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Predicting pine weevil risk: Effects of site, planting spot and seedling level factors on weevil feeding and mortality of Norway spruce seedlings

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ABSTRACT

Several insecticides used against large pine weevil (*Hylobius abietis* (L.)) feeding have been prohibited due to environmental and health issues. Thus, there is a need to find other protection methods. We investigated whether spot mounding without insecticide protection could ensure high seedling survival in boreal conditions. In addition, we predicted pine weevil feeding and mortality by site, planting spot and seedling level factors. A generalized linear mixed model (GLMM) was used for predicting feeding pressure. Multivariate GLMM was used for modelling the effects of feeding pressure on lambda-cyhalothrin insecticide-sprayed and unsprayed seedlings. We planted Norway spruce (*Picea abies* (L.) Karst.) container seedlings for two different years in central Finland. Seedlings were planted with and without insecticide treatment in spot mounds. Untreated seedlings were also planted in unprepared humus to predict pine weevil feeding pressure. Pine weevil feeding pressure was explained only by the age of the clear cuts: feeding pressure was high in fresh clear cuts and decreased if there was one growing season between the clear cut and the planting. On average, 8% of unsprayed seedlings planted in mounds died within two years after planting, while 2% of sprayed seedlings died. Under high feeding pressure, mortality probability of an unsprayed seedling planted in a mound was less than 0.1 only when the seedling was surrounded by mineral soil and the stem base diameter of seedlings was at least 4 mm. In mounds covered by mineral soil, especially if it was medium coarse, soil was splashed on the stem base and thereby protected seedlings from pine weevil feeding. Under lower feeding pressure, also thinner seedlings survived without insecticide treatment if mounds were covered by mineral soil. Thus, if Norway spruce seedlings are planted without insecticide treatment, they should have a relatively thick stem and need to be planted in mounds covered with mineral soil.

1. Introduction

The large pine weevil (*Hylobius abietis* (L.) Coleoptera, Curculionidae) is one of the most important insect pests in reforestation in many parts of Europe and Asia (Day et al., 2004). In the boreal zone, conifer seedlings are commonly protected against pine weevil infestations by insecticides. However, many insecticides have been prohibited during the last decades due to environmental and health issues, and alternative methods have been developed. In Sweden, feeding barriers such as glued sand grains or a wax layer on the bark are already being used to protect conifer seedlings (Eriksson, 2016). However, feeding barriers increase the cost of reforestation and are not commonly used in other countries. Thus, there is a need to verify how other methods may reduce the damage caused by pine weevils.

In European boreal forests, soil scarification is one of the most efficient methods to reduce pine weevil feeding (e.g. Luoranen et al., 2011; Luoranen and Viiri, 2012; Petersson et al., 2005). In practical forestry, both insecticide treatment and soil preparation are used simultaneously. In Sweden, a recent study indicates that the planting of Norway spruce (*Picea abies* (L.) Karst.) seedlings without insecticide or mechanical feeding barriers or waxes on mineral soil covered disc-trenched furrows might be possible (Nordlander et al., 2011). In Finland, Norway spruce seedlings (over 60% of annual planted seedlings) are mainly planted in mounds (Finnish Statistical Yearbook, 2014). Scarification methods differ in their effectiveness against pine weevils; weevils have damaged fewer seedlings in mounds than in disc-trenched furrows or in patches (Örlander et al., 1990; Saksa, 2011).

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The protective effect of scarification is based on mineral soil surrounding the seedlings. Especially the width of the mineral soil layer around a seedling is important: the longer the distance to the nearest humus edge, the less probable the damage caused by pine weevils (Saksa, 2011). Pine weevils have also difficulties climbing the sandy slopes (Nordlander et al., 2005). These factors protect seedlings and might enable regeneration without insecticide application.

The level of the pine weevil population as well as the feeding on seedlings varies among sites and within a site (Örlander et al., 1997; Wilson et al., 1996). In some sites, mounding alone may be effective enough but in some sites, other protection methods may be also needed. We were interested to know if it is possible to predict, using easily assessed site or seedling variables, the risk linked with pine weevil damage.

Leather et al. (1999) summarised that suitability of breeding sites, weevil developmental rate, planting site factors and weevil-seedling interaction may affect pine weevil feeding. One of the most important factors affecting the pine weevil population is the age of the clear cut, i.e. the time between clear cut and planting (e.g. Örlander and Nilsson, 1999). Heritage and Moore (2001) mentioned also that the time of felling (January–May, June–December) may affect the feeding level. There are also studies where the structure of the adjacent forest (Nordlander et al., 2003b; Örlander et al., 2000), size of plantation (Wilson et al., 1996), facing in a slope (Wilson and Day, 1996), soil type and soil texture (Luoranen et al., 2011; Luoranen and Viiri, 2012) as well as the site type and planted tree species (Långström, 1982) have affected the size of the migrating population and the risk of pine weevil infestations. Furthermore, tree species and quality of crop before felling, isolation from other felling sites as well as seedling size may affect the feeding level (Heritage and Moore, 2001). Especially the initial diameter influences the seedlings' risk to die from pine weevil feeding: the thicker the seedlings are, the smaller is the risk of mortality (Thorsén et al., 2001). Roots in the humus layer are a very important food resource for the pine weevil (Wallertz et al., 2006) and thus, the amount and vicinity of stumps and their roots may affect the feeding on planted seedlings.

Previously, Wilson et al. (1996) have built a predictive model of pine weevil damage from some forest-related variables in Ireland. Hereby, they used as explanatory variables size of the planted area, the age of the planting (years since planting), whether the seedlings were self-seeded or planted or if the site was previously planted or a newly planted area. From those variables, only the size of the planted area is relevant in Scandinavian conditions. For the southern part of Sweden, a model to predict the effect of different regeneration methods on the risk of pine weevil damage has also been developed (Snytbaggemodellen). For more northern boreal conditions, these earlier models are not suitable as the size of the pine weevil populations is usually lower and the development rate of the weevils is slower than in warmer conditions in the UK, Ireland and the southern part of Scandinavia.

It is important to know the factors affecting the size of the pine weevil population and feeding pressure for planted seedlings. Solbreck (1980) estimated that 60% of pine weevil females migrate at least 10 km to the new reproduction areas. This means that pine weevils are present in all regeneration areas in central and northern Europe, excluding the most northernmost areas. However, the level of the pine weevil population varies in different parts; e.g. in Scandinavia, it is greater in the southern Finland than in the northern part of the country (Långström, 1982) and greater close to the coast than in more northern inland sites (Johansson et al., 2015). The sizes of pine weevil populations have been assessed by pitfall and billet traps and mark-recapture technique, but estimates of pine weevil population densities given by these methods and damage in seedlings caused by pine weevils do not correlate well (Nordlander et al., 2003a; Örlander et al., 1997; Wilson and Day, 1994). Pine weevils feed especially the seedlings planted in undisturbed humus, with a mortality rate of over 75% (e.g. Heiskanen and Viiri, 2005; Örlander and Nilsson, 1999; Petersson and Örlander, 2003; Petersson et al., 2005, 2006). Thus, planting seedlings in unprepared humus can be a method to assess feeding pressure caused by pine weevils.

Lappi and Luoranen (2016) developed a generalized linear mixed model (GLMM) to analyse feeding pressure of pine weevils as well as a multivariate GLMM to predict feeding pressure effects in sprayed and unsprayed seedlings planted in mounds. In this study, we used this method to predict which site, planting spot and seedling level factor affects pine weevil feeding and seedling mortality. Further, we tested whether pine weevil feeding and mortality vary between insecticide-sprayed and unsprayed seedlings planted in mounds. The aim of the study was to investigate the effectiveness of mounding in preventing or reducing pine weevil damage in Norway spruce seedlings planted without insecticide treatment in boreal forest conditions.

2. Materials and methods

2.1. Study sites and experimental design

For the study, 11 and 9 regeneration sites in Suonenjoki-Rautalampi region in Central Finland were selected in 2012 and in 2013, respectively (Fig. 1). All sites were suitable for Norway spruce (*Picea abies* (L.) Karst.). The time of regeneration after clear cutting varied and was classified into three categories: site was cut (1) before July in the previous year (with one complete growing season between clear cutting and planting in May; before colonisation of insects, dried slashes), (2) in July or August in the previous year (with half a growing season between cutting and planting; after colonisation of insects, slashes and stumps dried in some extent), (3) after August in the previous year (no growing season between cutting and planting, fresh clear cut with fresh slashes and stumps). Sites were spot-mounded the previous summer, autumn or spring just before planting. For each regeneration site, the removal of slashes was recorded (Table 1).

Container Norway spruce seedlings were grown at the research nursery of the Natural Resources Institute Finland (former Finnish Forest Research Institute) in Suonenjoki (62°39′N, 27°03′E, altitude 142 m a.s.l.). In 2012, seedlings were one-year-old, grown in hard-plastic Plantek (BCC, iso-Vimma, Finland) 81F (81 cells per tray,

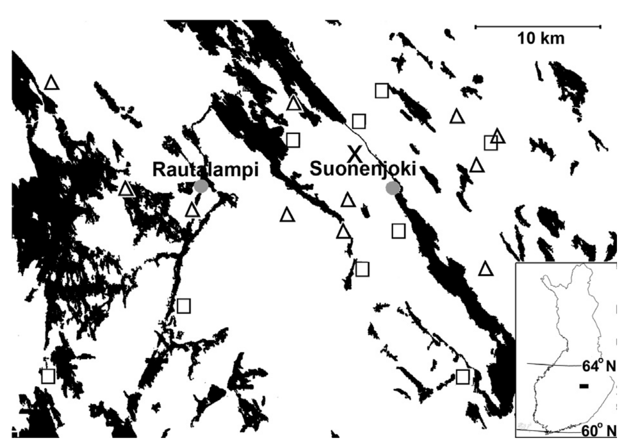

Fig. 1. Location of experimental sites shown in a black box in the index map. In the larger map, triangles represent regeneration sites planted in 2012 and squares those planted in 2013. Location of Suonenjoki Research Unit is marked with a cross. Large lakes (>0.3 km^2) are also shown in the map in black.