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Environment-induced growth changes in the Finnish forests during 1971–2010 – An analysis based on National Forest Inventory

Helena M. Henttonen [a], Pekka Nöjd [b], Harri Mäkinen [b,*]

[a] Natural Resources Institute Finland (Luke), Economics and Society Unit, Viikinkaari 4, 00790 Helsinki, Finland
[b] Natural Resources Institute Finland (Luke), Bio-based Business and Industry Unit, Jokiniemenkuja 1, 01370 Vantaa, Finland

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ABSTRACT

The annual growth of the forests of Finland has more than doubled in less than a century. While the increased growing stock and more efficient silviculture have contributed to the observed growth increase, there are also solid grounds for assuming that environmental changes have played a role. The aim of our study was to analyze and quantify the magnitude of changes of volume, basal area and height increment not attributable to changes in growing stock, forest structure and silvicultural practices.

We used the extensive data from National Forest Inventories during 1971–2010 to develop models for volume, basal area and height increment of individual trees on mineral soils without ditching or paludification with tree and stand characteristics as predictor variables. Differences between the measured and predicted increment were used to detect environment-induced increment changes. Then, we estimated the average changes of volume increment per hectare and totals in millions of m^3. Using this approach it was also possible to approximate the enhancing effects of volume increment change in growing stock volume.

From 1971–1975 to 2006–2010, the environment-induced volume increment increase was estimated to be 8.98 million $m^3\ a^{-1}$ (0.69 $m^3\ ha^{-1}\ a^{-1}$), which equals to 37% of the total observed volume increment increase. In relative terms the environment-induced increment increase was larger in the northern regions (up to 45% of volume increment change). During 1971–1990, the difference between the observed and predicted change was small. A large shift was observed after the mid-1990s in all regions. While the environment-induced increment change was substantial, a considerably larger increase representing 63% of the change was attributed to growing stock volume and forest structure, which both changed due to differences in forest management.

A comparison between the environment-induced increment changes and growing season temperature sums revealed similarities. In the southern Finland, April-May seemed to be influential, while in the north the temperature sum of May-September showed similar variation. As climate change is predicted to increase growing season temperatures, the trend can be expected to continue in the boreal conditions of Finland.

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1. Introduction

Concern about the degradation of forests due to emissions of harmful substances, such as acid rain, dominated the debate on environment-induced changes of forest growth until the 1990s (e.g., Sverdrup et al., 1994). Thereafter, the growth enhancing effects of global warming, the fertilizing effect of nitrogen deposition and the role of CO_2 enrichment have been in focus in temperate and boreal regions (e.g., Kauppi et al., 1992; Hyvönen et al., 2007; Thomas et al., 2010; Köhl et al., 2015).

There are a number of possible mechanisms behind growth changes due to the changing environment. Drought periods have limited forest production and led to extensive mortality in the temperate central Europe (Ciais et al., 2005). On the other hand, increasing temperature can lengthen growing period (Jyske et al., 2014) and enhance organic matter decomposition (Zak et al., 1999). Increasing soil temperature enhances root growth and nutrient uptake in the boreal forests (Lahti et al., 2005). Elevated nitrogen supply will increase leaf area (e.g., Binkley et al., 1995) and lengthen the radial growth period (Kalliokoski et al., 2013). Enrichment of atmospheric CO_2 may increase the photosynthetic production (e.g., Peltola et al., 2002; Hari and Kulmala, 2008), but in time, trees will also acclimate (Ainsworth and Long, 2005), and even genetically adapt to the changing environment.

* Corresponding author.
E-mail address: harri.makinen@luke.fi (H. Mäkinen).

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Spiecker et al. (1996) confirmed that in central Europe the tree- and stand-level growth was notably higher during the late 20th century than observed earlier in similar site and stand conditions. They listed several potentially affecting factors and stressed the difficulty of quantifying their individual effects. Kahle et al. (2008) suggested elevated nitrogen deposition as a likely affecting factor, but also listed several other potentially affecting factors and stressed the difficulty of quantifying their individual effects.

The forests of Finland provide an example of a large increase in productivity: the annual growth has more than doubled in less than a century. Sample-based national forest inventories were started in 1921 and the results of the first National Forest Inventory (NFI1, 1921–1924) were reported soon thereafter (Ilvessalo, 1927). During the first part of the 20th century, the annual growth showed only a limited change (Fig. 1b). A fast increase began during the early 1970s. The increasing trend has been observed in all parts of the country, but the relative growth increase has been largest in northern Finland. Since NFI1, the growing stock volume of the forests for the present area of Finland has also increased from 1385 million m^3 to 2356 million m^3 in NFI11 (2009–2013) (Korhonen et al., 2013; Luonnonvarakeskus, 2016) (Fig. 1a).

There are several potential causes for the increased growth of the Finnish forests, including forest management. In the past, low-volume stands and forest pastures were common (Ilvessalo, 1927, 1957; Kuusela and Salminen, 1991) and the gradually increasing growing stock has increased the annual growth (Siiskonen, 2007). Until the 1950s, selective logging removing the largest trees and leaving the remaining stand understocked was the norm (Ilvessalo, 1927; Sarvas, 1944; Kauppi et al., 2010). In addition, large-scale drainage of peatlands (5.7 million ha, equaling to 60% of the total area of peatlands (Minkkinen et al., 2002) and 22% of the area of forestry land in Finland), regeneration of low-yielding stands and more efficient regeneration methods including faster establishment of new stands (Kuusela and Salminen, 1991) and the use of genetically improved seed material have potentially increased forest growth as well (Stener, 2015).

While the increased growing stock and more efficient silviculture have contributed to the observed growth increase, there are also solid grounds for assuming that environmental changes have played a role. However, previous attempts of quantifying the contributing role of environmental factors on the observed increased growth of the Finnish forests have produced contradicting results. Several studies reported findings supporting the hypothesis that environmental factors explain a substantial share of it (Arovaara et al., 1984; Hari and Arovaara, 1988; Kauppi et al., 2014), but others discovered only slight (Mielikäinen and Timonen, 1996) or moderate (Henttonen, 1990, 2000) signs of such effects. Summarizing several regional case studies, Spiecker et al. (1996) concluded that Scots pine (*Pinus sylvestris* L.) did not show discernible growth changes not explainable by changes in forest structure in most parts of Fennoscandia and northwestern Russia. However, signs of a slight increase were detected for Scots pine and Norway spruce (*Picea abies* (L.) Karst.) in the southernmost part of Finland and in the region of St. Petersburg, Russia. A distinct increase in total volume yield and dominant height of Norway spruce was also reported in southern Sweden (Eriksson and Johansson, 1993), an area with a considerably higher nitrogen deposition than other parts of the region. Also Elfving and Tegnhammar (1996) reported a substantial trend-like increase of basal area and height growth of Scots pine and Norway spruce using data from the Swedish national forest inventories covering the years 1953–1992.

The aim of our study was to quantify the temporal and spatial changes of volume, basal area and height growth in the Finnish forest not attributable to changes in growing stock, tree and stand characteristics and silvicultural practices during the period of 1971–2010. Moreover, the potential causes of the observed increment changes were to be discussed. We use the term "environment-induced increment changes", as changes such as increased temperature, CO_2 enrichment and nitrogen deposition are obvious examples of factors causing these type of temporal increment changes. We realize that factors like fertilization and forest damage and use of improved genetic material are not fully described by our model-assisted approach.

2. Materials and methods

Tree-level increment models were developed using National Forest Inventory (NFI) data (1986–2008). Tree-level measured increments and model predictions were used in estimating increment changes per hectare and total changes (million $m^3\ a^{-1}$) for geographical regions and the whole country over the whole study period (1971–2010). Differences over time between measured and predicted increment reveal increment changes related to factors not included in the models.

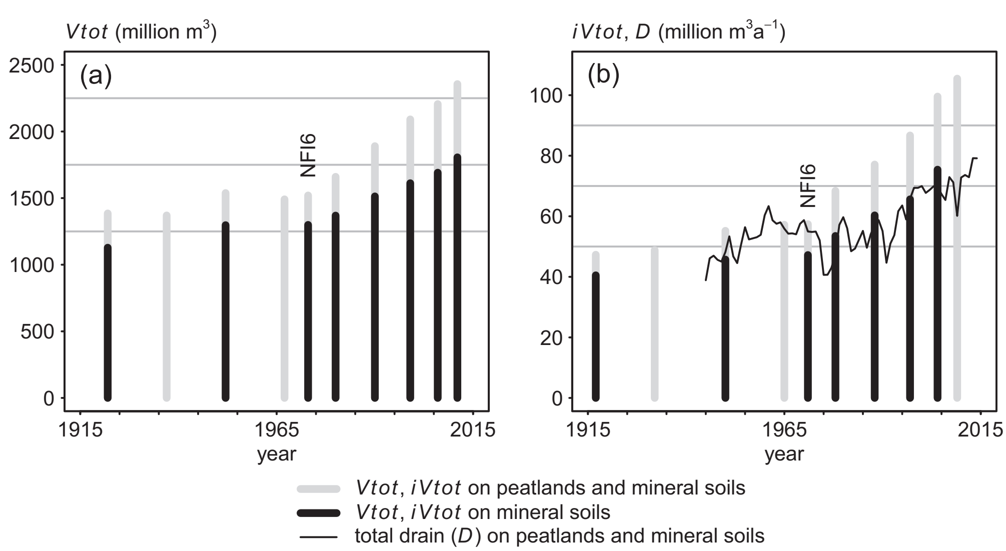

Fig. 1. Total growing stock volume (a) and volume increment estimates (b) in NFI1–NFI11 (Hökkä et al., 2002; Tomppo et al., 2011; Korhonen et al., 2013; Luonnonvarakeskus, 2016), with total drain from annual drain statistics (http://stat.luke.fi/en/roundwood-removals-and-drain). The estimates for NFI1 were calculated from the original field data for the present area of Finland.

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