculation of confidence intervals (with 95 % confidence level) of NFD m^3/ha data.

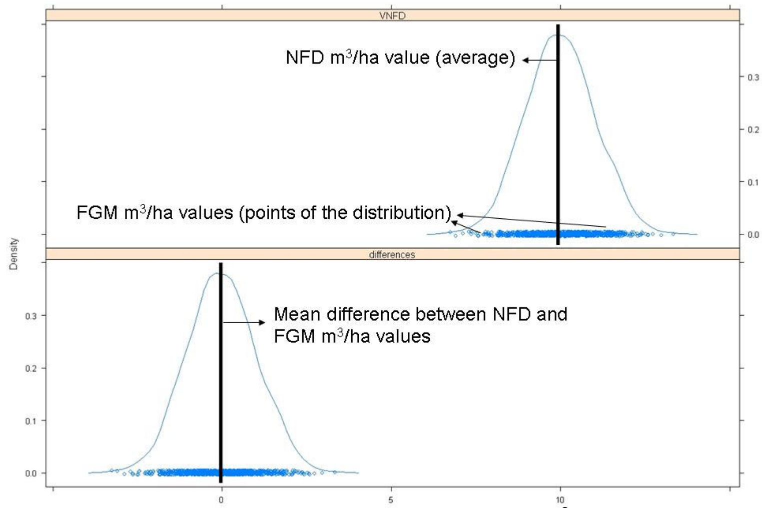

Figure 4 Background model of estimation of uncertainty of NFD m^3/ha values. The upper figure shows the hypothetical distribution of NFD m^3/ha values of a given subcompartment which is approximated by FGM data. The lower figure shows distribution of differences between NFD and FGM m^3/ha data.

The differences between the two types of m^3/ha data were expressed as percentage. In this way, data of subcompartments having different average m^3/ha values could be used to create distribution of differences of various tree species groups. The applied species groups are shown in NIR Table 7.8. At the same time, the resulted confidence intervals could be put directly into the error propagation equations. Relative differences were calculated by the following equation:

$d = (V_{NFD} – V_{FGM})/ V_{NFD}*100$

Thus, d values were obtained on a percentage scale relative to the NFD data.

Standing volume of various tree species of a given forest subcompartment is the product of m^3/ha data and the area of the subcompartment:

$V_f = V_{m3/ha} * A$

where:

V_f: standing volume of the given species in the given forest subcompartment; $V_{m3/ha}$: per hectare volume of the species; A: subcompartment area.

As uncertainty of $V_{m3/ha}$ is independent from that of A, the uncertainty of the product was calculated by approach 1 (Equation 3.2 in GL for LULUCF 2006). Summing up V_f values gives the total standing volumes on country-level by species groups (as shown in Table 7.8) and categories. The related uncertainties were determined by Equation 3.1 (GL for LULUCF 2006). Differences between standing volumes of the current and the previous year were regarded as activity data and converted to carbon stock-change by species groups and then summing up these changes gave the total net change of the given category (see NIR Chapter 7.3.1.2.1). Effects of summation and multiplication on error propagation were assessed by Equations 3.1 and 3.2 (GL for LULUCF 2006).

Note that it was impossible to aggregate emission factor uncertainties on category-level because activity data were multiplied by emission factors on species group-level. Thus, implied emission factor uncertainties were determined on category-level. It means that activity data and combined uncertainties were aggregated to category-level and implied emission factor uncertainties were calculated from them following error propagation rules (Equation 3.1 in GL for LULUCF 2006)

Uncertainty assessment of UNFCCC categories differed from that of the KP LULUCF categories because emissions and removals were calculated in a different way. The reason for this methodological difference is that category AR is not equivalent with category L-FL. AR includes afforestations and reforestations that have been planted since 1990 whereas L-FL is a transitional buffer category containing 0-20-year-old afforestations and reforestations. Due to administrative reasons, contrary to AR, L-FL area cannot be matched with concrete forest subcompartments (see NIR Chapter 7.3.2.2). Official documentation only shows total area of category L-FL by species and by age groups with the corresponding number of subcompartments. Thus, subcompartments of average sizes were used by species and age groups for the above-described bottom-up error propagation. As area uncertainty is much smaller than that of the standing volume, this simplification does not influence the results considerably. Losses caused by the previous land uses were accounted for L-FL, as in the case of category AR.

Stock change of category FL-FL was calculated by the following equation:
FL-FL = TF – L-FL – FF + D
where
TF: stock change of the total forest (which is equal to FL-FL + L-FL + FF – D);
FF: standing volume of found forests;
D: standing volume of areas to be deforested.
Stock-change of category FL-FL was calculated only on country-level so not with a bottom-up approach. That’s why results of uncertainty analyses may be substantially different from those related to category FM.

Uncertainty of wood densities was estimated from data published by Somogyi (2008). Uncertainty of root-to-shoot ratio and carbon fraction was taken from GPG for LULUCF 2003 Annex 3A.1 Table 3A.1.8 and GL for LULUCF 2006 Table 4.3, respectively. Default values of Table 3.3.2 in Chapter 3 of GPG for LULUCF 2003 were applied for calculation of uncertainties caused by losses in carbon stock of category L-FL induced by the previous land uses.

1.2 Results

Comparisons of NFD and FGM data were performed for seven species groups of sample size of minimum 300 (Table 1) which equals 100 independent FGM plots during the three sampling cycles. Uncertainty of the NFD m^3/ha values of the various species groups was of the same order of magnitude, approximately +/- 100 %. The only exception is the group of cultivated poplars where the half-width of the resulted confidence interval was almost 200 %.

Table 1 Percentage confidence intervals (CI, confidence level = 95 %) of m^3/ha values of various tree species groups stored in the NFD, relative to the FGM. Note that some half-widths are larger than 100 % due to the fact that NFD standing volume values were sometimes much smaller than FGM values. For further explanation see the text.

Tree species group	Sample size	CI (%)
Robinia pseudoacacia	1574	115
Fagus sylvatica	396	105
Quercus cerris	577	94
Pinus sylvestris	758	83
Quercus robur	620	86
Quercus petraea	669	73
Populus x spp. (cultivated poplars)	291	192

Two facts must be emphasized in connection with the results. 1. Some of the confidence interval half widths were larger than 100 % which would mean that standing volume can be negative. It is clearly impossible. The reason for this phenomenon is that NFD values are sometimes much smaller than FGM values which means that NFD per hectare standing volume data underestimate the true values. This gives a conservative character of our estimation of removals caused by growth of forests (see NIR Chapter 7.3.4). 2. FGM data are the most uncertain in the case of the cultivated poplars. This is because area size of the FGM plots containing identical number of trees can be highly variable due to the wide-spacing of cultivated poplar plantations. Thus, random error of plot area is far the highest in these stands.

Table 2 Uncertainty of volume growth expressed by the half-width of percentage confidence intervals (CI, confidence level = 95 %) by species groups on L-FL areas.

Tree species group	CI (%)
Quercus spp.	26.85
Quercus cerris and other hardwood	25.24
Fagus sylvatica	37.87
Robinia pseudoacacia	23.88
Populus x spp. (cultivated) - Salix spp.	25.64
Populus spp. (native) - other softwood	26.66
Conifers	45.88

Based on the resulted confidence intervals an interval half-width of 100 % was chosen for error propagation in the case of all species groups. This is clearly a simplification. However, application of the exact half-widths would have been unnecessary because the aim of the uncertainty analyses was to estimate the order of magnitude of confidence interval widths and not to assess directly the exact values since the latter estimation is not possible because of the lack of appropriate data. In the case of the cultivated poplars, a half-width of 100 % is also a reasonable choice because of the high random error of FGM plot area which increased the differences between NFD and FGM m^3/ha values (and which was overlooked due to methodological and practical reasons as described above).

The 100 % half-width of the NFD m^3/ha data is a strong overestimation of the real uncertainty. This statement is proved by an expert judgement which assessed that the half-range (not confidence interval!) of these data is 30 %.

The resulting wide confidence intervals can be traced back to methodological reasons. That is, the applied methods give a highly conservative estimation per se because of the fact that the FGM plot may be unrepresentative of the entire forest subcompartment. Furthermore, it is also true that uncertainty of m^3/ha data increases with decreasing spatial scale because the finer the spatial scale is the larger differences may occur between the local m^3/ha values and the country-wide averages (which are the corresponding values of the yield tables used in the NFD).

Table 2 and 4 show the results when this strong overestimation of uncertainty of m^3/ha values having been used. Table 5 shows uncertainties of total areas of various categories when a +/- 6 m random error having been assumed in location of the border lines of the subcompartments. Note that uncertainty related to category FL-FL was assessed only on category-level as described above.

2 Uncertainty estimation of carbon stock-changes in deadwood pool under FL-L

In Hungary, country-level deadwood monitoring has been started recently in the frame of the FGM project (Kolozs 2009). Total volume of deadwood accumulated in the Hungarian forests can be assessed by the obtained data. Moreover, the data gathered by applied systematic sampling design are appropriate for creation of confidence intervals (Table 3). Note that currently there is not enough data to estimate the changes in deadwood amount in the Hungarian forests because data of only two sampling years are available which do not give a reliable estimation.

Carbon stock-changes in deadwood-pool are accounted for in the case of deforestations (categories D and FL-L). In order to integrate FGM data in the uncertainty estimation of the national greenhouse gas inventory, the average per hectare amount of deadwood was calculated. Uncertainty of this coefficient was obtained from that of total area of the Hungarian forests and total deadwood volume. Uncertainties were combined by approach 1. Deadwood volume of deforested areas – that was regarded as activity data – was estimated by multiplication of this coefficient by the total area of deforestations. Multiplication effect on uncertainty was assessed by error propagation (Equation 3.1 in GL for LULUCF 2006) since no correlation occurs between input factors. It should be noted, however, that the resulted uncertainty underestimates the true one because it is inherently supposed that deadwood volume distribution of the deforested areas is identical with that of all Hungarian forests. Thus, a non-quantifiable error caused by the inappropriate representation appears.

Total deadwood volume was converted to carbon content and CO_2-equivalent as detailed in NIR Chapter 11.3.1.2.

Table 3 Uncertainty values of various quantities related to carbon stock changes in deadwood as expressed by the half-widths of percentage confidence intervals (CI, confidence level = 95 %).

	CI (%)
Average deadwood m^3/ha value on country-level	14.08
Total area of deforestations	1.9
Average deadwood m^3/ha value on deforested areas	14.21

Uncertainty values of carbon fraction were taken from Table 3A.1.4 in Appendix 3A.1 of GPG for LULUCF 2003. Percentage confidence intervals of wood densities were assumed +/- 10 % based on Somogyi (2008). Uncertainty of the implied emission factor was calculated on category-level as described above in connection with the biomass pool. Result is shown in Table 4.

3 Uncertainty estimation of emissions caused by slash burning and wildfires

Emissions caused by slash burning are estimated from volume of the harvested trees that was regarded as activity data. Multiplying this volume with slash fraction gives the amount of slash (see NIR Table 7.9). In the case of wildfires, emitted gas quantities are assessed from burned volume which is estimated by forest inspectors on field. Slash and burned volumes were converted to greenhouse gas amounts by being multiplied by various emission factors (see NIR Chapter 7.3.1.3).

Uncertainty of volume of the removed trees was calculated in the same manner as that of standing volume detailed above. In the forest management plant, volume of trees to be harvested is calculated from the standing volume of the given subcompartment.

Consequently, uncertainty of the former is equal to the latter. However, forest managers may cut more or less than the prescribed volume depending on the profitability of the given harvesting occasion and the development state or structure of the tree stand. By the applied method, a random error of +/- 100 % was estimated in (per hectare) volume of the removed tree which is a highly conservative approach.

Uncertainty of volume of trees burned in wildfires (i.e. activity data uncertainty) was estimated from that of standing volume and burned fraction. The latter was determined by expert judgement.

Uncertainty values of wood density and carbon fraction were identical with those used for uncertainty analysis of carbon stored in the living biomass. Emission factor uncertainties were taken from Table 3A1.15, Annex 3A1, GPG for LULUCF 2003. Random error of N:C ratios was assumed +/- 100 % based on the default value of Table A1-1, Annex 1ri, GPG for LULUCF 1996. Uncertainty of the rest of the emission factors was assessed by expert judgement: slash fraction - +/- 10 %; burned fraction (in the case of wildfires) - +/- 20 %; burned on site - +/- 30 %; oxidized in burn - +/- 10 %. Uncertainties of activity data and emission factors were combined by error propagation. On category-level, implied emission factor uncertainties were calculated as described in connection with the biomass pool. Results are shown in Table 4.

4 Uncertainty estimation of soil carbon stock changes under FL-L

Temporal changes of soil carbon content of deforestations were calculated by equation 3.3.3 of GPG for LULUCF 2003 (see NIR Chapter 7.3.3.1). Activity data (size of area) and emission factor uncertainties were combined by error propagation (approach 1, Equations 3.1 and 3.2 in GL for LULUCF 2006). The former data included the size of the deforested areas. These were multiplied by default emission factors which were taken from Table 3.3.4 of GPG for LULUCF 2003 (FLU, FI, FMG) as well as Table 2.3, Chapter 2, Volume 4, GL for LULUCF 2006 (SOCref). These tables show the corresponding uncertainty values, as well. Area uncertainties were assessed following the methodology detailed above.

Note that – as it is described in NIR Chapter 7.3.3.1 – several subcategories were distinguished when emissions having been calculated. Soil carbon stock changes of these subcategories were then added up. However, for uncertainty estimation a simpler but more conservative approach was applied. Uncertainty of total deforestation area was calculated by conversion types (FL-CL, FL-SE) with Equation 3.2 in GL for LULUCF 2006. This uncertainty was then combined with the corresponding emission factor uncertainties. It was unnecessary and impractical to calculate uncertainty values of area of each subcategory in each year of the conversion period and then combine these values with emission factor uncertainties because emission factor (FLU, FI, FMG) uncertainties are approximately equal (+/- 4-10 %) and at the same time SOCref uncertainty is much higher (a value of +/- 90 % was chosen based on Table 2.3, Chapter 2, Volume 4, GL for LULUCF 2006). Taking into account that uncertainty of size of deforested areas is also small (see Table 4) it can be concluded that results are mostly influenced by SOCref uncertainty because squares of uncertainty values are added up in error propagation equation. For the same reason, uncertainty of size of deforested area under the conversion period was assessed by that in the current year. Thus, the highest possible uncertainty values of emission factors (FLU, FI, FMG) were applied and uncertainty of carbon-stock changes was calculated only by conversion types. Results are shown in Table 4.

Table 4 Activity data, implied emission factor and combined uncertainties expressed by the half-width of percentage confidence intervals (confidence level = 95 %) by sink/source categories. Deforestations were classified according to the post-deforestation land uses if corresponding data were available. Implied emission factor uncertainties were calculated on category-level. For further explanation see the text.

Category	Sink/source	Gas	Activity data	Implied emission factor	Combined
FL-CL	soil	CO2	3.81	91.30	91.38
FL-CL	biomass (stock-change)	CO2	25.16	45.00	51.56
FL-FL	biomass (stock-change)	CO2	5.71	25.39	26.02
FL-FL + L-FL	slash burning	CH4	0.98	15.50	15.53
FL-FL + L-FL	slash burning	CO	0.98	17.53	17.56
FL-FL + L-FL	slash burning	N2O	0.98	40.56	40.57
FL-FL + L-FL	slash burning	NOx	0.98	40.02	40.03
FL-FL + L-FL	wildfires	CH4	43.21	17.69	46.69
FL-FL + L-FL	wildfires	CO	43.21	20.76	47.94
FL-FL + L-FL	wildfires	N2O	43.21	52.88	68.29
FL-FL + L-FL	wildfires	NOx	43.21	52.14	67.72
FL-GL	biomass (stock-change)	CO2	23.38	43.39	49.29
FL-L	deadwood	CO2	14.08	14.27	20.05
FL-L	biomass (stock-change)	CO2	13.42	39.46	41.68
FL-L	slash burning	CH4	13.37	17.10	21.71
FL-L	slash burning	CO	13.37	19.23	23.42
FL-L	slash burning	N2O	13.37	43.83	45.82
FL-L	slash burning	NOx	13.37	43.25	45.27
FL-SE	soil	CO2	2.44	96.38	96.41
FL-SE	biomass (stock-change)	CO2	18.15	40.82	44.67
L-FL	biomass (stock-change)	CO2	19.62	47.90	51.76

Table 5 Uncertainties of area of various categories expressed by the half-width of percentage confidence intervals (confidence level = 95 %). Deforestations were classified according to the post-deforestation land uses.

Category	CI (%)
FL-L	1.9
FL-FL	0.03
L-FL	0.12
FL-CL	3.81
FL-SE	2.44
FL-GL	5.01
Total forest	0.03

5 Limitations of the present uncertainty analyses and the planned future developments

Up to now, uncertainties have been combined by error propagation equations following approach 1. However, according to the GL 2006, approach 1 gives reliable results only if the coefficient of variation is smaller than 30 %. This assumption was not met in some cases so results should be cared with caution. (As Chapter 3.2.3.1 GL 2006 reads: *the approach will give informative results even if this criterion is not strictly met*). In future, Monte Carlo simulation is planned.

In some cases, default uncertainties were applied. Default uncertainties may be much larger than those calculated or estimated on country-level. Thus, it is planned to substitute default uncertainties greatly affecting the total uncertainty of a given category for those being determined on country-level by expert judgement or measured data.

Hungary made efforts in order to quantify uncertainty of the carbon stock changes of the above-ground biomass of forests. Here again we describe that random error of standing volume was assessed based on measured data. However, this investigation has some limits which can be summarized in the following way:

- Due to small sample sizes, appropriate data were not available for all species groups being included in quantification of emissions/removals. That's why results must have been extended by expert judgement to species not having enough data.
- Random errors occurred in those measured data which were used as a reference for uncertainty quantification. However, these errors were overlooked because of methodological and practical reasons.

Various innovations are planned to be carried out in the future:

- Sampling error of forest planning will be assessed by a detailed investigation of field data forms.
- Random error of per hectare standing volume and increment data of yield tables will be estimated based on measured data.

These planned analyses are independent from the comparisons of FGM and NFD data which are presented in this report, so results of the latter ones can be affirmed.

In the present report, uncertainty of soil C:N ratio and that of the litter carbon content are not analysed due to lack of proper data. However, a process of soliciting expert judgement is being carried out in connection with these random error types. Thus, next year the results will be incorporated in the uncertainty analysis.

6 Uncertainty estimation of KP-LULUCF categories

Uncertainties related to KP-LULUCF categories were estimated in a similar way as described above. Here again we describe that uncertainty of total standing volume of each tree species group was calculated by summing subcompartment-level standing volume data and then the differences in total values between the current and the previous year were calculated by species. These differences expressed as m^3 were then transformed to carbon contents and CO_2-equivalents by being multiplied with emission factors. Note that this method is a bottom-up calculation based on data of identified forest subcompartments contrary to methods related to the UNFCCC categories where uncertainty was assessed on an aggregated level in some cases (FL-FL) or where modelled data were used for the bottom-up calculation (L-FL). Approach 1 (including Equations 3.1 and 3.2 in GL for LULUCF 2006) was used for quantifying error propagation caused by the summation and multiplication (Tables 6 and 7). Uncertainties of total areas of various categories are shown in Table 8.

Table 6 Uncertainty of volume growth of various tree species groups as expressed by the half-widths of percentage confidence intervals (confidence level = 95 %).

	CI (%)	
	AR	FM
Quercus robur	2.10	0.51
Quercus petraea	3.93	0.45
Other oaks	6.02	1.00
Quercus cerris	4.01	0.42
Fagus sylvatica	11.68	0.60
Carpinus betulus	5.89	0.47
Robinia pseudoacacia	1.02	0.33
Acer spp.	6.71	0.76
Ulmus spp.	6.23	1.68
Fraxinus spp.	3.40	0.65
Other hardwood	5.61	0.98
Populus x spp. (cultivated)	1.28	0.71
Populus spp. (native)	1.96	0.69
Salix spp.	8.64	1.16
Alnus spp.	4.91	0.75
Tilia spp.	10.32	1.00
Other softwood	21.49	1.50
Pinus sylvestris	5.57	0.48
Pinus nigra	4.01	0.72
Picea abies	9.25	1.15
Larix decidua	13.80	1.70
Other conifers	21.48	3.52

As Table 7 shows some confidence intervals have a half-width larger than 100 % in the case of wildfires on AR lands. This is due to two reasons: 1. Uncertainty of standing volume was assessed by a highly conservative method and the applied default emission factor uncertainties were also high; 2. Wildfires occurred very rarely on AR lands. Thus, very few values must have been summed up, and consequently, random error was increased due to multiplication of emission factors and activity data but was not reduced by summation. In other words, due to the fine spatial scale, random errors in emissions remained extremely high. However, it should be kept in mind that the maximum half-width of the resulted confidence intervals in negative direction can be maximum 100 %.

Table 7 Activity data, implied emission factor and combined uncertainties expressed by the half-width of percentage confidence intervals (confidence level = 95 %) by sink/source categories. Note that some confiedence intervals have a half-width larger than 100 % in the case of wildfires on AR lands. This is due to methodological reasons because in negative direction the half-width can be maximum 100 %. For further explanation see the text.

Category	Sink/source	Gas	Activity data	Implied emission factor	Combined
AR	biomass (stock-change)	CO2	0.67	58.07	58.07
AR	slash burning	CH4	4.48	25.75	26.14
AR	slash burning	CO	4.48	29.13	29.47
AR	slash burning	N2O	4.48	67.49	67.64
AR	slash burning	NOx	4.48	66.59	66.74
AR	wildfires	CH4	102.25	29.03	106.29
AR	wildfires	CO	102.25	36.44	108.55
AR	wildfires	N2O	102.25	105.04	146.59
AR	wildfires	NOx	102.25	103.51	145.5
D	deadwood	CO2	14.08	14.27	20.05
D	biomass (stock-change)	CO2	13.42	39.46	41.68
D	slash burning	CH4	13.37	17.10	21.71
D	slash burning	CO	13.37	19.23	23.42
D	slash burning	N2O	13.37	43.83	45.82
D	slash burning	NOx	13.37	43.25	45.27
FM	biomass (stock-change)	CO2	0.23	34.21	34.21
FM	slash burning	CH4	0.99	15.49	15.52
FM	slash burning	CO	0.99	17.52	17.55
FM	slash burning	N2O	0.99	40.53	40.54
FM	slash burning	NOx	0.99	39.99	40.00
FM	wildfires	CH4	45.98	23.11	51.46
FM	wildfires	CO	45.98	25.65	52.65
FM	wildfires	N2O	45.98	55.94	72.41
FM	wildfires	NOx	45.98	55.20	71.84

Table 8 Area uncertainties of various categories expressed by the half-width of percentage confidence intervals (confidence level = 95 %).

category	CI (%)
AR	0.08
D	1.9
FM	0.03

References:

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