Available online at www.sciencedirect.com

SCIENCE DIRECT®

Ecological Modelling 181 (2005) 173–190

ECOLOGICAL MODELLING

www.elsevier.com/locate/ecolmodel

# Introducing effects of temperature and $CO_2$ elevation on tree growth into a statistical growth and yield model

J. Matala[a,*], R. Ojansuu[b], H. Peltola[a], R. Sievänen[b], S. Kellomäki[a]

[a] *Faculty of Forestry, University of Joensuu, P.O. Box 111, FIN-80101 Joensuu, Finland*
[b] *Finnish Forest Research Institute, P.O. Box 18, FIN-01301 Vantaa, Finland*

Received 8 September 2003; received in revised form 15 April 2004; accepted 4 June 2004

**Abstract**

Impacts of elevated temperature and $CO_2$ on tree growth were introduced into a statistical growth and yield model for Finnish conditions based on corresponding predictions obtained from a physiological growth model. This one-way link between models was made by means of species-specific transfer functions describing the increase in stem volume growth of trees as a function of elevated temperature and $CO_2$, stand density and the tree's competition status in a stand of Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*) and Norway spruce (*Picea abies*). This method allows the inner dynamics of the statistical model to be followed when the impacts of temperature and $CO_2$ elevation on tree growth are introduced into the calculation of volume growth and further allocated between diameter and height growth. In this way compatibility with previous predictions of tree growth by means of statistical models and related model systems under current climatic conditions could be retained.

The performance of the statistical model with species-specific transfer functions was evaluated by comparing its predictions with corresponding predictions given by a physiological model under conditions of elevated temperature and $CO_2$. These calculations revealed that the growth response of individual trees to elevated temperature and $CO_2$ can be introduced into the statistical model from a physiological growth model with an outcome that results in fairly satisfactory growth responses at the stand level as well.


*Keywords:* Physiological model; Statistical model; Model linking; Climate change; Boreal forests; Growth

## 1. Introduction

The predicted climate change in northern Europe during the next 100 years will involve a doubling of atmospheric $CO_2$ with a concurrent increase of 2–4 °C in mean annual temperature (high confidence, IPCC,

* Corresponding author. Tel.: +358 132513619; fax: +358 132514444.
*E-mail address:* juho.matala@joensuu.fi (J. Matala).

0304-3800/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2004.06.030

1996) and up to 6 °C in the winter months (Kettunen et al., 1987; Parry, 2000). Under the climatic conditions typical of Finland, for example, the growth of trees is currently limited mainly by the low summer temperatures and shortages in the supply of nitrogen (Melillo et al., 1996; Kellomäki et al., 1997). The productivity of the boreal forests is therefore likely to increase directly in response to elevated temperature in the future, and also through the longer growing season and enhanced mineralization of nitrogen (Linder, 1987; Ceulemans and Mousseau, 1994; Kirschbaum et al., 1994; Hättenschwiler et al., 1996; Mäkipää et al., 1999). Moreover, the elevation of atmospheric $CO_2$ is expected to further increase tree growth (Wang et al., 1995; Peltola et al., 2002); and water limitations are not excepted for Finland because of predicted 2.5–15% elevations in precipitation during the next 100 years (Carter et al., 1995).

Forest management should be modified in the future to respond to the climatic changes and thus avoiding increased self-thinning in managed stands, so that the increased stand productivity can be made use of in terms of earlier and/or more intensive thinnings and a shortened length of the rotation (Kellomäki and Kolström, 1993; Kellomäki et al., 1997). Thus, when quantitative, locally focused decisions are needed for future forest management, these should be based on predictions made at the local level and referred back to ground-true forest data (e.g. forest inventory data) with known geographical locations and environmental conditions (Talkkari, 2001). This requires that the models to be used should be able to accept as their inputs climate, soil and forest inventory data for a range of tree species and environmental conditions (Talkkari, 2001). Furthermore, the simulated results should also be comparable to existing forestry statistics and other data of a similar kind in order to enable the reliability of the predictions to be assessed (Talkkari, 2001). Such models could then be used for regional analyses of the impacts of climatic change on forests, in order to develop forest management strategies to cope with the risk of changing environmental conditions.

Forest growth models based on physiological processes (e.g. photosynthesis, transpiration and respiration) with hydrological and nutrient cycles controlled by climatic factors have been used in recent years to predict stand productivity under current and changing climatic (CC) conditions (McMurtie et al., 1994; Kellomäki et al., 1997; Landsberg and Waring, 1997; Constable and Friend, 2000; Kirschbaum, 2000; Lindner, 2000). Their utility has nevertheless been questioned as far as practical forest management planning (FMP) is concerned (Mohren and Burkhart, 1994), because of the excessive computational complexity that would arise if a detailed physiological model were to be used for large-scale FMP tasks. Despite this, some interest in using these models for more practical purposes has arisen recently, partly in connection with CC issues (Battaglia and Sands, 1998; Mäkelä et al., 2000a).

Statistical models of forest growth and yield are thought to be preferable when focused locally, and when reliable predictions are needed to support decision making (Mohren and Burkhart, 1994). The MELA system (Siitonen et al., 1996) has been widely used for FMP purposes in Finland, and the statistical growth simulator Motti, as a part of this MELA model, has been shown to be capable of providing reliable predictions for the full range of forests to be found in Finland under current climatic conditions (Hynynen et al., 2002). These predictions may prove biased in the future, however, if the climate changes, because the parameterisation of tree growth in the Motti model is based on growth data from a large number of sample plots reflecting past climatic conditions.

In the above context, we set out here to explore the possibilities for including CC impacts on forest growth in a statistical model that can be used for FMP tasks. This will be done by introducing a method for modifying the statistical Motti model (and hence MELA) on the basis of predictions of CC impacts on tree growth obtained from the physiological process-based model FinnFor (Kellomäki and Väisänen, 1997). The models will be linked by means of species-specific transfer functions for Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*) and Norway spruce (*Picea abies*), describing the increase in stem volume growth in these trees as a function of temperature and $CO_2$ elevation relative to current conditions, stand density and the competition status of the trees in a stand. The performance of the modified Motti model will be evaluated for specific CC scenarios with the results from the corresponding FinnFor predictions.