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ORIGINAL ARTICLE

Stand responses to initial spacing in Norway spruce plantations in Norway

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Abstract
Using data from nine spacing experiments of Norway spruce (*Picea abies* (L.) Karst.) in Norway, covering wide ranges of site index and initial spacing, this study evaluated stand basal area and volume responses to initial spacing and examined whether these responses varied by stand ages or site quality. We developed nonlinear regression models that described the standing basal area or volume responses to initial spacing along with site index and stand ages. The results show that closer spacings produced higher standing basal area and volume than wider spacings. The response curves are highly nonlinear in younger stands and become nearly linear in mid-rotation stands, indicating stronger responses at younger ages and weaker responses as age increases. Furthermore, for young stands, spacing effects are stronger at closer than at wider spacings. The basal area and volume responses to initial spacing tend to be similar across site indices. However, the interaction of site index and stand age on spacing responses makes it difficult to isolate the effect of site index on spacing responses. Mortality is higher and begins earlier at closer spacings than wider. The mean diameter of the largest 100, 400, 600, and 800 trees ha^{-1} increased with spacing in three out of the nine experiments. Dominant height did not vary by initial spacing for any of the experiments. The findings suggest that the extra volume production in stands of closer initial spacing is restricted to early stand development.

Keywords: *Basal area, initial spacing, Norway, Norway spruce, volume.*

Introduction

Norway spruce (*Picea abies* (L.) Karst.) is the major plantation tree species in Norway, managed mainly for timber, pulp, and paper. During the last decades, the initial density has decreased substantially. Forestry practices in Norway before the 1940s involved planting at rather close spacings, with more than 4000 trees ha^{-1} (e.g. Børtnes, 1970; Braathe, 1978; Brantseg, 1966; Skinnemoen, 1948) followed by light but frequent thinnings so that few but large crop trees remained at final harvest (Brantseg, 1966; Orlund, 2006). High timber prices in the 1950s and 1960s also for small trees favored management that involved frequent and light thinning operations. In the 1960s, pre-commercial thinning was introduced to favor the development of crop trees. Results of trials on initial spacing (e.g. Braastad, 1970; Braathe, 1952; Klem, 1942, 1952) and spacing regulation in young stands (e.g. Vestjordet, 1977) prompted refinements of the earlier plantation practices. A number of reports (Braastad, 1971, 1975, 1985; Frivold, 1976) supported a management regime with a rather low initial density of approximately 1500–2750 stems ha^{-1} and no thinning. In the late 2000s, less than 10% of the harvested timber volume in Norway came from thinning. However, some forestry districts in southeast Norway have a proportion of thinning compared to final felling of more than 20% (Granhus et al., 2011). The Forestry Act and Regulation (Norwegian Ministry of Agriculture and Food, 2005) recommends densities of 600–3000 plants ha^{-1} for spruce, on low and very high site indices, respectively. With a growing interest in energy wood production and carbon storage, higher planting densities could be of interest in order to maximize biomass production during early stand development (Fang et al., 2007; Gamborg, 1997; Harper et al., 2007).

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