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Immediate Effects of Logging, Mounding and Removal of Logging Residues and Stumps on Coarse Woody Debris in Managed Boreal Norway Spruce Stands

Ruut Rabinowitsch-Jokinen and Ilkka Vanha-Majamaa

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Wood fuel production has increased remarkably, but its environmental effects within the forest ecosystem have not yet been studied much. We investigated the immediate effects of two series of forest management treatments, which produce timber and forest chips, on the volume and decay classes of coarse woody debris (CWD). One of the treatment series included logging and residue harvesting (LRH) and mounding (M), while the other series included LRH and mounding combined with stump harvesting (MSH). We hypothesized that, i) LRH reduces CWD, excluding stumps; ii) the more intense the soil preparation treatment is, M vs. MSH, the more CWD is destroyed; iii) both LRH and soil preparation treatments (M and MSH) reduce the occurence of snags, highly decayed CWD and deciduous CWD in particular. Ten sample plots in mature managed Norway spruce (*Picea abies* (L.) H. Karst.) dominated forests were located in Southern Finland. The total volume of CWD on the sample plots was measured three times: before and after LRH, and after M or MSH. LRH significantly decreased the volume of snags and the combined volume of snags and logs. MSH significantly decreased the total volume of CWD, while M had no significant effect on the volume of CWD. The middle and highly decayed CWD were destroyed most easily in the treatments.

Keywords bioenergy, CWD, forest management, log, logging residues, snag, soil preparation, stump harvesting
Addresses Finnish Forest Research Institute, Vantaa Research Unit, P.O. Box 18, FI-01301, Vantaa, Finland **E-mail** ilkka.vanha-majamaa@metla.fi
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1 Introduction

Coarse woody debris (CWD) is an essential element of forest ecosystems. When a tree dies, it has only partially fulfilled its potential ecological function (Franklin et al. 1987). CWD belongs to many ecological processes and its importance for species diversity is remarkable. According to Stokland et al. (2003), CWD is one of the main forest biodiversity indicators. For example, approximately one fifth of all ~21 000 species in Finnish forests are dependent on decaying wood (Siitonen 1998). Furthermore, the reduction of CWD has been identified as the most or one of the most critical factors in the classification of 419 threatened species in Finland (Rassi et al. 2001). CWD provides habitats for a very large variety of organisms and may be utilized in various ways (Harmon et al. 1986, Samuelsson et al. 1994). Especially on severely disturbed sites, CWD may ameliorate environmental extremes and provide shaded microsites (Harmon et al. 1986). Characteristics of CWD contribute to the species composition utilizing it (Esseen et al. 1997, Dahlberg and Stokland 2004). The species communities differ amongst decay stages, and the intermediately decomposed log with softened wood supports the greatest array of inhabitants (Maser and Trappe 1984).

In the managed forests of Southern and Central Finland, the time for a log (diameter >5 cm) to decompose until disappearance is 25–40 years for silver birch (*Betula pendula* Roth) and 60–80 years for Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) (Mäkinen et al. 2006). The above ground stump wood decomposition in Southern Finland is found to be fastest in birch, followed by spruce and then pine (Shorohova et al. 2008). The decomposition of bark was found to be faster in spruce than in birch and pine (Shorohova et al. 2008). Dead wood also stabilizes the nutrient cycle of an ecosystem, is an important material for humus increment, enhances water absorbance and decreases acidity of soil (Siitonen 2001). In a recent study by Palviainen et al. (2009) the stumps of Norway spruce, Scots pine and silver birch have been found to be long-term pools of carbon (C) and, especially, nitrogen (N), acting as N sinks to potentially diminish N leaching into ground water and watercourses after clear-cutting.

Forest management has reduced the amount of CWD in boreal forest landscape (Esseen et al. 1997, Ekbom et al. 2006). The volume of CWD is clearly lower in managed Finnish forests as compared to unmanaged (FFRI 2006). In the old-growth, Norway spruce dominated forests in Southern and Middle Finland, the average amount of CWD (diameter ≥5 cm) is 111 $m^3\ ha^{-1}$ (Siitonen et al. 2000). In Southern Finland, the mature (101–140 yr old) managed forests average only 4.4 $m^3\ ha^{-1}$ of CWD (Ihalainen and Siitonen 2006). According to the 9th National Forest Inventory, the average volume of CWD (diameter >10 cm) in Southern Finland forests is generally only 2.7 $m^3\ ha^{-1}$ (FFRI 2006). Owing to this, one of the national environmental goals is to increase the amount of CWD in managed forests (MAF 1999). Several ways of restoring the natural forest structures have been recently studied and adapted in Fennoscandia (Jalonen and Vanha-Majamaa 2001, Vanha-Majamaa and Jalonen 2001, Lilja 2006, Vanha-Majamaa et al. 2007). However, the multitude of ordinary managed forests in Fennoscandia emphasize the impact of varying forest management options on CWD, which is of great importance in assessing the ecological sustainability of current forest management.

Present biodiversity-oriented forestry management includes green-tree retention practices and recommended CWD preservation (MAF 1999, Vanha-Majamaa and Jalonen 2001). Green-tree retention is approximated to produce about 0.5 million m^3 of fresh CWD each year in Finland (Hetemäki et al. 2006), whereas the volume of dead wood harvested for forest fuel is significantly larger, aiming to 5 million m^3 per year by 2010 (MAF 1999), to as much as 8–12 million m^3 per year by 2015 (MAF 2006, 2008). Until now, the annual use of forest chips has increased from 0.8 to 4 million m^3 during the years 2000–2008 (FFRI 2009).

The main final felling method in Finland is clear-cut logging, used in 85% of the sites (FFRI 2008). After logging, the sites are usually prepared, exposing mineral soil and ensuring regeneration. During the past ten years, mounding has become the most common soil preparation method in Finland at the expense of harrowing, covering 43% of the overall soil preparation area in the year 2007 (FFRI 2008).

Logging has been found to decrease the volume of standing and downed CWD (Zarnowitz and Manuwal 1985, Eckerberg 1988, Fridman and Walheim 2000, Hautala et al. 2004), while the inclusion of stumpwood in CWD measurement actually increases overall CWD volume (McCarthy and Bailey 1994). Hautala et al. (2004) observed a significant decline in the volume of downed CWD (hereafter 'logs') especially due to soil preparation (harrowing). Harrowing especially affected deciduous and highly decayed logs (Hautala et al. 2004). However, the effects of bioenergy-oriented forest management treatments, as well as the corresponding effects of mounding, on CWD are poorly known.

The aim of this study was to estimate the immediate effects of logging and residue harvesting (LRH), mounding (M) and mounding combined with stump harvesting (MSH) on the volume and quality of CWD consisting of stumps, snags and logs. Two treatment series were included: LRHM and LRHMSH, depending on whether LRH was followed by M or MSH. We hypothesized that, i) LRH reduces CWD, excluding stumps; ii) the more intense the soil preparation treatment is, M vs. MSH, the more CWD is destroyed; iii) both LRH and soil preparation treatments (M and MSH) reduce the occurence of snags, highly decayed CWD and deciduous CWD in particular.

2 Materials and Methods

2.1 Study Sites and Treatments

The study area (1.7 km × 3.2 km) was located in the Längelmäki area (61°48´N, 24°44´E–24° 47´E) in Southern Central Finland (Fig. 1). The area belongs to southern-boreal vegetation zone (Kalela 1961, Ahti et al. 1968), with a temperature sum of 1200 degree days, and a growing season of approximately 150 days (FMI 2006). The altitude above sea level is 100–150 m, and the mean annual temperature +3 °C (Drebs et al. 2002). The annual precipitation is about 600 mm, and about 70 rainy days occur from May to September (Drebs et al. 2002).

Mature *Myrtillus* type or *Oxalis-Myrtillus* type (Cajander 1926) Norway spruce dominated stands were chosen for the study to be appropriate for stump harvesting according to UPM-Kymmene Ltd forestry company instructions (Halonen 2005). To ensure the comparability and homogeneity of the stands, the structure, basal area and age of trees in the stands had to match closely. The stands were also chosen according to a minimum requirement of some standing CWD (hereafter 'snags') and logs in order to sufficiently address the aims of the study. The study was arranged to follow a randomized block design with five blocks; one sample plot for both treatment series was randomized amongst them (Fig. 1). The size of a sample plot had to be relatively large – one hectare – so that it would imitate a usual logging site under average influence of forestry machines. In order to achieve five blocks, one sample plot pair (block) was divided in two separate study stands.

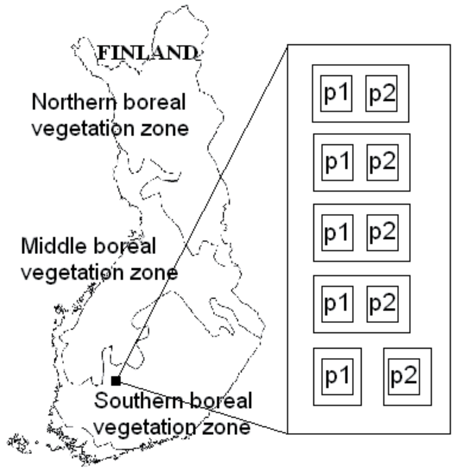

Fig. 1. Experimental setup consists of five sample plot pairs (pair: p1 & p2), of which one had to be divided in two study stands. Each sample plot was 1 ha in size and the six study stands were located within 1.7 km × 3.2 km in Längelmäki area.

The stands were 100–125 years old, managed and mature Norway spruce dominated forests with signs of previous thinnings. The height of the dominant trees was 26–28 m, basal area 24–29 m^2, and the volume of the stands 256–393 m^3 ha^{-1}. The sample plots were placed randomly in the study stand so that the major paludified spots and edge effect areas were excluded. The plots were shaped either 100 m × 100 m or 133.3 m × 75 m, according to the shape of a stand and location of paludified spots.

LRH were carried out in August, and the soil preparation treatments in October of 2005. Neither the contractors nor the operators differed within the treatments. Additionally, they were not aware of the aims of the study. M was done with a Caterpillar 312 LHW and a 60 cm wide mounding bucket, whereas MSH was carried out with a Caterpillar 320C and a stump rake with a 55 cm wide mounding blade.

2.2 Data Collection

CWD was measured in three categories: logs, snags and stumps. Both the new CWD, produced of living wood as a by-product of logging, and old CWD consisting of other CWD, were included. The living retention trees that fell down after logging were excluded from the volume of CWD, because the cause of the fall was probably the wind rather than the treatment directly. Logs and snags were measured throughout the total area of the sample plots, and stumps were measured from the randomly chosen half of each sample plot. However, the new logging stumps (new stumps) were measured only in plots in which MSH was carried out. The harvester data system gave information about the number and the tree species of the new stumps on all plots.

The measurements of CWD were carried out three times in 2005: before and after LRH, and after M or MSH. The CWD was measured using the same method as in the 9th National Forest Inventory (NFI9) in Finland. According to the NFI9 guidelines (FFRI 1998), the snags and logs were counted only if meeting the requirements: minimum of 10 cm at breast height diameter and 1.3 m in length. Also, a minimum diameter of 10 cm at the stump level and a corresponding height of less than 1.3 m were applied to the stumps. The measurements included the diameter at breast height or at the base, tree height and the height of the possible breaking level. Several other characteristics were defined and recorded, such as the tree species, decay class (Appendix 1), and the tree appearance. The stump volumes were calculated by above-ground parts only.

The treatments affected the CWD in many ways. Examples include snags that might fall down and become logs, logs and stumps which were buried into the ground or under logging residues, damaged, or even completely destroyed or disappeared. The CWD was considered 'destroyed' when the wood had broken into several pieces and more than half of its shape had smashed. Neither the destroyed parts of the CWD were measured, nor the pieces of CWD or stumps buried in the ground or under logging residues.

The damage to the ground surface was measured 2 years after the treatments. The damage was measured systematically at 20 m intervals in a continuous back and forth transect line throughout the plots (including 19–20 measurement places on a plot) with a 178 cm long measurement line. The first measurement place and the proceeding direction in a plot were randomized. The damage was evaluated by each centimeter on the line: either the surface was undamaged or the mineral soil was exposed or mixed with humus.

2.3 Data Analysis

The volumes of snags and logs and the stumps attached to them were calculated using KPL-software designed by Heinonen (2003). The KPL-software uses taper curve, bark coverage, stump height and volume functions by Laasasenaho (1976, 1982) for Norway spruce, Scots pine and birch (*Betula pendula* Roth*, Betula pubescens* Ehrch.) and unpublished functions by Laasasenaho for other Finnish deciduous tree species. The length functions were formulated from the living tree data in Jalonen and Vanha-Majamaa (2001). The data consisted of altogether 949 living sample trees in six research stands within four kilometers from our study area. The stands consisted dominantly of mature 92–143 years old *Myrtillus* type spruce forests.

The volumes of all individual stumps were calculated by equation

$$V = V_c \cdot (\bar{V}_{KPL} / \bar{V}_c) \tag{1}$$

where V_c is the volume of a cylinder with diameter equal to the cut level diameter of a stump, $\bar{V}_{KPL}$

is the tree species specific mean volume of the stumps computed by KPL and $\overline{V}_c$ is the mean of the V_c values of the same stumps.

The mean volumes of new (induvidual) stumps were calculated separately for each sample plot and tree species according to the field measurements of remaining new stumps after MSH and the data from harvester data system.

The effect of the treatments on the quality of CWD was investigated by observing changes in decay class and tree species distributions. In order to clarify the effects of treatments on the quality of CWD, the tree species and decay classes were grouped. The tree species were divided into coniferous and deciduous, and the decay classes into less, middle and highly decayed. The coniferous species were Norway spruce and Scots pine, and deciduous species consisted of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) with some rowan (*Sorbus aucuparia* L.), alder (*Alnus incana* (L.) Moench and *A. glutinosa* (L.) Gaertn.), aspen (*Populus tremula* L.) and willow (*Salix caprea* L.). The less decayed CWD consisted of wood that was still hard or had started to soften (decay classes 1a, 1b & 2, Appendix 1). The group of middle decayed CWD consisted of the wood that was clearly soft (decay classes 3 & 4), and the group of highly decayed CWD of the very soft wood (decay class 5, or decay classes 5a & 5b).

The differences between volumes before and after M or MSH were tested using a linear mixed model. The model (Eq. 2) was:

$$y_{ij} = m + \text{series}_i + \text{block}_j + b * V_{ij} + e_{ij} \qquad (2)$$

where y_{ij} is the difference of volumes, m is a constant, series ($i = 1, 2$) is a fixed treatment effect, block$_j$ ($j = 1$–4) is a random block effect, volume in the second measurement V_{ij} is a fixed covariate, b is a regression coefficient and e_{ij} is a residual. The differences between the volumes before and after LRH were tested using the same model without any covariate. Similarly, the volumes were compared between the series before LRH. It was assumed that the errors are independent and normally distributed with homogenous variance. The assumptions and need for transformation of response variables were checked graphically using Q-Q probability plots and scatter plots of residuals.

3 Results

The treatments damaged the ground surface by moving the humus layer, exposing mineral soil or by mixing them. However, series LRHM left 39% and series LRHMSH 24% of the ground surface undamaged.

Before and after LRH the volumes (m^3 ha^{-1}) of any type of CWD did not differ statistically between the series. LRH affected significantly the volumes of snags ($p = 0.008$, Table 2), snags combined with logs ($p < 0.001$), stumps ($p < 0.001$), and the total volume of CWD ($p < 0.001$): The volume of snags (–30%) and snags combined with logs (–15%) moderately decreased. However, the total volume of CWD increased (+29%) due to addition in stump volume (+346%).

The subsequent treatments had different effects on the volume of CWD (Table 1 and 2). M significantly decreased the volume of snags ($p = 0.018$, –20%), while MSH significantly decreased the volume of stumps ($p < 0.001$, –58%), and the total volume of CWD ($p = 0.002$, –20%).

LRH significantly decreased the volume of less decayed snags ($p = 0.001$, –33%) and highly decayed stumps ($p = 0.003$, –58%, Fig. 2). Additionally the middle decayed logs (–27%) and stumps (–29%) decreased, although not statistically significantly ($p = 0.142$, $p = 0.088$). The volume of less decayed logs significantly increased ($p = 0.006$, 23%). Also the volume of coniferous snags significantly decreased ($p = 0.01$, –30%, Fig. 3), and the volume of coniferous logs increased ($p = 0.01$, 11%, Fig. 3).

The effect of both M and MSH on CWD quality was relatively similar except for the less decayed stumps and snags (Figs. 2 and 3). The less decayed snags decreased due to M (–18%), and increased due to MSH (20%). However, these changes were not significant ($p = 0.052$, $p = 0.075$). Both M and MSH decreased, although not significantly, the volume of middle decayed logs (M: $p = 0.234$, –31%; MSH: $p = 0.164$, –34%). Both treatments also decreased highly decayed stumps (M: $p = 0.005$, –69%; MSH: $p = 0.001$, –94%) and highly decayed logs, although the effect of M ($p = 0.042$, –39%) was slightly more significant than of MSH ($p = 0.063$, –52%). MSH significantly decreased the volumes of less decayed and coniferous stumps ($p < 0.001$).

Table 1. The mean volumes ± SE of CWD before and after logging combined with residue harvesting (bLRH and aLRH, all sample plots combined), after mounding (aM) or after mounding combined with stump harvesting (aMSH).

Series	LRHM & LRHMSH				LRHM		LRHMSH	
Treatment	bLRH (n = 10)		aLRH (n = 10)		aM (n = 5)		aMSH (n = 5)	
	$m^3 ha^{-1}$	SE	$m^3 ha^{-1}$	SE	$m^3 ha^{-1}$	SE	$m^3 ha^{-1}$	SE
Snags	9.43	*1.77*	6.61	*1.28*	5.40	*1.39*	6.70	*1.87*
Logs	7.01	*1.10*	7.36 (0.23[a])	*0.89*	8.50 (0.27[a])	*0.72*	7.79 (0.15[a])	*2.08*
Snags and logs	16.44	*2.18*	13.96 (0.23[a])	*1.38*	13.90 (0.27[a])	*1.23*	14.42 (0.15[a])	*3.49*
Stumps	2.27	*0.32*	10.15 (8.56[a])	*0.48*	10.32 (8.57[a])	*0.96*	4.25 (2.80[a])	*0.42*
Total CWD	18.71	*2.36*	24.11 (8.79[a])	*1.40*	24.22 (8.84[a])	*1.96*	18.69 (2.95[a])	*3.49*

[a] Proportion ($m^3 ha^{-1}$) of new CWD produced of living woods a by-product of logging.

Table 2. The change of the mean volumes ($m^3 ha^{-1}$, %) of CWD before and after logging combined with residue harvesting (bLRH or aLRH, all sample plots combined), after mounding (aM) or after mounding combined with stump harvesting (aMSH). The CWD contains also new CWD produced by logging.

Series	LRHM & LRHMSH		LRHM		LRHMSH	
Treatment [a]	bLRH–aLRH (n = 10)		aLRH–aM (n = 5)		aLRH–aMSH (n = 5)	
	$m^3 ha^{-1}$	%	$m^3 ha^{-1}$	%	$m^3 ha^{-1}$	%
Snags	–2.82**	*–29.91*	–1.36*	*–20.12*	0.24	*3.76*
Logs	0.35	*5.03*	0.68	*8.63*	0.85	*12.37*
Snags and logs	–2.47***	*–15.05*	–0.68	*–4.69*	1.08	*8.09*
Stumps	7.87***	*346.27*	0.05	*0.47*	–5.77***	*–57.56*
Total CWD	5.41***	*28.90*	–0.64	*–2.56*	–4.67**	*–20.00*

The asterisk markings show the level of significance in a linear mixed model comparing the mean volumes in the specific plots ($p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***).
[a] The abbreviations with a line in between indicate the change between the specific measurement times.

4 Discussion

The results support our first hypothesis: the volume of CWD, stumps excluded, was reduced by 15% in LRH. Several other studies have pointed out decline of CWD after clear-cutting (Zarnowitz and Manuwal 1985, Eckerberg 1988, Fridman and Walheim 2000). However, often the effects of different components of logging procedure have not been studied separately. Hautala et al. (2004) indicated that after the logging only, the decline in the volume of logs was only 7.8% in South Eastern Finland.

Additionally, some new CWD was produced of living wood as a by-product of logging. The significant decrease in the volume of snags was expected to increase the amount of logs. However, despite the decrease in the number of snags and the formation of new fresh logs, the total amount of logs barely changed, and the combined volume of snags and logs decreased significantly. According to measurements and field observations there were two processes causing the combined loss during LRH; destruction by machines and harvesting of less decayed snags and logs. The observed harvesting of CWD (besides stumps) in logging might have happened by accident, but according to Rudolphi and Gustafsson (2005), a considerable amount of retention logs can be also intentionally removed during residue harvesting.

Secondly, our results support the hypothesis that the more intense the soil preparation treatment is, M vs. MSH, the more CWD is reduced. MSH significantly decreased the volume of total

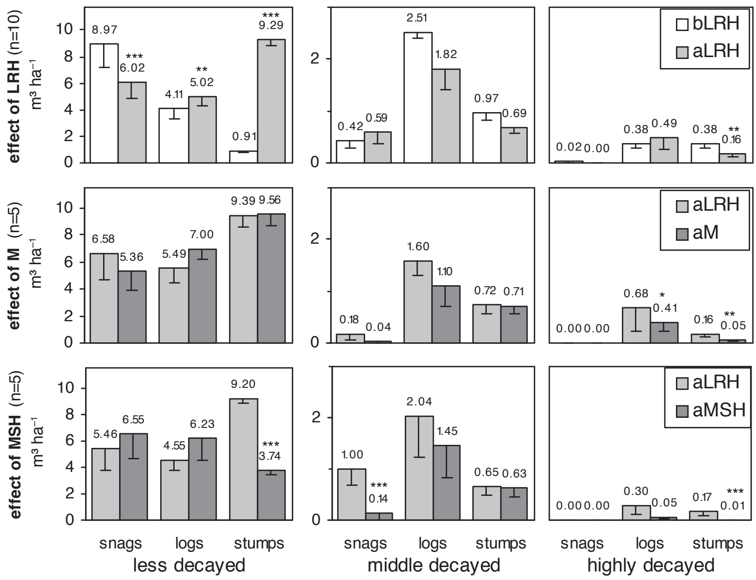

Fig. 2. The effect of treatments on mean volumes ± SE of CWD on sample plots by decay class groups. The volumes are shown before and after logging combined with residue harvesting (bLRH or aLRH, all sample plots combined), after mounding (aM) or after mounding combined with stump harvesting (aMSH). The asterisk markings show the level of significance in a linear mixed model comparing the mean volumes in the specific plots (p ≤ 0.05 = *, p ≤ 0.01 = **, p ≤ 0.001 = ***).

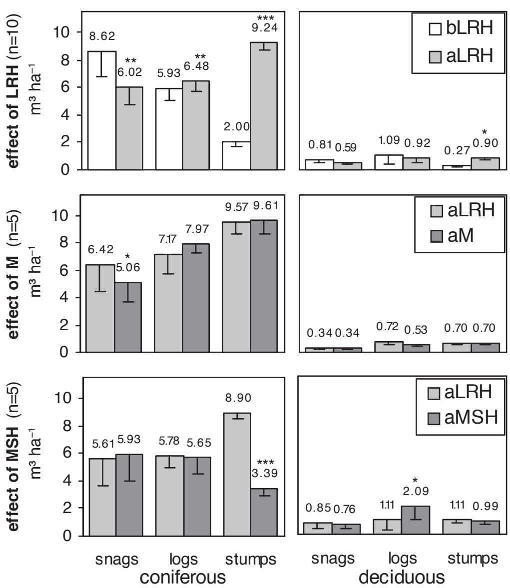

Fig. 3. The effect of treatments on mean volumes ± SE of CWD on sample plots by tree species groups. The volumes are shown before and after logging combined with residue harvesting (bLRH or aLRH, all sample plots combined), after mounding (aM) or after mounding combined with stump harvesting (aMSH). The asterisk markings show the level of significance in a linear mixed model comparing the mean volumes in the specific plots (p ≤ 0.05 = *, p ≤ 0.01 = **, p ≤ 0.001 = ***).

CWD, but it was only due to stump volume reduction. However, it is notable that the significant reduction in snag volume due to M was opposite to the effect of MSH, in which the living retention trees died quickly and unexpectedly, forming new snags (see addition in less decayed snags: Fig. 1) in four out of the five sample plots. This might be a consequence of damage to roots of living trees during stump harvesting.

In the study by Hautala et al. (2004), the effect of soil preparation was studied by monitoring harrowed stands. Harrowed area was estimated to comprise approximately 50% of the ground surface, which is slightly less than the impact of our treatment series including M (61% of the surface was damaged). Harrowing destroyed 57% of the volume of logs (Hautala et al. 2004), which is far more than the effect of the treatments in this study. The difference between the results of Hautala et al. (2004) and our study suggest that soil preparation, such as M, is less destructive for logs than continuous soil preparation, such as harrowing.

The above ground stump wood represented 43% of the total volume of CWD on the plots that were treated with M. However, the volume of remaining stumps was only 23% of the volume of CWD on the plots in which stumps had been harvested. The average amount of harvested new stumps was 5.8 m^3 ha^{-1}. According to Hakkila (1972), the above ground stump wood of spruce and pine trees represents only 15% of the volume of stump root system (down to roots of 5 cm in diameter). Accordingly, the actual loss in stump wood averaged 38 m^3 ha^{-1}. This amount is considerably less than the usual yield. The average yield in stump harvesting by UPM is approximately 80 m^3 ha^{-1} (Backlund, C. 2007 pers. comm.). According to the prevailing instructions of stump harvesting, there should be left at least 20 fresh stumps (diameter ≥15 cm) per hectare, preferably of various tree species (Äijälä et al. 2005). In the plots there were left on average 97 new stumps per hectare. Accounting for this, our results from less intense stump harvesting indicate that the effects of MSH in general may have more severe consequences on CWD.

Our results partially supported our third hypothesis as well. We hypothesized that LRH and soil preparation treatments reduce snags, highly decayed CWD and deciduous CWD in particular. For part of snags the results were in accordance with the hypothesis. Snags decreased significantly due to LRH and they were most vulnerable also in M. The vulnerability of highly decayed CWD was also evident. Highly decayed stumps were significantly decreased by all treatments. Additionally, the decrease was clear, although insignificant, in nearly every case of middle and highly decayed logs. As for deciduous CWD, no significant difference between the tree species was observed. However, the methodology caused some difficulties interpreting the results for some of the tree species. The population of deciduous CWD was small and the study setup did not include individually marked CWD population.

Hautala et al. (2004) studied the effects of logging and harrowing on the log quality within a marked log population. Their results indicate that the volume of both less and highly decayed, as well as deciduous and coniferous logs, significantly decreased due to the treatments. Hautala et al. (2004) also concluded that the deciduous and highly decayed CWD are the most vulnerable CWD categories. Correspondingly, McCarthy and Bailey (1994) found that highly decayed logs with diameter ≥2.5 cm were easily crushed in a harvest process.

In unmanaged forests, the CWD consists mainly of logs, snags and broken snags with mean diameter of 20–39 cm (Siitonen et al. 2000). In managed forests, however, the CWD consists mainly of stumps and small sized logging residues (Siitonen et al. 1995). According to Söderström (1988) managed stands may contain even more highly decayed CWD than unmanaged stands due to the stump wood. Therefore stumps may often be of great importance for epixylics and many other organisms in managed forests. Stumps play an important role in maintenance of plant (Kennedy and Quinn 2001) and lichen species richness (Caruso et al. 2008), and they are an equally preferable substrate for epixylics as logs in managed forests (Andersson and Hytteborn 1991).

The importance of stumps in the forest ecosystem emphasizes the need for compensating the loss of above ground stump wood (mainly due to stump harvesting) and loss of well decayed CWD on a landscape level. A quick way to improve the ecological sustainability of forest management would be to preserve large enough forest patches and CWD in various CWD categories on a landscape level (Hokkanen et al. 2005). For example, one effective way would be leaving these patches in locations with an initially high amount of CWD (Vanha-Majamaa and Jalonen 2001, Hautala et al. 2004). Retention patches might be the only way to conserve drought-sensitive and late-succession species on both stand and landscape level over the regeneration period.

5 Conclusions

Our study shows that LRH and subsequent M treatments do not immediately decrease the amount of CWD on a regeneration stand. However, the old CWD is reduced and its quality is changed by the treatments. The new CWD, consisting mainly of the new stumps, partly compensates the loss of old CWD. Our results show that even a partial stump harvesting (removing 66% of stump volume), may remove as much as one fourth of the potential CWD remaining after soil preparation. This may be an underestimation, while it is based on study stands including relatively large amount of other CWD besides stumps.

Intermittent soil preparation in spots seems to be a less destructive method for CWD than continuous harrowing or stump harvesting. More research is still needed to develop forest management treatments to minimize their negative ecological impacts.

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Appendix 1. The description of the decay classes. The classification is based on the 9th National Forest Inventory (FFRI 1998) with few additions from Hottola and Siitonen (2008): The decay class 1 has been divided into 1a and 1b, and decay class 5 into 5a and 5b (only the logs).

Decay class	Description
Snags and stumps	
1a	Tree has just died, the phloem is fresh, a knife penetrates only few millimeters into it, bark is intact.
1b	Wood is hard, a knife penetrates only few millimeters into it, bark is intact.
2	Wood is softened, a knife penetrates on average 0.5–2 cm into it, bark has started to drop off (conifers).
3	Wood is soft, a knife penetrates on average 3–5 cm into it, bark has dropped off (conifers).
4	Wood is soft, a knife penetrates into it relatively easily, a snag sways.
5	Wood is very soft, a knife penetrates into it very easily, a snag hardly stands.
Logs	
1a	Tree has died in a year, the phloem is fresh, a knife penetrates only few millimeters into it, bark is intact.
1b	Wood is hard, a knife penetrates only few millimeters into it, bark is intact.
2	Wood is softened. A knife penetrates on average 0.5–2 cm into it and its bark has started to drop off (conifers).
3	Wood is soft, a knife penetrates on average 3–5 cm into it and its bark has dropped off (conifers).
4	Wood is soft, a knife penetrates it relatively easily.
5a	Wood is very soft, a knife penetrates it very easily, epixylics often cover the log.
5b	Wood is very soft, a knife penetrates it very easily, epixylics often cover the log, log has lost its shape.