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Effects of sampling design on the probability to detect soil carbon stock changes at the Swiss CarboEurope site Lägeren

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ABSTRACT

Soil carbon stock changes are an important element in our attempt to understand and quantify the role of terrestrial carbon sinks. Unfortunately, the large spatial variability of organic carbon stocks in soils complicates their analytical quantification. At a heterogeneous forest site, we conducted a pilot study to estimate whether the choice of a suitable sampling design reduces the uncertainty of the stock estimate to an extent that permits the detection of carbon stock changes within a reasonable time period. Parent material had a strong effect on soil carbon stocks and stratified sampling of parent material classes reduced the error of the carbon stock estimate for the top 10 cm of the mineral soil from 3.1 to 1.7 t C ha^{-1}. We estimated that replacing an unpaired sampling approach by a paired sampling approach could improve the detection limit of stock changes approximately by a factor of four. Despite these improvements, we estimate that about 15 years will be necessary to detect carbon stock changes in the top 10 cm if soil carbon sequestration occurs at the rate (0.43 t C ha^{-1} a^{-1}) predicted by current carbon cycle models.

1. Introduction

In the context of mitigating rising CO_2 levels in the atmosphere, understanding and quantification of terrestrial carbon sinks is of crucial importance. Therefore, an international network of eddy covariance flux sites has been set up worldwide to measure carbon dioxide exchange between the biosphere and the atmosphere over a wide range of ecosystems (Baldocchi et al., 2001). At the European level, ecosystem CO_2 exchange is monitored within the CarboEurope-IP network (Aubinet et al., 2000). Despite these large-scale efforts, there is also a need for independent estimates of carbon stock changes, such as inventory methods (e.g. Bellamy et al., 2005). These inventories can serve to verify eddy covariance estimates of NEE and to identify those ecosystem compartments where the most significant changes occur.

An important issue with soil carbon stock inventories is the spatial heterogeneity of organic carbon (OC) stocks in soil (e.g. Don et al., 2007). In addition, changes are usually expected to be small compared to the size of the stocks. Therefore, only few attempts have been made to assess OC stock changes by comparing inventory data between two years. After 15 years of a Sitka spruce afforestation on formerly unmanaged grassland, Black et al. (2007) conducted a complete ecosystem inventory including soil OC stocks. In their example of a land-use change, they observed soil OC stock changes of >1 t C ha^{-1} a^{-1} which accounted for approximately 10% of the total ecosystem OC stock change. On the other hand, in another inventory of OC stock changes in a Scots pine forest, Kolari et al. (2004) assumed the change in soil OC stocks to be zero, because of the enormous sampling effort necessary to detect a potential change. However, some theoretical considerations may help to reduce the sampling effort. Peltoniemi et al. (2007) used stand age data and standard forest management regimes in a growth model to predict changes in C stocks. They showed that stratification of soil sampling according to expected C stock changes reduces the standard error of the stratified mean relative to random sampling. Their stratification approach relied strongly on stand age and they did not attempt stratification by edaphic factors. It is, however, well established that organo-mineral interactions play a key role in stabilizing organic matter in soils (Kögel-Knabner et al., 2008). Thus, the type of minerals present (esp. Fe and Al oxides or hydroxides formed during weathering which have a large reactive surface area) can greatly affect C dynamics in soil (e.g. Rasmussen et al., 2005, Eusterhues et al., 2005). This effect of mineralogical composition makes parent material a potential key factor determining C stocks.

Post et al. (2001) emphasized the importance to recognize spatial patterns in the field when designing a sampling scheme. They also report that conducting a repeated inventory at exactly the same sampling locations as the first one (paired sampling) will help to reduce variability. In a detailed study on spatial variability in a forest site, however, Schöning et al. (2006) pointed out, that some residual small-scale variability cannot be eliminated in this way. In this article we address the question how the uncertainty both of a stock estimate and of a stock change estimate from a repeated inventory at a

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heterogeneous mountainous forest site can be reduced by stratified sampling and resampling with a paired sampling design. The method was tested in a case study at the Lägeren research site (CH-Lae in CarboEurope IP), from which we present our results. From these data we deduce and predict the required minimum time interval between this and any future inventories that is required for detecting a specific sequestration rate with acceptable statistical confidence.

2. Materials and methods

2.1. Site description

The research site Lägeren is a forest site in CarboEurope-IP (CH-Lae). It is located at the south slope of the Lägeren, a W–E-extending mountain ridge formed by Jurassic limestone and Tertiary molasse

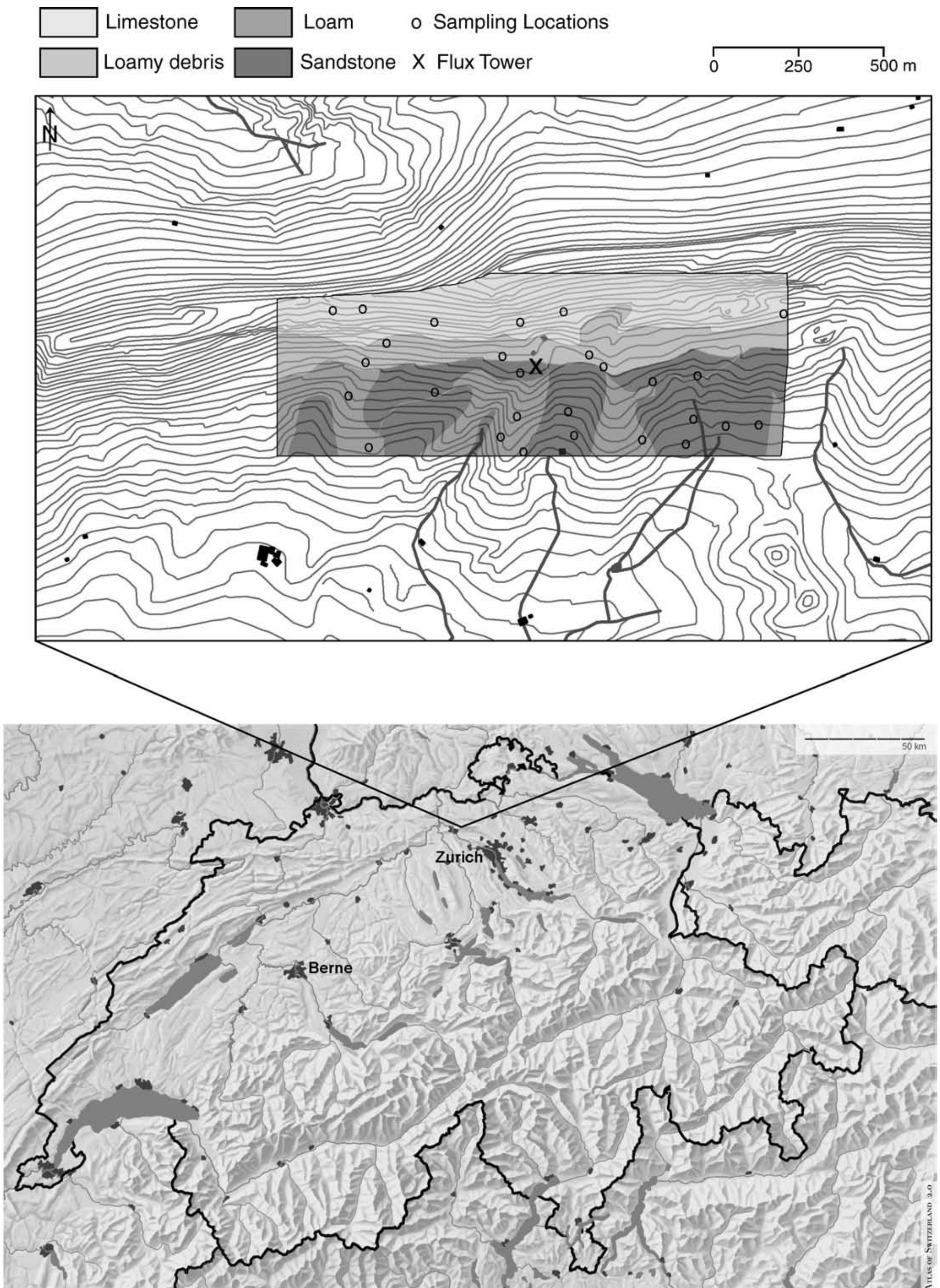

Fig. 1. Location of the study site within Switzerland (bottom) and detailed map of the study site (top), with geological units (grey shades), locations of the sample plots (circles) and the flux tower (cross). Exact geographic coordinates are given in the text. Reproduced by permission of swisstopo (JA082267).