

Uncertainties of inventory-based carbon budget of Finnish forests

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Introduction

The uncertainty of regional carbon budgets of forests is currently an issue of special interest due to requirements set for the greenhouse-gas reporting in Kyoto Protocol (1997), and following agreements.

The studies concerning the uncertainties of forest carbon budgets are few although there is a strong political stress for the estimates of uncertainties (UNFCCC, 1997; UNFCCC, 2001). So far, there are few studies, which take into account both vegetation and soil in forest carbon assessments. Existing studies have focused on the sensitivities of the system or uncertainties of scenarios (Kurz and Apps, 1994; Chen *et al.*, 2000; Heath and Smith, 2000; Zhang and Xu, 2003). There is a need for studies, which consider the reporting perspective of forest carbon and the consistent estimation of sinks in vegetation and soil.

In this work, we analysed the uncertainty of carbon budget calculation of Finnish forests during the period of 1988-2004. The calculation combines inventory data, biomass expansion factors, turnover rates and a dynamic soil carbon model.

The objective of this study was to assess the role of forests in national greenhouse gas inventory and to find out what are the key factors affecting the uncertainty of sinks and stocks of carbon in Finnish forests.

Materials and methods

Forest carbon model of this study combines aggregated forest inventory data, growth variation of trees, statistics of drain (hereafter called input data), and models of biomass and its turnover (vegetation parameters), and a dynamic soil carbon model, *Yasso* (Liski *et al.*, submitted manuscript; Liski *et al.*, 2005). The calculation of forest carbon sinks and stocks of Finnish forests (upland soils) were performed for years 1988-2004; in this paper the results are presented for year 1990 and 2003, and for average sinks during the period.

The biomass of trees is calculated from inventory estimates of growing stock using biomass expansion factors (Lehtonen *et al.*, 2004) Ground vegetation biomass is calculated using forest area estimates and mean biomass (Peltoniemi *et al.*, 2004). These two sum up to vegetation biomass, of which $50 \pm 1\%$ (SE) is carbon.

In order to operate, the soil model requires data on annual litter input, and climatic variables (temperature sum, drought = PET-precipitation). The litter input is derived from biomass estimates using turnover rates. The soil model starts from a steady state with the input and climate of the first year. The time step for the system is one year, and the sinks are calculated as differences between two consecutive stocks.

All of the input data and all parameters of forest carbon model were appended with uncertainty estimates (Monni et al., accepted manuscript; Peltoniemi et al., submitted manuscript). Due to the lack of data on uncertainties, the estimates of variable distributions were often based on expert opinion.

For the analysis of this study, we did a Monte Carlo type of simulation. Random samples were taken from variable distributions, and the calculations were repeated several thousand times. After 6 000 simulations, the variance of result variables stabilised within 1%, and the simulations were stopped, and the results were analysed.

The uncertainties of emissions on other sectors were estimated in a similar manner.

Results and discussion

Forest carbon sinks were highly variable between the years and the uncertainties were large in comparison to uncertainties on other sectors (Figure 1). For this reason, the uncertainty of overall GHG inventory depends mostly on uncertainty of forests sinks.

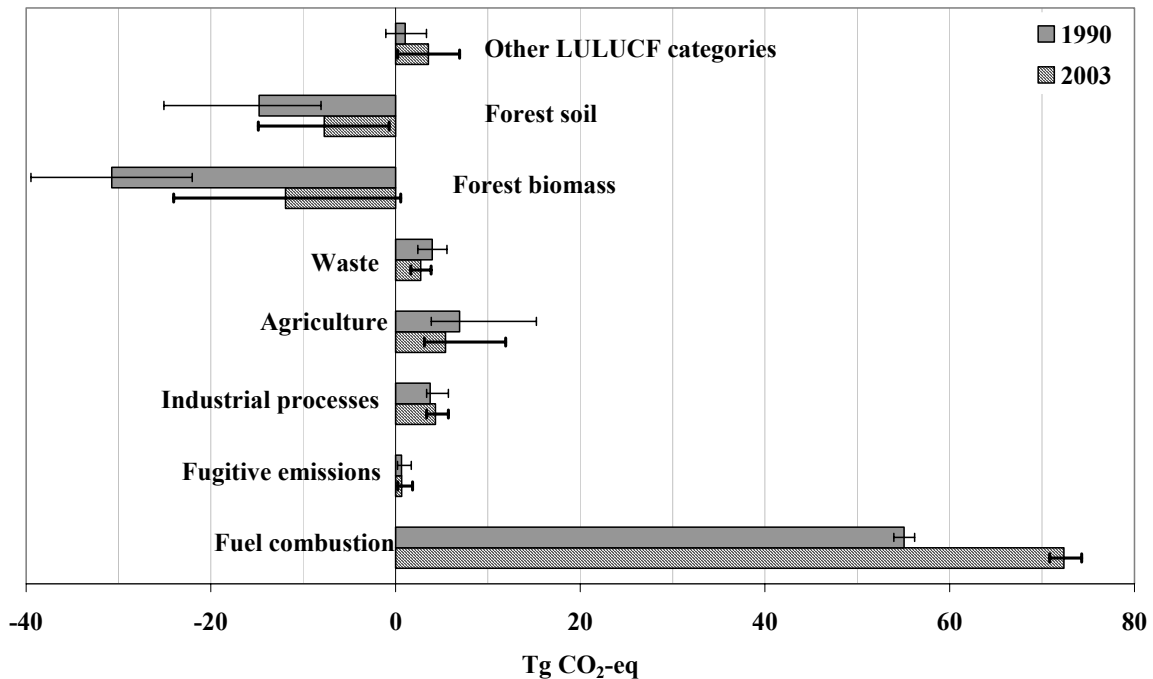


Figure 1. Greenhouse gas emissions and removals in 1990 and 2003 according to National Inventory Report (Statistics Finland, 2005a) and results of this study (forest vegetation and forest soils). Industrial processes include also non-energy use of fuels and product use. Error bars denote 95% confidence interval of emissions/removals according to the results of this study. From Monni et al., accepted.

Uncertainty of soil carbon sink dominated the uncertainty of forest carbon sink (Figure 2). However, uncertainty of soil sink decreased with time elapsed since soil model initialization. Uncertainty of initial state was the most important parameter for the uncertainty at the start of the period but levelled rather soon with other uncertainties. If soil sinks are interpreted as

probability densities instead of estimates, model initialization does not present an obstacle for the use of soil model in inventory.

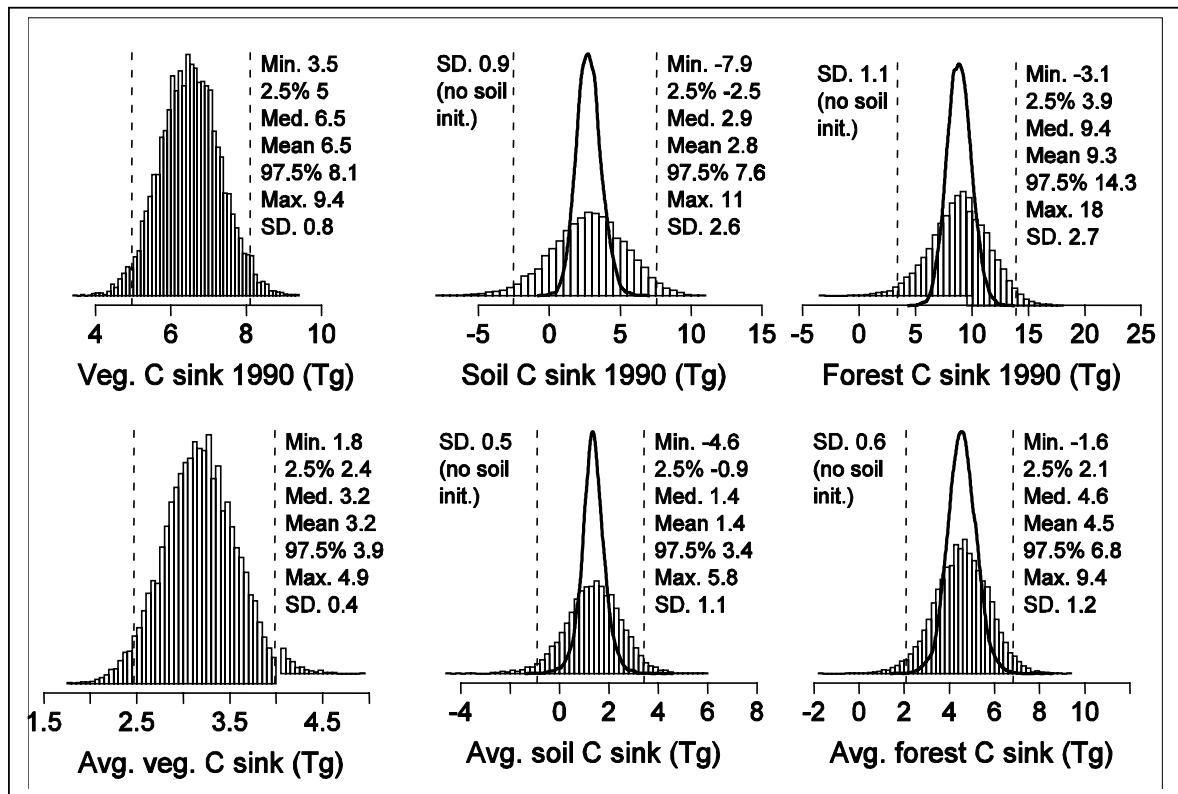


Figure 2. Simulated probability densities for carbon sinks of forests on mineral soil. Average sinks are calculated for the period of 1989-2004. The effect of soil initial state uncertainty ($\pm 10\%$) on soil and forest carbon sinks can be seen by comparing bold solid lines and histograms, and corresponding standard errors. From Peltoniemi et al., submitted manuscript.

After effect of initial state had decreased, drain estimates, decomposition temperature, and net area change became more important for soil carbon sinks. Input variables, drain and growth indices were important for annual sinks of vegetation.

Rather large effect of input data is understandable because sinks are differences of two consecutive stocks. Their estimation shares the same model parameters; therefore, the effect of model parameters is cancelled out (if the operation is linear).

Conclusions

It seems more reasonable to report average carbon sinks for forests instead of annual sinks. But if annual sinks will be reported in future, more precise data is needed on growth variation, drain and effect of temperature on decomposition. Accurate estimation of annual sinks of soil requires also data how litter production and biomass allocation vary between the years; current model and data cannot capture this variation.

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