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Long-term effects of single-tree selection on the frequency and population structure of root and butt rot in uneven-sized Norway spruce stands

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ABSTRACT

The goal of this study was to assess the long-term effects of partial harvesting and supplementary soil scarification on the frequency of root and butt rot in managed uneven-sized Norway spruce stands. Frequency of rot and the population structure of the rot fungi were assessed on 1353 stumps after clear-cutting 21 years after a selection harvesting experiment. The initial experiment was comprised of three harvest strength (low, intermediate and high) of single-tree selection, removing approximately 25, 45 and 65% of the stand basal area. Uncut control plots were established at the same time. Supplementary soil scarification was applied in subplots within the single-tree selection plots, using a medium-sized excavator. After clear-cutting the stumps were analyzed with respect to rot caused by *Heterobasidion parviporum*, *Armillaria* spp., *Stereum sanguinolentum* as well as other rot fungi. Rot caused by *Armillaria* spp. was most common (8.6% of the stumps), while infection by *H. parviporum* (2.9%) or *S. sanguinolentum* (3.0%) was less frequent. The group "other rot" (5.4%) comprised 21 identified taxa, each occurring in 1–15 stumps. Significantly lower rot frequencies were found for the uncut control (16.3%) and intermediate harvest strength (15.7%), compared with low harvest strength (23.6%). A rot frequency of 21.0% was found in the high harvest strength. In two of three harvest strengths, the rot frequency was higher than for the uncut control. As the observed rot frequencies did not increase consistently with increasing harvest strength, the results do not completely support the initial expectations of increased rot after single-tree selection compared with the uncut control. However, since the probability of rot in individual stumps on plots treated with single-tree selection was significantly affected by the distance to the nearest strip road (*H. parviporum*) as well as dependent on the size of and distance to the nearest stump of trees cut during the experimental harvest (*H. parviporum*, *S. sanguinolentum* and total rot), it is evident that the single-tree selection harvesting was partially responsible for some of the observed rot. One of the selection criteria in the initial harvest was a sanitary removal of trees of poor vitality. Varying degrees of sanitation felling may therefore have offset the effects of new infections in wounds or spread of rot fungi through adjacent stumps. Supplementary soil scarification in small gaps of the residual stand had no significant effect on the frequency of rot, suggesting that such treatment may be used to facilitate regeneration in uneven-sized spruce stands on similar sites.

1. Introduction

Root and butt rot fungi cause substantial economic losses for the European forestry sector. The largest losses are due to the species in the *Heterobasidion annosum* complex, which have been estimated to an annual cost of around 800 million Euro within the countries of the European Union, when both quality- and growth reductions are accounted for (Garbelotto and Gonthier, 2013). Among the different species causing root and butt rot in Norway spruce, *Heterobasidion parviporum* Niemelä and Korhonen is the most important in the Nordic countries. In Norway, a survey carried out in 1992 showed that more than 25% of Norway spruce (*Picea abies* (L.) Karst.) trees cut in final fellings had rot (Huse et al., 1994). Their study also showed that *Heterobasidion* was present in 71% of the infected stumps. Similarly, in Finland, nearly 80% of the butt rot is caused by *Heterobasidion* (Tamminen, 1985; Piri et al., 1990). *Heterobasidion* species typically infect fresh stumps and then spread further into the stand through root contact with living trees (Stenlid and Redfern, 1998).

Other root rot fungi frequently damaging Norway spruce in Norway include *Armillaria borealis* Marxmüller and Korhonen and *Armillaria*

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cepistipes Velenovský (Keča and Solheim, 2011). These, however, usually infect fewer trees than *Heterobasidion*, although locally *Armillaria* may be more common than *Heterobasidion* (Heggertveit and Solheim, 1998). While the rot column caused by *Heterobasidion* may reach a height of 10–12 m (Rönnberg et al., 2013), *Armillaria* rot is usually confined to the lower part of the stem, thus affecting less wood volume (Solheim, 2006). Similarly to *Heterobasidion*, *Armillaria* is also able to spread into the next tree generation and may infest host trees by rhizomorphs (Shaw and Kile, 1991; Nierhaus-Wunderwald, 1994; Schönhar, 1994).

A third common species causing rot in Norway spruce is *Stereum sanguinolentum* (Alb. & Schwein.) Fr. This is the most common species causing rot through wounds on Norway spruce (Roll-Hansen and Roll-Hansen, 1980; Solheim and Selås, 1986). This species may infect wounds of all kind, both on the roots and stem (Vasiliauskas, 2001).

The risk of infection by root and butt rot in Norway spruce is influenced by several tree and stand characteristics, such as tree and stand age (Thor et al., 2005; Mattila and Nuutinen, 2007; Arhipova et al., 2011), tree diameter at breast height (Swedjemark and Stenlid, 1993; Thor et al., 2005; Mattila and Nuutinen, 2007) as well as site index (Thor et al., 2005; Mattila and Nuutinen, 2007; Arhipova et al., 2011), soil moisture and texture (Thor et al., 2005). In some studies from the Nordic and Baltic countries, the probability of damage has been found to decrease with increasing elevation (Thor et al., 2005; Mattila and Nuutinen, 2007) and with decreasing temperature sum (Hanso and Hanso, 1999; Thor et al., 2005; Mattila and Nuutinen, 2007). In contrast, a new model based on increment cores (Hylen and Granhus, in review) shows that high elevation forests in Norway have a higher rot probability than lowland forests. Different studies show contradictory results on the effect of tree species mix. In some cases a high proportion of Norway spruce in the stand has been found to increase the decay frequency (Lindén and Vollbrecht, 2002; Thor et al., 2005), whereas some other studies report no or only a slight effect of species mix (Siepmann, 1984; Piri et al., 1990).

Previous forest management is also important for the risk of infection and spread of root and butt rot (Piri, 1996; Rönnberg and Jørgensen, 2000; Piri and Korhonen, 2001; Pukkala et al., 2005; Honkaniemi et al., 2014). Regarding disease development, thinning has been found to cause more rot (Swedjemark and Stenlid, 1993; Piri and Korhonen, 2008), especially early thinning, which seems to be more important than subsequent multiple thinnings (Rönnberg et al., 2013). The increased probability of rot due to thinnings is partly due to the fresh stumps being suitable substrates for spore infection by *Heterobasidion*. Thinning infections may possibly spread more easily to adjacent trees through the root systems of the dead trees where especially larger stumps seem to be a driving factor for the dynamics (Honkaniemi et al., 2017). Mechanical wounding on the stem or root systems may also make the residual trees prone to infection by several wood-decaying fungi, dependent on the severity of the damage and season of harvesting (Isomäki and Kallio, 1974; Roll-Hansen and Roll-Hansen, 1980). This is of particular concern in connection with single-tree selection in multi-layered stands, where, due to a high tree density, it is practically impossible to avoid contact between the harvested trees and the residual stand during felling and processing (Fjeld and Granhus, 1998; Sirén et al., 2015). The risk of decay in connection with thinning or other types of selective cuttings may, however, be dependent on site conditions as shown by Mattila and Nuutinen (2007). In their study, the frequency of rot 10 years after selection cutting was higher in high-risk areas than low-risk areas.

Successful application of any silvicultural system requires understanding of the factors causing the infection and spread of forest pathogens because of their effects on forest production and protective functions. In many countries, the interest in integrating multiple-use concepts and natural forest dynamics into forest management and silvicultural practices has generated an increased focus on continuous cover forestry. While the complexity of factors and processes influencing the development and spread of pathogens can be considerable in even-aged management, responses to stand treatments may be even more difficult to predict in continuous cover management. Many studies have been conducted on root and butt rot in typical even-aged thinning stands (e.g. Swedjemark and Stenlid, 1993; Piri and Korhonen, 2008; Rönnberg et al., 2013), but less is known about the epidemiology of root rot in Norway spruce stands subjected to uneven-aged management. An association between frequent selective harvesting and the intensity of *Heterobasidion* root rot has, however, been found in North American studies (Schmitt et al., 1984; Goheen and Goheen, 1989). Finnish studies of uneven-sized Norway spruce stands have also shown transfer of *Heterobasidion* rot between different size classes (overstory, intermediate sized trees and saplings) to be important (Piri and Valkonen, 2013). To the authors knowledge, no other studies than the above mentioned have been conducted to investigate the population dynamics of root and butt rot fungi in uneven-aged stands, or to assess the effect of different harvest strengths on decay frequency.

Given the need to improve knowledge on the dynamics of root and butt rot in connection with partial harvesting, we decided to carry out a survey of root and butt rot 21 years after an experimental single-tree selection in south-east Norway. The initial trial examined different harvest strengths of single-tree selection in uneven-sized Norway spruce stands combined with supplementary soil scarification. The following three hypotheses were formulated: (1) single-tree selection harvesting would result in an increased frequency of rot compared with the uncut control, (2) the residual trees growing close to the strip roads for single-tree selection harvesting would be most prone to rot infection, and (3) supplementary soil scarification in the gaps of the residual stand would increase the risk of rot.

2. Materials and methods

2.1. The experimental site and treatments

The experimental site is located 450 m a.s.l. in Åsnes municipality, Southeast Norway (60.52°N, 11.75°E). The climate is moderately continental, with an estimated annual precipitation of 620 mm, and the estimated mean temperatures for July and February are 13.5 and −10.2 °C, respectively (Granhus et al., 2016). The trial was initially established in 1993–1994, and comprised six harvest treatments and three replicates (Fig. 1). The treatments included: an uncut control (1),

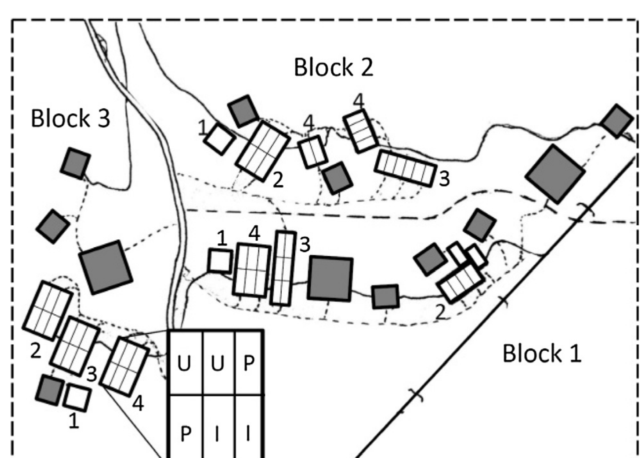

Fig. 1. The experiment initially comprised six harvest treatments replicated in three blocks. Only the uncut control (1) and the plots treated with single-tree selection (2–4) were used in the current study. The patch clear-cut treatments (5 and 6) are here indicated by grey colour. Three soil scarification treatments (U = untreated, P = patch scarification, I = inverting) were applied to subplots within the single-tree selection treatment plots.