



Radial growth changes in Norway spruce montane and subalpine forests after strip cutting in the Swiss Alps



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ARTICLE INFO

Article history:

Received 26 October 2015

Received in revised form 8 January 2016

Accepted 13 January 2016

Available online 21 January 2016

Keywords:

Picea abies

Dendrochronology

Edge effect

Tree-ring

Strip cutting

Mountain forest

ABSTRACT

New forest edges are continuously being created by forest management. In the Swiss Alps, silvicultural treatments have partly changed from the selection cutting widespread two decades ago to a more intensive strip cutting. However, little is known about the impact of such harvesting on tree growth and on the structural development of Alpine forest stands dominated by Norway spruce (*Picea abies* (L.) Karst.), which have high economic and protective value.

We therefore investigated the effect of strip cutting in four Alpine spruce stands differing in site and stand conditions through a dendrochronological analysis of 134 tree stems. The change in growth rate was assessed for the 10-year period before and after the cutting year, and rate changes in edge and non-edge trees were compared. The relative change in Hegyi's competition index before and after the cut was used as a proxy for the change in space and related resources. A linear model was developed to assess the effects of biotic and abiotic variables on changes in growth after strip cutting.

Radial growth responses varied greatly between the stands, with a significant increase only in edge trees in the two north-facing sites, i.e. 12% and 60%. Changes in tree competition had the strongest impact on tree growth, followed by site effects. With the same relative change in competition index, the radial growth of edge trees increased more strongly in reaction to cutting than that of non-edge trees. Additionally, small-diameter trees growing near edges benefited more from the strip cutting than larger trees.

Our results suggest that strip cutting on north-facing slopes can boost the growth of trees on the east and north-east-facing forest edges. Small spruce trees growing along newly created forest edges can be kept to enhance stand yield. As cutting often leads to long forest edges and may thus affect the growth of a significant proportion of the forest area, such effects should be considered in planning cutting layouts.

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1. Introduction

Norway spruce (*Picea abies* (L.) Karst.), which we refer to as “spruce” hereafter, is one of the most important tree species for timber production in Europe temperate forests (Spiecker, 2003) and in Alpine protection forests (e.g., for Switzerland, Duc et al., 2010). In Switzerland alone it accounts for nearly 45% of the growing stock and almost half of the timber harvest, with even higher proportions in the Swiss Alps (58% and 60%, respectively) (Swiss National Forest Inventory NFI 4, data shown for the period 2009–2013). To initiate natural regeneration in Norway spruce forests, a cutting layout with narrow strips seems to work well (Imbeck

and Ott, 1987). The creation of slit-shaped gaps, increased the solar radiation (Bischoff, 1987; Imbeck and Ott, 1987; Trepp, 1955) and successfully stimulated natural regeneration (Streit et al., 2009; Wunder and Brang, 2001). Gap dimensions of around 20 m in width and 50–70 m in length have been recommended (Bischoff, 1987; Imbeck and Ott, 1987) to provide sufficient direct sunlight (Brang, 1996, 1998; Vandenberghe et al., 2009), while at the same time maintaining the protective effect, especially against snow avalanches (Cunningham et al., 2006).

Implementing small strip cutting in practice is, however, costly. The trend has therefore shifted in the last two decades toward cutting larger strips 40–100 m wide to allow more timber extraction and make the operations more profitable. This new approach is increasingly being practiced, although not in protection forests, where management guidelines prescribe smaller gaps to preserve

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the protective effect (Frehner et al., 2005). How these intensive silvicultural operations influence tree growth and the forest structure of the remaining stands is, however, unclear.

Many recent studies have looked into tree growth changes after thinning in spruce stands (Bachofen and Zingg, 2001; Laurent et al., 2003; Mäkinen and Isomäki, 2004; Sohn et al., 2013) or after retention cutting (Dieler et al., 2008; Pretzsch et al., 2014). Only a few, however, have focused on their effects on the growth reactions of trees newly exposed to edges, i.e. following one-sided exposure. A study of the edge effects in North Carolina Piedmont across a range of tree species with different light requirements (McDonald and Urban, 2004) found the tree radial increment considerably improved in the first seven to ten m from the edge, with the highest growth increase in light-demanding species. This suggests solar radiation is the limiting resource for the light-demanding tree species, although other factors, e.g. water ability, appeared to also play a role near edges (McDonald and Urban, 2004).

Releases related to light changes have similarly been detected in sub-alpine spruce stands in trees growing along edges on a north-facing slope in the Swiss Alps (Bräker and Baumann, 2006). The radial increment at the tree stem base was greater than at breast height (dbh), possibly because the root system had adapted to stabilise the border trees (see also Pretzsch et al., 2014). Another study in boreal Scots pine (*Pinus sylvestris* L.) forests in Sweden found that the greater radial increment in trees along the north-facing edge was related to them consuming more water than non-edge trees (Cienciala et al., 2002). In a modelling approach, growth releases in edge trees were explained by the reduced competition after cutting, with effects being greater in young than in old stands apparently due to the greater stand density (Sandoval and Cancino, 2008). This finding suggests that younger trees are more sensitive to changes in growing space than older trees.

The great variability in the edge-tree growth patterns reported may arise from a number of interacting biotic and abiotic factors, such as species-specific differences, site-specific characteristics related to elevation, aspect, soil and climatic conditions as well as to tree age and size (Mäkinen and Isomäki, 2004). The response of forest trees to new edge conditions is not yet, however, well understood, and not enough research has been conducted to estimate the magnitude of these effects and to support associated management decisions, particularly in those mountain and sub-alpine forests that have a crucial protective function.

Radial growth changes can be quantified and dated with dendrochronological methods (Nowacki and Abrams, 1997; Rubino and McCarthy, 2004), and the radial growth analyzed to elucidate a stand's disturbance history (Cherubini et al., 1998). The reaction of trees to a specific event can be assessed with a yearly resolution. Disturbances usually induce growth releases in the surviving trees in a stand, but they are often difficult to distinguish from releases induced by climatic trends and events (Fraver and White, 2005). To identify a release or suppression of radial growth retrospectively, dendrochronological methods have been widely used, adjusted and tested (Black and Abrams, 2003, 2004; Trotsiuk et al., 2012). In our study, we used tree-ring width as a proxy for annual tree radial growth, focusing on radial increment before and after a known event, i.e. the year of strip cutting. Non-edge trees, which grew in an interior environment, were compared with edge trees, which experienced one-sided release from competition following strip cutting. Tree-ring growth patterns were analyzed and correlated with site and tree characteristics, and the following questions addressed:

1. How large is the mean growth change in reaction to a change in competition, i.e. in growing space?
2. How is this reaction related to site conditions?
3. Does the growth reaction depend on tree size?

2. Materials and methods

2.1. Study area

Three study sites were selected in the Upper Rhine Valley and one in the Lower Engadine (Canton of Grisons, Switzerland) (Fig. 1) according to four criteria: (1) stand composed of at least 80% spruce; (2) a minimum of 10 years since last strip cutting; (3) a clear border along the cutting area, 20–70 m in width; and (4) not actively managed or naturally disturbed during the last 30 years prior to strip cutting. The sites are located at elevations ranging from 1215 to 1680 m a.s.l. on slopes with an inclination between 50% and 70%. Two sites have a south- and two a north-west aspect (Table 1), with winds predominantly from the west.

The spruce stands differed in stand age, density and growing stock. Furna is the oldest stand with trees up to 266 years old, but with the lowest tree density (332 trees ha⁻¹), and the highest growing stock and basal area (1029 m³ ha⁻¹ and 71.2 m² ha⁻¹, respectively) (Table 1). The youngest stand is Jenins, its oldest trees having a mean age of 59 years, with a relatively high stand density and growing stock. The stand in Siat is similar to Furna, but with a lower growing stock, while Sur En has the smallest growing stock (400 m³ ha⁻¹) and lowest basal area (34.6 m² ha⁻¹). According to Keller's site index (Keller, 1978), Furna is the most productive site (site index 22), and Sur En the least (site index 16; Table 1).

Three stands originated from natural regeneration, but the stand at Jenins was planted. Strips of variable size were cut between 1997 and 2006 (Table 1) but with a similar east to south-east orientation. Forest management plans (Cantonal Forest Office, Chur, Switzerland), available for all the stands, were used to reconstruct the stand's history.

Daily means of temperature and precipitation for each site were interpolated using the DAYMET software (Thornton et al., 1997) on the basis of meteorological data recorded at the MeteoSwiss meteorological stations closest to each study site during the period 1991–2013. Average temperatures varied from 3.6 °C to 5.7 °C, with the largest intra-annual variation in Sur En, located in Lower Engadine, characterized by a continental climate (Table 1). The average annual precipitation sum (*P*) ranged from 811 to 1481 mm at the four different sites, with Sur En receiving the lowest amount of precipitation per year. The Lower Engadine is one of the driest regions in Switzerland, although, according to the climatic classification of de Martonne (1926), the annual aridity index DMI (De Martonne Index) still places Sur En in the “humid” climate class, whereas Siat, Furna and Jenins (with a DMI over 60) are classified as “very humid” (Fig. 2). At each study site, a strong decrease in the DMI was observed during the extremely dry year 2003 (Ciais et al., 2005), but the DMI did not recover to pre-drought levels until 2008 (Fig. 2).

2.2. Sampling design

A rectangular 40 m × 20 m plot inside the forest stand was set up at the edge of each cutting area and as an inlay in the permanent plot. In each plot all living trees with a stem diameter at breast height (dbh), i.e. at 1.3 m height above ground, larger than 7.5 cm were mapped and cored for tree-ring analysis. Trees with crown perimeters exposed to the cutting area were defined as edge trees and the remaining trees as non-edge trees. The plot size was chosen to ensure a minimum sample size of 20 trees with variable dbh. The plot width was chosen to cover a range of tree reactions to the cutting, from trees fully exposed to the cutting area to trees unaffected by the cutting, and set at 20 m according to the results of a similar study in conifer plantations in North Carolina. In this

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