Forest Ecology and Management 311 (2014) 41–55

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Tree growth in Swiss forests between 1995 and 2010 in relation to climate and stand conditions: Recent disturbances matter

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ARTICLE INFO

Article history:
Available online 21 June 2013

Keywords:
Net primary productivity
Basal area increment
Climate change
Stand density
Disturbance
Drought

ABSTRACT

Forest growth is affected by various concurrent and counteracting climate change related factors and the overall impact of environmental changes on forest growth is still uncertain. In order to evaluate the variability of tree and forest growth and the possible impact of climate change, we analysed 15 years (1995–2010) of tree growth data from 18 Level II plots in Switzerland, spanning a wide range of altitude, temperature and precipitation conditions.

Stem diameter of all trees within the Level II plots was measured every 5 years. Other above- and belowground parts of the trees were modelled by allometric relationships and validated with measurements if available. We analysed individual tree growth (basal area increment, bai) and the whole forest net primary productivity (NPP), here the sum of carbon gain by tree growth within the plot, during three inventory periods. Additionally, annual stem diameter increment, assessed on single trees at each plot since 2001, was used to approximate annual NPP of the forest.

Temporal patterns of NPP could not easily be related to climate conditions, since forest management and disturbance events (e.g. storms, diseases) overshadowed the climate impact on NPP. However, when looking at the individual trees, a clear decrease of bai by 2–30% (mean 19.3%) was observed for most of the sites during the second inventory period (2000–2005), which could not solely be explained by increasing stand density over time. Tree growth was most likely reduced due to the dry conditions during this period that included the extreme year 2003. An increased tree growth during the third inventory period (2006–2010) at a few sites could be clearly related to growth enhancement after stand density reducing events, such as storms or thinning. Thus, understanding climate impact on forest growth requires detailed site history knowledge and available long-term data sets.

The variability of mean NPP levels could be described with a function of the sites' climate conditions and nutrient deposition (adj. $r^2 = 0.86$), with N deposition enhancing forest productivity up to a threshold of 20–25 kg ha^{-1} yr^{-1} of N and with no further growth increase beyond that threshold.

1. Introduction

Forests mitigate climate change effects through numerous ecosystem services, such as balancing water regimes (Allewell and Bebi, 2011), protection against natural hazards (Brang et al., 2006), or by cooling-down the local and regional climate (Renaud and Rebetez, 2009). In return, forest growth is affected by various concurrent and counteracting climate change related factors – operating on global, regional, and local scales. Climate change is anticipated to alter long-term climatic conditions and to increase the magnitude of weather fluctuations (IPCC, 2007). Gradually changing environmental conditions enhance or reduce the individual tree growth slowly. In contrast, damaging events due to weather extremes abruptly alter the tree mortality rate, the forest area and stand structure, and have much more drastic consequences on tree growth (Loustau et al., 2005; Fuhrer et al., 2006).

Several studies, based on forest inventory data, ecological site studies and models, reported accelerated forest productivity in central Europe during the last centuries due to climate change (Spiecker et al., 1996; Ciais et al., 2008; Kahle et al., 2008; Luyssaert et al., 2010). Hence, for central Europe, forest growth has been postulated to be enhanced by a prolonged vegetation period and warmer temperatures, atmospheric CO_2 enrichment and increased nitrogen input (Spiecker, 1999; Hyvonen et al., 2007; Lindner et al., 2010), and models suggest a further increase of forest productivity in the future (Norby et al., 2005; Meehl et al., 2007). However, elevated ozone levels and sulphate deposition, nitrogen saturation (Nellemann and Thomsen, 2001; Braun et al., 2010), as well as the increasing occurrence of abiotic and biotic disturbance events (e.g., drought, storms, fire, snow breakage, insects) are expected to have a negative impact on forest health and thus growth

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http://dx.doi.org/10.1016/j.foreco.2013.05.040

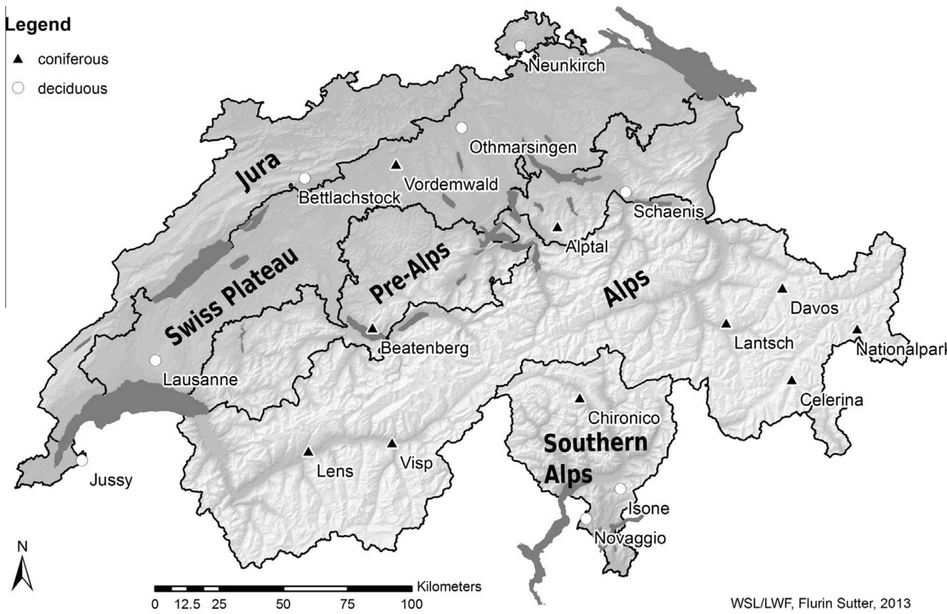

Fig. 1. Geographical regions and location of the 18 LWF sites in Switzerland. A white circle indicates sites dominated by deciduous species, a black triangle those dominated by coniferous species.

(Schelhaas et al., 2002), and could decrease or even offset a further increase of forest productivity. However, such extreme events are much harder to predict or to include in model simulations due to their stochastic nature.

Furthermore, forests react differently to environmental changes, depending on forest type, species composition, and site conditions. During the extreme year 2003, for example, forest growth decreased in the lowlands (Ciais et al., 2005), but was normal or even above average at higher altitudes (Jolly et al., 2005). For European beech forests a recent decline in growth during the last decades was reported for the temperate (Charru et al., 2010) and southern (Jump et al., 2006) range edge of European beech, while European beech forests in the Carpathians were found to be very stable ecosystems (Kucbel et al., 2012).

The majority of the literature on climate change impacts on forest growth is of a model-based nature (Lindner et al., 2010), and only a few reviews of the current forest status exist on a country or regional level. This means that information on causal factors, impacts and specific properties is often inconsistent or lacking (Campioli et al., 2012). Hence, the overall impact of the environmental changes on forest growth and forest vulnerability is still highly uncertain. However, knowledge about the current forest condition and the impact of environmental changes on forest vitality and growth is highly important when aiming at mitigating climate change by management adaptation, and improving tree growth and carbon models and thus future scenario predictions. In this study, we combined measurements on tree growth, forest condition, meteorology and atmospheric deposition, foliar and soil contents from permanent forest research sites in Switzerland, enabling us to document the whole stand dynamics, and to evaluate the variability of individual tree and forest growth.

Tree and forest growth is a sensitive indicator for forest vitality and buffer capacity against environmental changes (Dobbertin, 2005). Earlier studies on forest growth focused mainly on changes in tree and stand wood volume, or stem and height increment (Spiecker et al., 1996). Present studies try to address total biomass production of forest ecosystems, such as the net primary productivity (e.g. Karjalainen et al., 2003; Luyssaert et al., 2010). Net primary productivity (NPP) is defined as the increase in plant biomass per unit area and unit time. Physiologically, it is gross primary production (GPP) by plant photosynthesis minus autotrophic respiration (IPCC, 2003). Thus, forest NPP includes the production of biomass in different plant components: foliage, wood (stems and branches) and roots (including coarse and fine roots), and needs to be corrected for removed biomass by harvest or natural herbivory (Clark et al., 2001). Other components of the total ecosystem NPP, such as understory plant growth, emission of volatile organic compounds, exudation from roots and carbon transfer to root symbionts, are difficult to measure and in some cases of minor importance, and therefore often neglected (Luyssaert et al., 2010).

In this study, we assessed the individual tree growth as basal area increment (bai), the total forest biomass production as NPP, and the carbon losses due to mortality and management. Tree growth and factors influencing tree growth have been monitored for 15 years (1995–2010) on 18 forest sites across Switzerland within the long-term forest ecosystem research program (LWF). This time period includes the nine warmest years in Switzerland since the start of homogeneous meteorological data series in 1864 (MeteoSwiss, 2011) and two extreme events affecting large parts of the forested area in Switzerland: the storm Lothar in 1999 and the extreme summer heat wave in 2003. Our data set offers the possibility to study the recent trend of forest growth in Switzerland, as well as the reactions and regeneration ability of different forest types to severe weather anomalies. This is especially important in the face of the predicted further increase of temperature in Switzerland by 2.7–4.8 °C per end of the century and the predicted increasing occurrence of heat waves, drought and storm events (CH2011, 2011).

We particularly aimed at (i) quantifying the tree and forest growth, as well as the carbon sequestration potential of the LWF forest sites in Switzerland between 1995 to 2010, (ii) identifying the environmental factors that explain the temporal variability of growth on the individual tree level and on the forest ecosystem level, and (iii) determining the relationship between forest productivity and mean site conditions. Furthermore, we used the measured data on tree growth to validate allometric models, which are applied to upscale to regional levels.