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An approach to assessing site index changes of Norway spruce based on spatially and temporally disjunct measurement series

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ABSTRACT

Site index is an important characteristic for forest management and growth modelling, especially with regard to the ongoing environmental changes. This study introduces a new methodological approach to detecting and quantifying long-term changes in site index. It consists of: (1) a module to construct a reference site index curve from the data under investigation, (2) an OLS-based-CUSUM test to identify change points in development of site index over time, (3) a composite estimator for quantifying changes of the site index over time. The approach was developed using data from 541 Norway spruce (*Picea abies* [L.] Karst.) long-term experimental plots in southwest Germany between 1872 and 2010. The method is designed to exploit height measurement series of stands growing at different times and different locations (temporally and spatially disjunct). The approach indicated a change in the trajectory of site indices in the early 1950s. Site indices were stable until the change point and have displayed an almost continuous increase since then.

1. Introduction

Changes of environmental conditions affect growth of trees and stands. This statement, trivial as it is, leads to the question how such effects may be assessed and quantified, especially with regard to the ongoing discussion of climate change. In forestry, site index (S) is widely used as a versatile parameter expressing the aggregated impact of environmental conditions on forest growth and site productivity. Conventionally, S is determined for each tree species and expressed through height of dominant or co-dominant trees at a specific age (Assmann, 1961).

In pursuit of properly expressing height growth, as well as to accurately assess S, various types of models have been developed. With the traditional yield tables, the usual approach has been to use anamorphic site index curves (Assmann, 1961). The inherent assumption for these curves is that although the curves differ between site classes, they share a common shape (Clutter et al., 1983). The assumption of an anamorphic form across all site classes is, however, restrictive and may fail to represent real height growth patterns among site classes (e.g., Assmann, 1961; Carmean, 1972; Marschall, 1976). Accordingly, variable height growth patterns have been reported for several tree species due to climatic differences between the regions (e.g., Marschall, 1976; Wang et al., 1994).

Polymorphic site index curves were introduced to account for variations in height growth pattern with site class (Carmean, 1972; Clutter et al., 1983; Newnham, 1988). The estimation of polymorphic site index curves is based on techniques such as the algebraic difference approach (ADA) (Bailey and Clutter, 1974), or the generalised algebraic difference approach (GADA) (Cieszewski and Bailey, 2000; Cieszewski, 2002). Site factors have been incorporated into polymorphic height growth models to render them site specific with variations in climate, soil, or genetics (Monserud, 1984; Monserud and Rehfeldt, 1990; Wang et al., 1994). For example, Wang et al. (2007) developed a nonlinear mixed effect height growth and site index model, and included climate characteristics such as mean annual rainfall and mean daily maximum temperature in July as independent variables representing local spatial variations. However, the temporal variations of environmental variables are usually not incorporated in height growth or site index models (Rayner and Turner, 1990).

In addition to annual variations, environmental factors may display decadal and centennial fluctuations, which result in long-term growth trends triggered by long-term changes and accumulated effects in climate or nutrient influx (e.g., Kellomäki et al., 2008). Therefore, the identification of environment related changes in site

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productivity in the recent past (Spiecker et al., 1996; Sterba, 1996; Pretzsch, 1999; Boisvenue and Running, 2006; Latta et al., 2010) is a crucial task. Growth trend analysis are commonly based on the comparison with references (e.g. yield tables or growth models), assuming that those express mean growth dynamics under relative constant environmental conditions (Spiecker et al., 1996; Röhle, 1997; Pretzsch and Utschig, 2000). However, the applicability of a reference model for comparison is only valid as long as the "external" reference and the data under investigation share similar stand characteristics, management regimes, and comparable locations (Spiecker et al., 1996; Pretzsch, 1999). These constraints are unlikely to be satisfied in practice.

Other straightforward approaches are, for example, the comparison of consecutive generations of stands growing at identical locations (Eriksson and Johansson, 1993) or stands of different germination dates growing synchronously at sites with identical characteristics (Untheim, 1996). However, in such approaches the multitude of potential influences related to management regime, disturbance, and tree genetics still needs to be excluded or controlled for (Eriksson and Johansson, 1993; Untheim, 1996). As these requirements are rarely met by available data sources, they limit the applicability of such straightforward approaches to case studies usually involving small databases. Moreover, the previous studies have mainly been based on simple graphical interpretations or static deterministic models which are not optimal for statistical inferences (e.g. Röhle, 1997). Another shortcoming of such straightforward approaches is that they are not applicable for the analysis of databases which comprise a multitude of temporally and spatially disjunct measurement series.

To contribute to the solution of these problems, the major objective of the study was to develop an approach for detecting and quantifying changes in site index, especially for cases where the database consists of temporally and spatially disjunct measurement series when no "external" growth reference is available. In addition to this primary methodological objective, we intended to demonstrate the methodology to evaluate long-term changes in site index of Norway spruce (*Picea abies* [L.] Karst.) stands in southwest Germany in the period from 1872 to 2010. Norway spruce was chosen for two reasons: first, the species is widely distributed and of major ecological and economic importance in Europe (Teuffel et al., 2004). Second, a substantial database for Norway spruce was available from the network of long-term growth and yield experiments of the Forest Research Institute of Baden-Württemberg in southwest Germany.

2. Material and methods

2.1. Study material

The database for this study comprised repeated measurements of 541 Norway spruce experimental plots at 228 different locations (stands) in Baden-Württemberg (Fig. 1). The oldest measurements dated back to the end of the 19th century. However, only a few data from such old experiments were available. Later on, the number of plots increased consistently reaching a maximum in the 1990s (297 plots). Since then, the number of plots has decreased again.

All the stands were even-aged. They covered a broad range in elevation, precipitation, and temperature and, therefore, in site indices (Table 1). The thinning treatments varied from unthinned dense stands, across low intensity thinnings from below and crop-tree thinnings with high intensity, to open grown (almost solitary) stands. The changes in thinning applied on the plots mirror the temporal evolution of forest management practices from low intensity thinnings from below in the past to the current more widely spaced stands under intensive thinning regimes in favour of selected crop trees (e.g., Abetz and Klädtke, 2002). With this selective thinning, the competitors of the crop trees are removed. Since the crop trees are selected almost exclusively from the most vital trees in a stand, such a thinning regime does hardly affect dominant height. Furthermore, although the thinning intensity of the sample plots has increased by time, there are numerous studies giving evidence that height growth, in contrast to diameter growth, is little affected by stand management (e.g., Mäkinen and Isomäki, 2004; Mäkinen et al., 2005; Herbstritt et al., 2006). Harvesting strategies, which have impact on dominant height (i.e. target diameter cutting), have been excluded from the dataset.

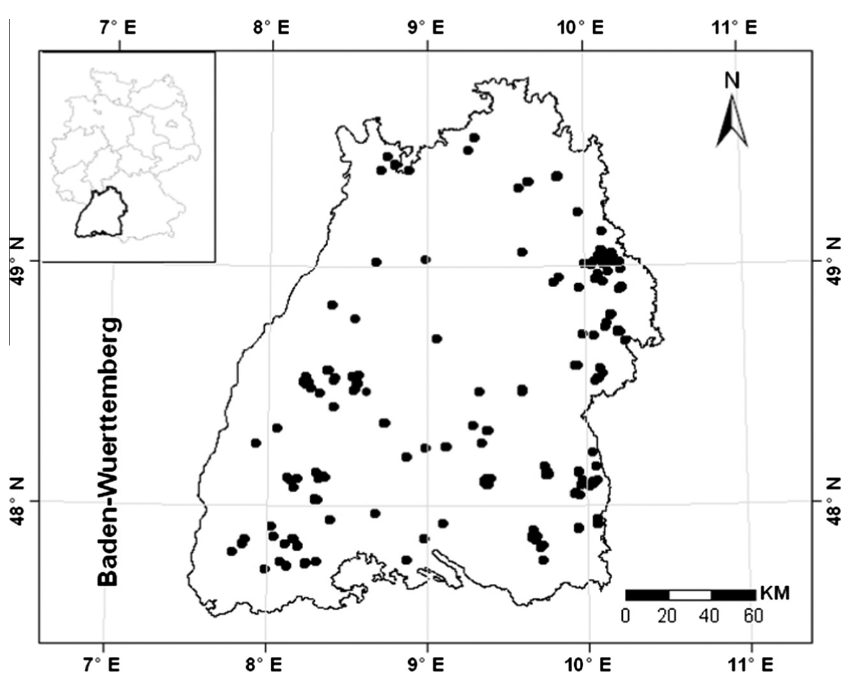

Fig. 1. Location of the Norway spruce plots in southwest Germany (Baden-Württemberg).