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Is stump removal for bioenergy production effective in reducing pine weevil (*Hylobius abietis*) and *Hylastes* spp. breeding and feeding activities at regeneration sites?

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ABSTRACT

Stump harvesting can help in managing forest pests, improve site preparation, and provide a source of bioenergy. However, stump removal does not remove all the roots from clear-cut areas. To investigate whether stump removal helps to manage forest pests, the effect of stump removal and its timing on the breeding and larval feeding activities of pine weevil (*Hylobius abietis*) and *Hylastes* spp. was studied. In eastern Finland, 16 commercial regeneration sites dominated by Norway spruce (*Picea abies*) (eight control areas, eight stump removal areas) were selected. Stumps were harvested in 2011, within the year following logging in three of the stump removal sites (short delay extraction), and in the second year after logging at five of the stump removal sites (long delay extraction). Root samples were excavated from sites three years after logging to examine the amount of roots, gnawing intensity, and density of larvae. In the control plots, gnawed root surface areas were 24% and 50% greater than those in long delay and short delay stump removal sites, respectively. After timing treatment, the estimated larval densities of both species were lower than the estimated larval densities in the control sites. In conclusion, the timing of stump extraction may partially regulate the breeding material and abundance of *Hylobius* and *Hylastes*. However, it is probable that this effect is not strong enough to substantially limit the future damage on planted seedlings.

1. Introduction

Tree stumps from forest regeneration areas are potentially an important source of raw material for bioenergy production because stumps offer more biomass than logging residues (Egnell et al., 2007). As well, stump harvesting may open new opportunities for managing forest pests and diseases and improve quality in site preparation (Saarinen, 2006). However, stump harvesting can also adversely affect soil carbon stores, increase soil erosion and compaction, reduce soil nutrient stocks, and cause valuable habitat loss for mosses, fungi, insects, etc. (Walmsley and Godbold, 2010).

Previous studies focused on the effects of stump harvesting on species dependent on dead wood (Work et al., 2016; Victorsson and Jonsell, 2016; Shevlin et al., 2017). However, few studies have focused on the effects of stump harvesting on pest populations, especially on the *Hylobius* genus (Coleoptera: Curculionidae), one of the most common and abundant economic pests in conifer seedling stands in Europe (Långström and Day, 2004). *Hylobius* breeds in conifer stumps and roots, and hampers the restocking of regeneration sites. In addition, larvae of *Hylastes cunicularius* Er., and *Hylastes brunneus* Er., another potential but poorly studied pest group in conifer seedlings, and longhorn beetles (Cerambycidae), often exist both in pine and spruce stumps and roots (Victorsson and Jonsell, 2016).

In a fresh clear-cut area, stumps and logging residues emit volatile compounds (e.g. several monoterpenes and ethanol) that attract potentially harmful insects to the site, including pine weevil (*Hylobius abietis)*, (Nordlander, 1987; Brattli et al., 1998) and *Hylastes* spp. (Joseph et al., 2001) which reproduce in the stumps and roots of logged trees. Pine weevils lay their eggs in the soil and bark of the roots (Nordlander et al., 1997) and *Hylastes* spp. also lay their eggs in recently clear-cut stumps (Lindelöw et al., 1993). *Hylastes cunicularius* Er. breeds mainly in Norway spruce and *Hylastes brunneus* Er. breeds mainly in Scots pine. After hatching, pine weevil larvae overwinter in stumps, feeding under the bark of stumps and roots, and pupate in the following summer (Nordenhem, 1989). New adult weevils emerge in autumn of the year following clear-cutting. In this way, pine weevil breeding continues actively for a few successive years after clear-cutting has occurred.

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Table 1
Description of study sites and temperature sum, dd °C (threshold > + 5 °C).

Site name	Pair code	Distance between pair sites (km)	Logging volume(m^3/ha)	Coordinates	Area, ha	Site type	dd	Logged	Stump extraction	Root sampling date
Uimaharju	P1	35	223	62°56′ 30.24″, 30° 19′ 28.239″	0.73	Damp (*Myrtillus type*)	1066	2009	No	9.–20.8.2012
Katajavaara	P1		237	62°51′ 33.396″, 29° 50′ 32.868″	0.89	Damp (*Myrtillus type*)	1043	2009	2010	8.–16.8.2012
Korpivaara,	P2	55	260	62°50′ 22.696″, 30° 42′ 24.108″	0.91	Damp (*Myrtillus type*)	1026	2009	No	21.–24.8.2012
Havukkavaara 1	P2		287	62°36′ 59.054″, 30° 9′ 35.772″	2.95	Damp (*Myrtillus type*)	1017	2009	2010	6.–14.8.2012
Kokonsalmi	P3	85	234	62°26′ 2.793″, 28° 52′ 58.572″	0.70	Damp (Myrtillus type)	1172	2009	No	31.8.–5.9.2012
Havukkavaara 2	P3		244	62°36′ 50.369″, 30° 9′ 39.412″	3.42	Damp (*Myrtillus type*)	1020	2009	2010	7.–13.8.2012
Rempsu	P4	20	256	62°26′ 4.524″, 28° 53′ 54.41″	1.97	Damp (*Myrtillus type*)	1167	2009	No	11.–14.9.2012
Juurikka	P4		260	62°32′ 3.482″, 28° 50′ 50.81″	1,12	Damp (*Myrtillus type*)	1141	2009	2010	31.8.–5.9.2012
Petrumansalo	P5	15	294	62°26′ 34.754″, 28° 53′ 22.978″	2.93	Damp (*Myrtillus type*)	1154	2009	No	20.–25.9.2012
Juurikkajärvi	P5		298	62°32′ 10.792″, 28° 51′ 0.221″	2.07	Damp (*Myrtillus type*)	1143	2009	2010	17.–19.9.2012
Polvijärvenniemi	P6	30	304	62°24′ 44.94″, 28° 19′ 22.589″	0.92	Damp (*Myrtillus type*)	1215	2010	2010	4.–9.9.2013
Jalaslampi	P6		301	62°23′ 10.059″′, 28° 47′ 24.971″	1.19	Rich (*Oxalis-Myrtillus type*)	1179	2010	No	27.9.–2.10.2013
Polvijärvensalmi	P7	30	262	62°24′ 45.805″, 28° 19′ 9.735″	2.23	Damp (*Myrtillus type*)	1215	2010	2010	11.–13.9.2013
Kermansalo	P7		258	62°23′ 39.13″, 28° 47′ 31.512″	0.95	Rich (*Oxalis-Myrtillus type*)	1173	2010	No	19.–26.9.2013
Valkeinen	P8	40	267	62°23′ 14.925″, 28° 48′ 46.041″	0.43	Damp (*Myrtillus type*)	1169	2010	No	9.–14.10.2013
Arhinmäki	P8		265	62°36′ 34.767″, 28° 39′ 37.257″	3.43	Damp (*Myrtillus type*)	1122	2010	2010	15.–18.10.2013

Pine weevils and *Hylastes* spp. preferentially feed on the thin bark of coniferous tree species (Manlove et al., 1997; Leather et al., 1999; Löf et al., 2005; Wallertz et al., 2014). Pine weevils feed on the roots and branches of mature trees and on the stems of seedlings. Both *Hylastes* species feed on the roots of mature trees, and on the roots and at the stem base of seedlings, but just on the basis of feeding marks it is impossible to separate the species. In boreal forest regeneration sites, pine weevil feeding can cause the death of 60–80% of planted coniferous seedlings (Örlander and Nilsson, 1999). Sustained pine weevil feeding on seedlings can last at least three consecutive years (Långström, 1982). Most serious economic damage due to pine weevil feeding occurs at newly planted coniferous regeneration sites where previous stands have been clear-cut coniferous forests (Långström and Day, 2004).

In theory, the rapid harvesting of stumps and coarse logging residue after clear-cutting might effectively reduce the amount of volatile compounds, which lure new adults to the clear-cut area. In addition, it could also reduce the amount of suitable breeding material available and decrease the subsequent larval population. Consequently, stump removal might reduce the feeding damage caused by pine weevil and *Hylastes* spp. on planted seedlings. Thus, stump removal might function as a silvicultural method in the integrated management of root-feeding pests However, immediate and total stump removal may not be possible in practical forestry management terms. In practice, in stump harvesting, an excavator uproots the main tree root system, but many side roots and rotten roots remain in the soil. Silvicultural instructions recommend to leave at least 25 stumps ha^{-1} for biodiversity and to prevent erosion (Koistinen et al., 2016). Moreover, stumps less than 20 cm in diameter are often left due to the high cost of excavation (Kärhä, 2012).

The pine weevil has a strong ability to dig in the soil and lay eggs in small roots (Nordlander et al., 1997). *Hylastes* spp. also can dig up to 100 cm in the soil to enter buried roots (Lindelöw, 1992). Furthermore, if stump removal is delayed for a long time and done after arrival of pine weevils and *Hylastes* spp. in clear-cut areas, then they have already succeeded in colonising the stump and root system. This may compromise the potential pest control effect of stump removal. Therefore, it is necessary to know how many roots are left for breeding substrate and how the timing of stump removal in clear-cut areas contributes to the reproduction potential of *Hylobius abietis* and *Hylastes* spp.

The concerns about the relationship of pine weevil and *Hylastes* spp. with stumps in clear-cut areas are as follows: (1) both species feel attraction to stumps, and immigrate to clear-cut areas in early summer; (2) weevils and *Hylastes* both breed in stumps and roots, and after completion of the larval stage, emergence can take more than two years after immigration for young adult pine weevils, and more than one year for *Hylastes* spp. in eastern Finland; (3) normally, stump removal will be carried out in clear-cut areas after pest insect immigration. With this knowledge, theoretically, it can be assumed that early stump removal might decrease the amount of breeding material and the abundance of pine weevil and *Hylastes* spp. in the regeneration site. To determine how stump removal and its timing affect the breeding and abundance of pine weevils and *Hylastes* species, we studied the effects of stump removal on the amount of coniferous root material remaining in clear-cut areas available for *Hylobius* and *Hylastes*. We also tested short delay (within a year of clear-cut) versus long delay (the year following clear-cut) stump removal on the populations of *H. abietis* and *Hylastes* spp. by measuring their larval feeding intensities on roots. *Hylastes* spp. and pine weevil feeding intensities in the remaining roots were compared between control sites (with no stump removal) and sites with stump removal.

2. Material and methods

2.1. Study sites and experimental design

In this study, 10 and 6 regeneration sites, logged in 2009 and 2010,