Forest Condition Monitoring in Finland – National report

Photo: Metla/Erkki Oksanen

Monitoring changes in the carbon stocks of forest soils

By Raisa Mäkipää, Petteri Muukkonen & Mikko Peltoniemi

Summary

Soil carbon stock changes can have remarkable influence on global climate. Forest management and climate change may enhance release of soil carbon to the atmosphere, which further accelerates climate change. Under the Climate Convention, countries have agreed to monitor and report changes in the soil carbon stock, but majority of the European countries has not established systematic nation-wide soil monitoring. Development of efficient sampling design for soil carbon monitoring requires information on variation of soil carbon stock and expected rate of change. This report is a summary of our studies, where we addressed questions on appropriate sample size and interval of consecutive measurements in the nation-wide soil survey.

Introduction

Forests have been accounted for in the Climate Convention and the Kyoto Protocol because of their importance in atmospheric carbon dioxide concentration (UNFCCC 1992, 1997). The potential of forests in mitigation of climate change has created a need to develop and improve methods to estimate the carbon budgets of forests. Under the Climate Convention, countries have made commitments to report changes in the carbon stocks of forests, including the carbon stock of soils. The IPCC (2003, 2006) has set general requirements for soil inventories, but operational soil monitoring methods applicable on the large scale in question are under development and only some European countries have established a national system of soil carbon monitoring. National and European greenhouse gas (GHG) reporting of forest soil can be based on soil carbon modelling or on empirical data of repeated soil carbon measurements or a combination of these two.

Soil carbon stock is large, and relatively small changes may have a remarkable influence on forest carbon balance. It is a challenging task to detect a small change in a large stock, especially in the case of forest soils where the regional between-site variation and spatial within-site variation are remarkable (Conen et al. 2003, Yanai et al. 2003, Häkkinen et al. 2011). Consequently, a large number of samples is required in order to provide soil carbon estimates that are accurate enough for monitoring purposes. Due to the high costs of the regionally representative soil surveys, sampling efforts need to be effectively allocated within a monitoring programme.

Constructing a sampling design is an optimisation problem, where the trade-off is between required resources and the reliability of resulting estimates. When planning a sampling to detect a potential change, it is necessary to be aware of how many samples need to be taken to estimate the change statistically significantly. Appropriate sampling intensity (sample size) and sampling intervals (time between consecutive measurements) can be designed after collecting information on between-site variation and estimation of the rate of the potential change. Efficiency of the sampling can be improved by stratification, if prior information on the variation of the target variable is available.

In this study, we were aiming to provide means to improve efficiency of soil carbon monitoring. The specific questions addressed by this study were: 1. What is the appropriate sampling intensity – the number of study sites and sampling interval?, 2. How much is model-based stratification expected to improve the efficiency of soil sampling?, 3. What is the appropriate location of sample points and their number at study sites?

What is appropriate sampling intensity – the number of study sites and sampling interval?

In designing soil monitoring, information on between-site variation of soil properties can guide the decision on the total number of plots to be measured.

The number of plots needed for detection of a change in the soil carbon stock is estimated using the equation:

$\mathbf{n = (t * s/E)^2}$ where **n** is the number of sample plots required, **t** is a value taken from a student's t distribution table for a given number of degrees of freedom and a desired confidence interval, **s** is the estimated standard deviation of the measured soil carbon stock estimates (assuming independence of the observations), and **E** is the desired half of the confidence interval for the carbon stock estimate.

The desired confidence interval of a carbon stock estimate should allow detection of the expected change in the soil carbon stock. The true rate of soil carbon change is not known, but it can be estimated with soil modelling. If we assume that the average rate of change is 11 g C m^{-2} yr^{-1} from a modelling study of Liski et al. 2006, the desired half of the confidence interval of the carbon stock estimate (E) is 27.5 g C m^{-2} with a sampling interval of five years, increasing to 137 g C m^{-2} with an extension of the sampling interval to twenty-five years (assuming that the carbon change increases linearly over time) (Mäkipää et al. 2008).

We can assume a standard deviation of 1000 g C m^{-2} (which is the value reported for the mean carbon stock of the uppermost soil layers of boreal soil by Peltoniemi et al. 2004), and apply also standard deviations of 1250 and 1500 g C m^{-2} in order to determine the sensitivity of the results to this assumption. With these assumptions, the approximate estimate for the minimum number of sample plots required to detect a change in this soil layer is 3,000 plots with a sampling interval of ten years (Fig. 1). This sampling intensity allows detection of an expected change of 110 g C m^{-2} per ten-year period if the standard deviation of the measured carbon stock is less than 1500 g C m^{-2}.

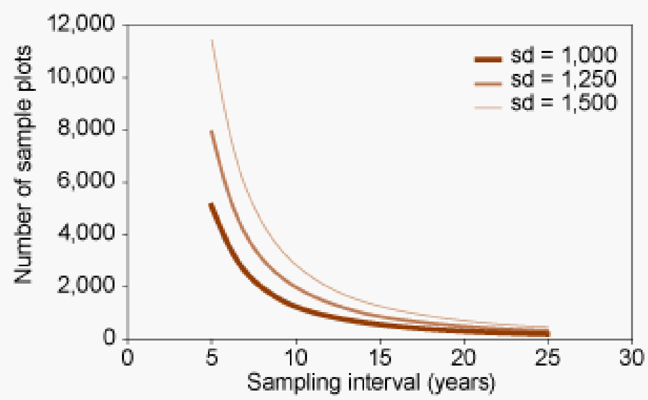

Figure 1. Sample size required with different sampling intervals calculated based on the assumption that the change to be detected is 11 g C m^{-2} per year. Standard deviation (sd) of measured carbon stock was assumed to be 1000 g C m^{-2}. Larger values (1250 and 1500 g C m^{-2}) were applied to show the sensitivity of the results to this assumption. Source: Mäkipää et al. 2008.

How much is model-based stratification expected to improve the efficiency of soil sampling?

The efficiency of soil carbon monitoring can be improved and costs can be reduced by stratification. Stratification increases efficiency if a subdivision of the population is made so that within-stratum variability is lower than the variability within the entire population. Stratification by land-use category, soil type, and so on, i.e. by groups where the rates of soil carbon change are similar will improve the efficiency of the sampling targeted for soil carbon monitoring. Target variable in soil carbon monitoring is a change in soil carbon stock, but there is far less information on spatial variation of soil carbon changes than on soil carbon stock (Häkkinen et al. 2011). Therefore, information on the variation of carbon stock (or other measured soil variables) may be used for sampling design, but such information on stocks cannot be used for stratification since large soil carbon stock do not necessarily indicate a large change.

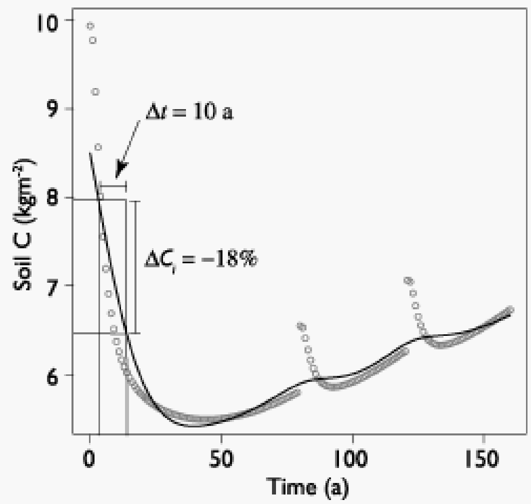

Figure 2. Example simulation of soil carbon stock using a Motti stand simulator combined with the Yasso soil carbon model. Predictions of soil carbon stock changes (with scenario uncertainties) were used as the basis of stratification of soil sampling. Source: Peltoniemi et al. 2007.

Soil models can help to design effective soil sampling. We tested how stratified sampling on an existing grid of forest inventory plots by model-predicted changes in soil C affects sampling efficiency (Fig.2) (Peltoniemi et al. 2007). Model-based stratification improved the sampling efficiency, even though the uncertainties both in model predictions and measurements are large. Stratification with the optimal allocation of plots can reduce the standard error of the mean by 20–34% relative to simple random sampling, with different assumptions of harvesting (and thinning) timing uncertainties. The use of optimal allocation (Neyman) is recommended for soil C change sampling design, since it succeeded up to 10% better (relative to SRS) than proportional or equal allocation (Peltoniemi et al. 2007).

What is the location and number of sampling points required within a plot to obtain a reliable carbon stock estimate?

Knowledge on the within-site variation in the soil carbon stock is used to determine the number of sub-samples per plot that yield estimates accurate and precise enough for monitoring purposes. The accuracy of the mean estimate increases with the number of samples per plot.

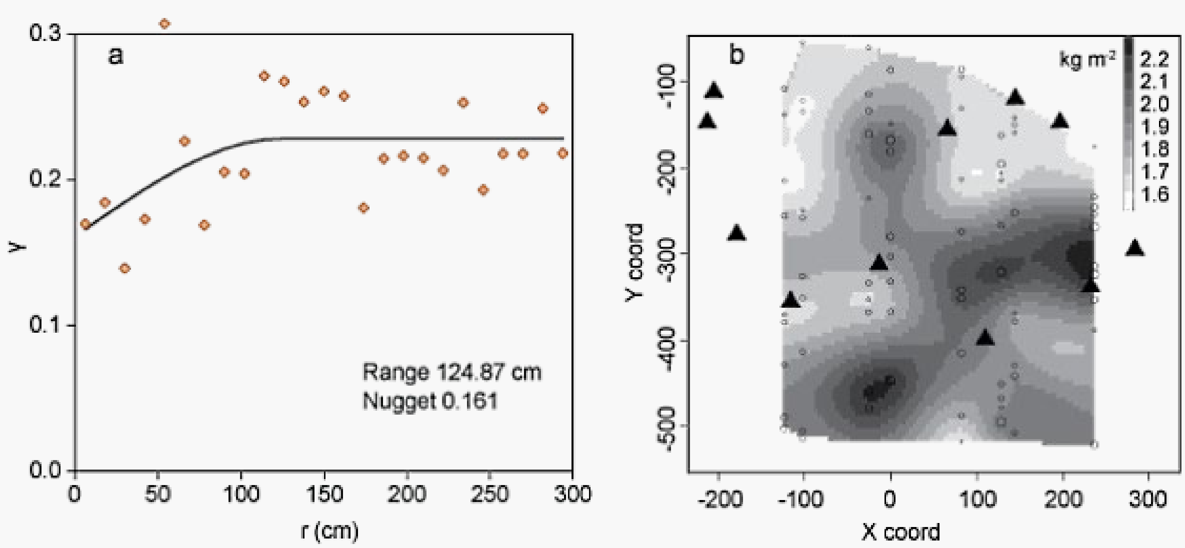

Figure 3. Example of variogram (A) and kriking interpolation (B) for soil C in the organic layer of one Scots pine stand. In the

figure 3B, the black triangles refer living trees and small circles refer soil sampling points. Source: Muukkonen et al. 2009.

We analysed within-site spatial variation of the carbon stock of humus layer on the basis of a total of 1,107 soil samples taken from eleven forest stands (six Scots pine stands and five Norway spruce stands) (Muukkonen et al. 2009). Spatial autocorrelation of carbon stock was lost in distances larger than 0.7–8.2 m depending on the site (Fig. 3). This indicates that the distance between non-correlated sampling points should be several metres (up to 8 m). More than twenty sub-samples per site should be taken to gain a reliable plot level estimate of the mean carbon stock of humus layer (Fig. 4) (Muukkonen et al. 2009, Mäkipää et al. 2010).

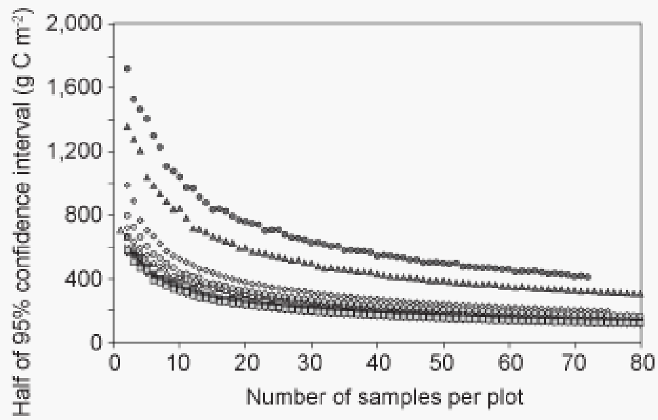

Figure 4. Confidence intervals of the carbon stock of organic layer according to sample size for ten different study sites. Source: Mäkipää et al. 2008.

References

Conen, F., Yakutin, M. V., & Sambuu, A. D. 2003. Potential for detecting changes in soil organic carbon concentrations resulting from climate change. Global Change Biology 9: 1515–1520.

Häkkinen, M., Heikkinen, J. & Mäkipää, R. 2011. Soil carbon stock increases in the organic layer of boreal middle-aged stands. Biogeoscience 8: 1279–1289.

IPCC 2003. Good practice guidance for land use, land-use change and forestry. IPCC, National Greenhouse Gas Inventories Programme, Kanagawa, Japan.

IPCC 2006. Guidelines for national greenhouse gas inventories. IPCC, National Greenhouse Gas Inventories Programme, Kanagawa, Japan.

Liski, J., Lehtonen, A., Palosuo, T., Peltoniemi, M., Eggers, T., Muukkonen, P. & Mäkipää, R. 2006. Carbon accumulation in Finland's forests 1922-2002 - an estimate obtained by combination of forest inventory data with modelling of biomass, litter and soil. Annals of Forest Science, 63: 687–697.

Mäkipää, R., Häkkinen, M., Muukkonen, P. & Peltoniemi, M. 2008. The costs of monitoring changes in forest soil carbon stocks. Boreal Environment Research, 13 (suppl. B): 120–130.

Muukkonen, P., Häkkinen, M. & Mäkipää, R. 2009. Spatial variation in soil carbon in the organic layer of boreal forest soil – implications for sampling design. Environmental Monitoring and Assessment, 158: 67–76.

Peltoniemi, M., Mäkipää, R., Liski, J. and Tamminen, P. 2004. Changes in soil carbon with stand age – an evaluation of a modeling method with empirical data. Global Change Biology 10: 2078–2091.

Peltoniemi, M., Heikkinen, J. & Mäkipää, R. 2007. Stratification of regional soil sampling by model-predicted change in soil carbon. Silva Fennica, 41: 527–539.

UNFCCC 1992. The United Nations Framework Convention on Climate Change.

UNFCCC 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change.

Yanai, R. D., Stehman, S., Arthur, M., Prescott, C., Friedland, A., Siccama, T., and Binkley, D. 2003.Detecting change in forest floor carbon. Soil Science Society of America Journal 67: 1583–1593.

Citation: Mäkipää, R., Muukkonen, P. and Peltoniemi, M. (2013). Monitoring changes in the carbon stocks of forest soils. In: Merilä, P. & Jortikka, S. (eds.). Forest Condition Monitoring in Finland – National report. The Finnish Forest Research Institute. [Online report]. Available at http://urn.fi/URN:NBN:fi:metla-201305087586. [Cited 2013-05-07].