Carbon sequestration potential of soils in commercial forests in Germany – contribution of National Forest Monitoring to the advancement of knowledge

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Abstract

In Germany, National Forest Monitoring is based on a system of representative areas surveyed in the National Soil Condition Survey (BZE) and in detailed case studies (Level-II) of processes within forests. This complex monitoring system is appropriate for Germany's greenhouse gas reporting (THG 2008 to 2012). The representative BZE plots can be used to obtain regional data for the National Carbon Stock Inventory. Here, an approach adopting a combination of geostatistics and regression analysis is preferred.

The difficulty of showing the statistical significance of expected small changes while carbon stocks are generally high is one of the major challenges in carbon stock monitoring. However, through intensive preparation and cooperation with the forestry authorities responsible in each of the federal states, the errors incurred in determining changes in carbon stocks in forest soils, which must be stipulated in greenhouse gas monitoring, could be minimised.

In contrast to the detailed soil case studies, in which essentially the sources of error occur repeatedly in carbon stock change calculations, the BZE data can be stratified to form plots with homogenous properties, thereby reducing the standard error of estimate. Subsequently, the results of the stratification are projected across Germany, the reporting unit for greenhouse gas monitoring. As greenhouse gas reporting follows a different time frame from that of the BZE survey, models need to be applied which can be calibrated at the intensive sites (Level II/ LIFE+) and transferred to the BZE plots for spatial interpolations using key processes and/or key parameters.

Keywords: Soil, carbon sequestration, forest monitoring, Germany

Zusammenfassung

Kohlenstoff-Sequestrierungspotentiale forstwirtschaftlich genutzter Böden in Deutschland - Beitrag des nationalen forstlichen Umweltmonitorings zur Kenntniserweiterung

Das nationale forstliche Umweltmonitoring stellt ein System aus flächenrepräsentativer Erhebung der bundesweite Bodenstandserhebung (BZE) und prozessorientiertem Intensivmonitoring an 89 Level II-Flächen dar. Dieses komplexe System ist für die Treibhausgas-Berichterstattung (THG 2008 bis 2012) Deutschlands geeignet. Die flächenrepräsentativen BZE-Punkte können zur Regionalisierung der bundesweiten Kohlenstoff (C-)-Vorräte genutzt werden. Als Ansatz hierzu wird eine Kombination aus Geostatistik und Regressionsanalyse bevorzugt.

Die Schwierigkeit bei hohen C-Vorräten, die zu erwartenden geringen Veränderungen statistisch abgesichert nachzuweisen, stellte eine der größten Herausforderungen dar. Durch intensive Vorbereitungen und Kooperation mit den zuständigen forstlichen Behörden in den Ländern, können jedoch die im Rahmen des Treibhausgas-Monitorings zu berichtenden Fehler der Kohlenstoffvorratsveränderung in Waldböden minimiert werden.

Die BZE bietet – im Gegensatz zu bodenkundlichen Fallstudienuntersuchungen, bei denen grundsätzlich dieselben Fehlerquellen bei der Herleitung von Veränderungen auftreten, die Möglichkeit der Herleitung von Veränderungen auf der Basis größerer Kollektive von Stichprobeneinheiten und damit der Reduktion des Standardfehlers der Schätzung. Die Berechnung der Veränderung an den BZE-Punkten wird stratifiziert erfolgen; die Ergebnisse werden aber nachfolgend für das gesamte Bundesgebiet als Berichtseinheit für das THG-Monitoring hochgerechnet. Da die Berichterstattung für das THG andere Zeiträume vorsieht, als der jetzige Erhebungszeitraum der BZE, sollen Modelle einsetzt werden. Diese Modelle können an den Intensivstandorten Level II kalibriert werden und mit Hilfe von Schlüsselprozessen /-parametern auf die BZE-Punkte übertragen werden zur räumlichen Interpolation.

Schlüsselworte: Boden, Kohlenstoffsequestrierung, forstliches Umweltmonitoring, Deutschland

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1 Introduction

In December 2006, the German government opted to manage forests as carbon sinks to reduce greenhouse gas emissions in accordance with Article 3.4 of the Kyoto Protocol. The National Forest Monitoring data contribute to the fulfilment of these reporting commitments.

The National Soil Condition Survey (BZE) and the European intensive monitoring Level II enable changes in carbon stocks in German forest soils to be derived nationwide for the period between two inventories (BZE: 15 years). Models can be applied to calculate annual changes in carbon stock for the years 2008 and 2012 (Kyoto Protocol Art. 3.4).

In particular, establishing the statistical reliability of carbon stock changes presents a difficult task. In the event of a high C stock, relatively small changes in carbon are difficult to prove, particularly in view of the large spatial heterogeneity of carbon stocks in forest soils (Liski et al., 2002; Baritz and van Ranst, 2006). In contrast to other European countries, forest monitoring is a state responsibility in Germany. This is reflected in the organisation of the BZE. The states are responsible for the field surveys and laboratory analysis involved in the monitoring process, while the Institute of Forest Ecology and Forest Inventory is responsible for national coordination and federal evaluation for forest stands.

In the following report, the opportunities and limitations for determining the national carbon stock and carbon stock changes from forest monitoring are shown.

2 National Forest Monitoring

National Forest Monitoring constitutes a system of representative areas surveyed in the National Soil Condition Survey (BZE) and the intensive monitoring of forest ecosystem processes of 89 Level II plots (figure 1).

The BZE characterises the condition of forest soils, identifies changes in forest condition since the first inventory, and answers any new research questions, e.g., about carbon inventory. The BZE represents a national, systematic sampling inventory of the condition of forest soils. The first BZE inventory (BZE I: 1987 to 1993) was carried out on a systematic 8 x 8 km grid on the same sampling plots adopted in the Forest Condition Survey (WZE). In some areas the network of sampling plots involves 1900 grid points. The first BZE I field survey was repeated after 15 years, between 2006 and 2008, by the national and the state authorities in cooperation. Afterwards, extensive laboratory and statistical analyses were conducted.

The European Intensive Monitoring (EU Level II) was initiated by the UN/ECE, and co-financed by the EU. In 1995, the German states began establishing the 89 Level II sites, and have investigated them continually since then. This task was coordinated by the Institute of Forest Ecology and Forest Inventory, which now acts as a national data centre with the aim of developing hypotheses for cause-effect relationships in forest ecosystems. The soil condition is surveyed every 15 years as part of the Level II monitoring.

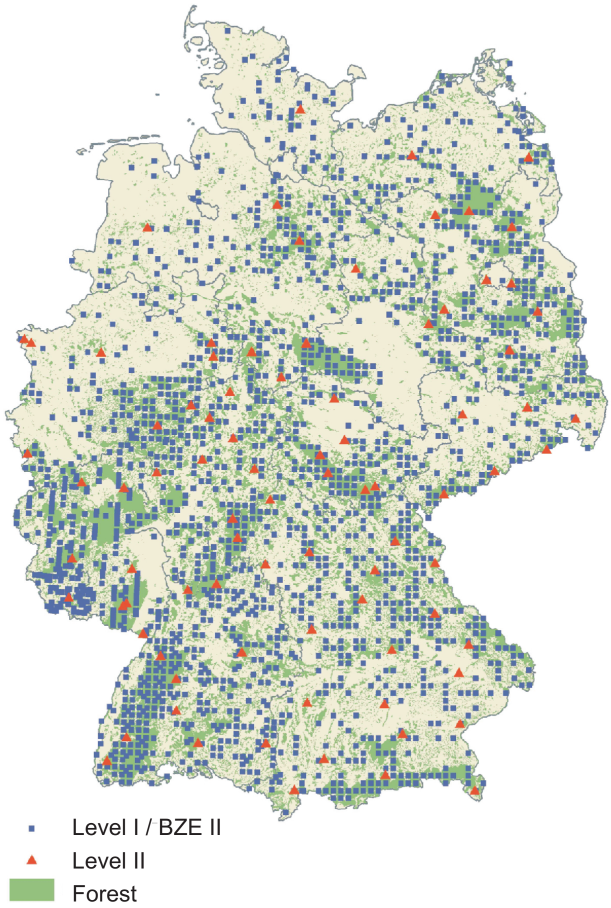

Figure 1:
Location of Level II and BZE II study sites as at 2006

2.1 Soil sampling

The standard methods for sampling soils at the BZE grid points involve satellite sampling, with a soil profile from the centre of a BZE point. Sampling for soil chemical analysis is conducted, as for BZE I, in soil depth classes (0 - 5, 5 - 10, 10 - 30, 30 - 60, 60 - 90 cm; and 90 - 140 and 140 - 200 cm where possible) to ensure comparability between the states. In addition, soil profiles are classified.

In the Level II programme, sampling methods based on area are adopted. Twenty-four single samples are combined to produce three mixed samples, which then are analysed. This sampling is also carried out in different soil depth classes (0 - 5, 5 - 10, 10 - 20, 20 - 40, 40 - 80 cm; and 80 - 120 and 120 - 200 cm where possible).

2.2 Parameters for carbon monitoring

The national and state governments have defined the minimum set of parameters required in the BZE to carry out a national assessment and to meet the reporting obligations for the European programme (Wellbrock et al., 2006). The EU set the range of parameters in the Level II programme (UN/ECE 2006). As intensive monitoring is envisaged, additional parameters over and above those recorded in the BZE need to be determined, such as element concentration in the soil solution, and also meteorological variables at a higher temporal resolution.

Only some the monitoring parameters are necessary for the soil carbon inventory (table 1). Maps and models can be used in the upscaling of grid point information.

Table 1:

List of parameters for the carbon inventory (Level II / BZE II)

Components	Parameters
Point level	
Field sampling	Width of depth classes, Fine roots, humus (< 2 cm), dry bulk density, stone content, area of humus layer sampled, height a.s.l., litterfall, deadwood (from 10 cm)
Analysis	C content, fine soil fraction, weight of humus layer, DOC in the soil solution
Carbon stock calculations	Carbon stock
Regional Level	
Plot	Soil type, parent material, vegetation type or forest type, forest management
Regionalisation	Soil and land use maps, statistical models, ecological regions, digital elevation models, climate regions

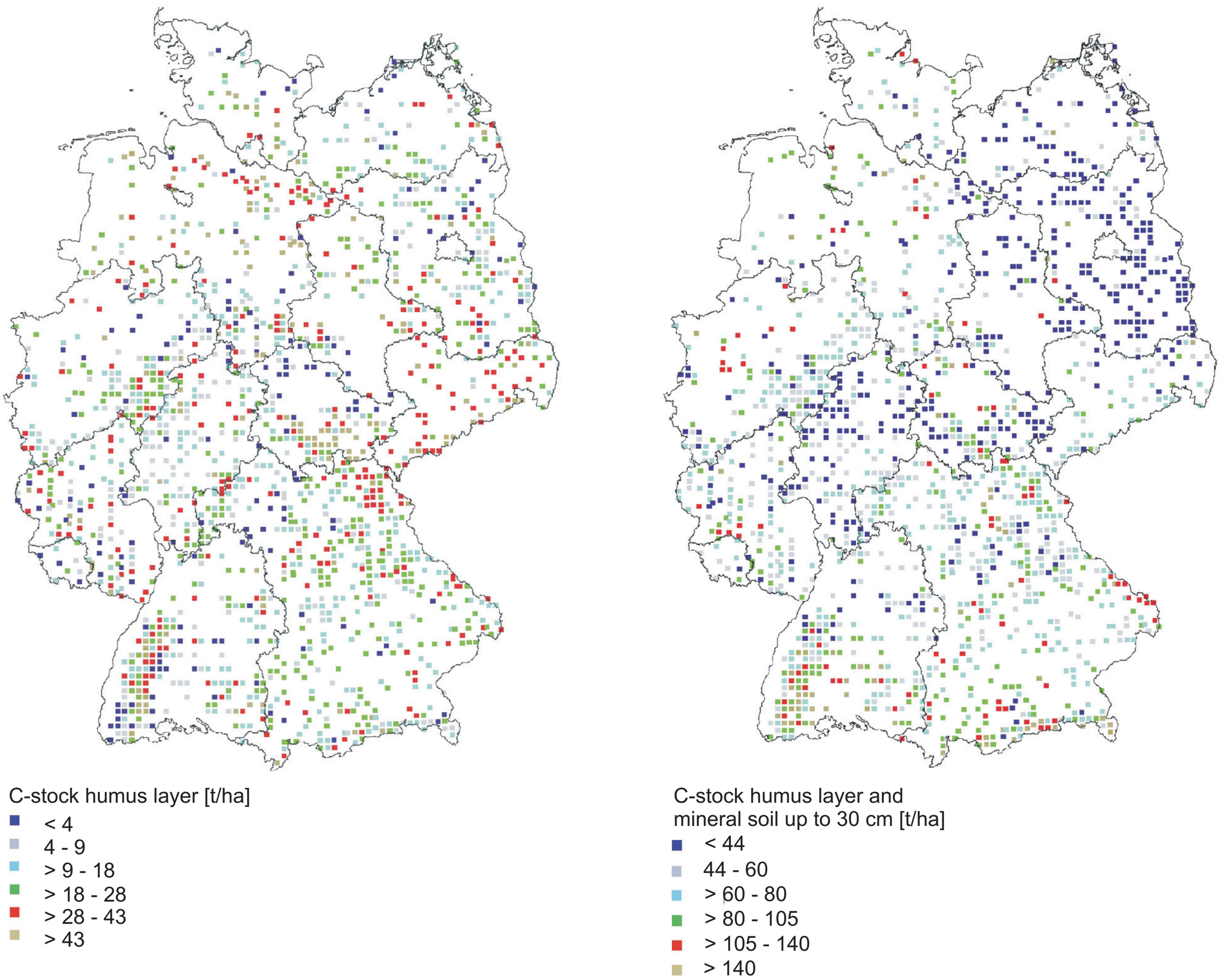

Figure 2:

Spatial distribution of carbon stocks of BZE I in the humus layer, and in the mineral soil up to 30 cm

3 BZE I (1989/1992) – carbon stock results

The spatial distribution of carbon stock at the BZE I grid plots typically varies (figure 2). The carbon stock in the sandy soils under Scots pine forests in northeast Germany is low. In contrast, at higher elevations, such as in the Black Forest or in the Thuringen Forest, the carbon stock is above average. The high carbon stock values in northwest Germany are conspicuous. The C/N ratio, which relates closely to the carbon stock levels, indicates carbon accumulation in the more humus layers due to the nitrogen inputs, which cause acidification and consequently have resulted in a reduction in the turnover of litter (Baritz, 1996; 1998; Wolff and Riek, 1997).

4 Consideration of errors

Random and systematic errors in an inventory lead to erroneous results. To identify changes between two inventories, the errors need to be minimised, particularly the systematic errors, which produce results biased in a certain direction. Errors occur at different levels and for different components.

Changes in the analytical methods can lead to an increase in the standard error, and hence to an increased uncertainty in the estimate of changes in carbon stock (Wolff and Wellbrock, 2005). However, one can assume that no major analytical changes have occurred in determinations of carbon content.

The following errors are of particular relevance for the BZE:

- Field survey:
  - Number of the BZE sampling plots changed; previous survey sites not found; survey error; small scale variability at the site.
- Chemical analysis:
  - New laboratory methods, method comparability, different laboratory technicians and analysists, analytical error
- Absent values or data

5 Dealing with errors

In the BZE II, an attempt was made to minimise the major errors in the manner outlined below.

5.1 Spatial heterogeneity

The spatial heterogeneity of the soil characteristics makes it difficult to derive changes in the carbon stock, even from large-scale inventories. To reduce the influence of minimal heterogeneity, a sufficient number of soil samples must be taken. Yet the labour input and costs are restrictive.

Once a sample design appropriate for the given conditions has been nominated, eight samples are taken on a circle of 10 m radius, combined to produce a mixed sample, and then analysed. As a preliminary study showed, the samples within the 10 m circle were auto-correlated, and hence represent a homogeneous area with minimal variability (Mellert et al., 2007).

5.2 Fine soil fraction

The fine soil fraction is calculated from the soil bulk density and stone content. The soil bulk density can be measured reliably with different methods (Heinkele et al., 2005). However, the stone content is often neglected, leading to a systematic overestimation of the fine soil fraction. In the BZE I, bulk density was estimated, which also led to systematic error (Wirth et al., 2004). Therefore, in BZE II, the comparability of the different methods was tested in preliminary investigations, and the results used to identify comparable methods (Heinkele et al., 2005, Riek and Wolff, 2006). Only those sites recorded by the comparable methods identified were included in the assessment.

5.3 Chemical analyses

In the BZE, the fact that comparability of the laboratory analyses carried out by different laboratories was very important since 12 laboratories were contracted for the analyses. Furthermore, changes had been made to some methods since the first inventory. Consequently, ring analyses were carried out in the German laboratories for every parameter. In addition, a comparative analysis of the European Soil Monitoring Laboratories (BioSoil) and the European Central Laboratory was carried out (König and Wolff, 1993; Blum and Heinbach, 2006; Cools et al., 2006). The authorised methods are described in a Handbook of Forestry Analysis (GAFA, 2005), and also presented in the BZE II manual. Furthermore, the data are tested under the auspices of the national database management.

6 Upscaling approach

There are different approaches for presenting extensive carbon stock data (Baritz et al., 2006). The availability of georeference plots means one can merge the point data with map data. In Germany, an approach was tested that combines regression analysis with spatial data analysis (Zirlewagen, 2003).

7 Derivation of changes in stock

In contrast to the soil case studies, in which essentially the same sources of error occur repeatedly in the derivation of changes in carbon stock, the BZE facilitates the derivation of changes on the basis of larger collectives of sample units (strata), and thus a reduction in the standard error of estimate. The strata should be based strictly on ecological criteria. Within these strata, e.g., in the event of different sampling density (grid point distances), further stratification may be necessary (weighting the mean value and error by proportional area). The ecological strata selected may be pedogenic or geogenic strata, as in BZE I, or, given the improved forest descriptions, even stand types. Furthermore, the newly developed natural forest areas across the Germany also may be used as regional stratification units (Gauder et al., 2005).

Despite the comparatively high number of samples, post-stratification of BZE data has its limitations. As forest condition is dependent on many factors, the classification according to only one parameter still would lead to very inhomogeneous classes. The necessary, further stratification of these groups would reduce the sampling size to an unacceptable level. This problem could be counteracted by a multivariate statistical analysis of forest condition types (Riek and Wolff, 2000), or similarly, statistically derived complex types, because these are already characterised by a specific group of parameters for the stand, soil, crown and nutrient status, as well as for weather and deposition conditions (cf. also Wellbrock et al., 2006). For parameters that are recorded exclusively for a sub-sample, such as woody debris or litter fall, one needs to test whether the BZE II data can be extrapolated together with data from other available national or regional data sources to obtain a national result.

The determination of annual changes in carbon stock can be achieved only with nutrient cycling models. These should be calibrated and validated with Level II data.

8 Outlook

In the future, the German monitoring system will be used for new tasks like greenhouse gas reporting. For that reason, some preparatory efforts have been made:

- Germany will use the Forest Monitoring System (BZE, Level II) for greenhouse gas reporting (THG 2008 - 2012).
- Special efforts will be undertaken in BZE II to minimise errors in measurements of carbon stock changes in forest soils reported in THG monitoring.
- Errors will be separately considered for every component of the stock calculations.
- It is essential that data are stratified for assessments; however, subsequently, the results will be extrapolated across Germany which is the reporting unit for greenhouse gas monitoring.

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