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The Volume and Composition of Dead Wood on Traditional and Forest Fuel Harvested Clear-Cuts

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Logging residue and cut stumps are increasingly used as a renewable energy source known as forest fuel. Forest fuel harvesting obviously reduces the volume of dead wood and is likely to alter the dead wood composition, but the magnitude of the change is not known. Such information is important for the evaluation of the effects of forest fuel harvesting on biodiversity because a large proportion of forest dwelling species are directly dependent on dead wood. We measured the volume and characteristics of all dead wood units with a minimum diameter of 2 cm and a minimum length of 20 cm on 10 forest-fuel harvested and 10 traditional (control) clear-cuts. The total volume of dead wood at forest fuel harvested and control clear-cuts was 26.0 and 42.3 m^3/ha, respectively. The volumes were much greater than expected suggesting that the volume of dead wood on clear-cuts has been underestimated in previous studies. Forest fuel harvested clear-cuts had 42% less branches and 81% less cut stumps than control clear-cuts but there were no differences in the volume of logs and pieces of logs, snags or roots. The volume of fine woody debris was negatively affected by forest fuel harvesting. We conclude that fine woody debris and cut stumps form a considerable resource on clear-cuts that is reduced by forest fuel harvesting. These components of dead wood have potential to be of importance in managed forests and thus deserve more attention in future biodiversity studies.

Keywords dead wood, forest fuel harvesting, fine woody debris (FWD), clear-cut
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1 Introduction

One of the greatest differences between managed and natural forests is the volume and composition of decaying wood (Siitonen 2001a, Gibb et al. 2005, Jönsson and Jonsson 2007). The volume of coarse woody debris (CWD) in natural forests can be up to 25–30 times higher compared to that in managed forests. In contrast, the volume of fine woody debris (FWD) with a diameter less than 10 cm may be even higher in managed than in natural forests (Siitonen et al. 2000, Siitonen 2001b).

So far, the majority of research has focused on the volume and importance of CWD. This is because the occurrence of several endangered species is associated to high volumes of CWD and to large-diameter logs and snags (Siitonen 2001a, 2001b). Recently, some studies have also pointed out the importance of FWD for biodiversity (Kruys and Jonsson 1999, Kruys et al. 1999, Norden et al. 2004, Selonen et al. 2005, Küffer et al. 2008). When the overall volume of dead wood is low, the same volume of dead wood composed of smaller but more numerous pieces may actually support more species than dead wood composed of few larger pieces (Kruys and Jonsson 1999). Therefore, the importance of FWD is likely to be particularly high in managed forests where a typical amount of CWD (according to the National Forest Inventories of Sweden and Finland) is about 5 m^3/ha. FWD is unlikely to substitute CWD when some specialized rare or red-listed species are concerned (Kruys and Jonsson 1999), but it may harbor some species that do not occur on CWD (Küffer et al. 2008). Thus, FWD is also likely to have an independent biodiversity value.

Current climate and energy politics as well as the interests of forestry companies are all placing more pressure to increase the use of wood-based, renewable energy sources (Hakkila 2004, Koistinen and Äijälä 2005). The greatest future potential is seen in forest chips (Hakkila 2004) which are produced from logging residue from the clear-cuts and small-diameter wood from forest thinnings. Development of forest fuel technologies has also increased the removal of stumps and roots from clear-cuts (Hakkila 2004).

So far, little research has been conducted on the effects of increasing forest fuel harvesting on the volume, composition and diversity of dead wood. The effects have been studied mostly from the perspective of forest management and thus especially the long term effects on the forest ecosystems are poorly known (Hakkila 2004, Koistinen and Äijälä 2005, Rudolphi and Gustafsson 2005, Äijälä et al. 2005).

On Swedish clear-cuts, Rudolphi and Gustafsson (2005) estimated that forest fuel harvesting resulted in removal of 65% of the volume of branches and tree tops and 29% of the volume of logs. The great majority of removed logs were of small diameter (<15 cm); only 17% of logs with larger diameter (>15 cm) were removed in forest fuel harvesting.

It seems that in Fennoscandian forests the majority of the dead wood removed from the clear cuts in forest fuel harvesting consists of fine woody debris. FWD also forms the majority of the dead wood in general both on clear-cuts and in mature managed forests (Gibb et al. 2005). In Swedish mature, managed coniferous forests, where all pieces of dead wood with a minimum diameter of 5 cm and a minimum length of 30 cm were measured, 63% of the pieces were FWD (Kruys et al. 1999).

The effects of removing stumps are even more poorly known than those of removing logging residue. The potential volume of wood gain from stumps has been estimated to reach even 100 m^3/ha (including below ground volume). However, the exact volume of stumps is still poorly known (Hakkila 2004).

Our aim was to determine the effects of forest fuel harvesting on the volume and composition of dead wood on clear-cuts. The study was particularly designed to obtain detailed information on the dead wood types (cut stumps and fine woody debris) that are most likely to be affected by forest fuel harvesting. The aim was also to provide detailed information concerning the occurrence of these dead wood types at forest regeneration areas in general.

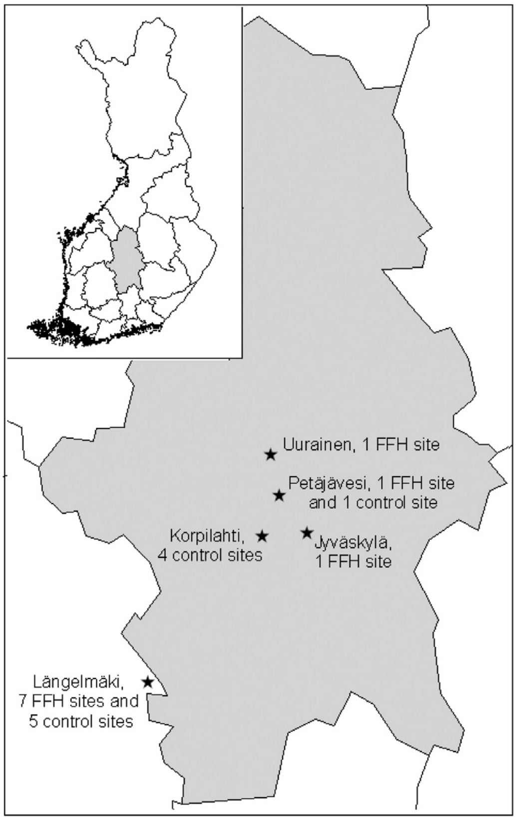

Fig. 1. The location of study sites and the number of the forest-fuel harvested (FFH) and traditional clear-cuts per different municipalities. (© National land survey of Finland 315/MML/10).

2 Materials and Methods

2.1 Study Sites

The research area was located in the municipalities of Längelmäki, Korpilahti, Petäjävesi, Jyväskylä and Uurainen in Central Finland (Fig. 1). The studied forests were owned by Metsähallitus (Finnish Forest and Park Service), forest company UPM and city of Jyväskylä. The study sites were Norway spruce (*Picea abies*) dominated mesic forests which had a history of standard commercial management and which had been clear-cut either in 2001 or in 2002. The sites selected were four or five years old because the study reported here was a part of a larger research project in which the fungal diversity at clear-cuts was also explored (Anni Markkanen, Tero Toivanen, Janne S. Kotiaho and Panu Halme, manuscript).

The study was conducted on 20 sites. From the pool of clear-cuts provided by the land-owners (representing correct forest type and logging year), we selected randomly 10 clear-cuts from which logging residue and stumps had been harvested and 10 traditional (control) clear-cuts where no forest fuel harvesting had taken place. Many of the latter sites had been prepared by mounding treatment (Sutton 1993) after cutting. The size of the clear-cuts varied from 0.5 to 5 ha. After clear-cutting, forest companies had not retained information about the pre-logging stand structure, but based on the size (mean diameter 24.7 cm) and number of cut stumps (on average 662 stumps / ha) at the control clear-cuts, the sites had been typical mature managed forests of southern Finland (Siitonen et al. 2000). The average diameter of cut stumps on forest fuel harvested sites was 19.9 cm due to forest fuel harvesting being biased towards larger stumps while small stumps are usually retained. The volume of old dead wood (see below and results) did not differ between forest fuel harvested and control clear-cuts indicating that the sites had a similar management history.

2.2 Sample Plots and Measurements of Dead Wood

Field work for the research was conducted in May–June 2006. On each of the 20 study sites, four sample plots of 10 m × 10 m were randomly allocated. Thus, on each study site the volume of dead wood was measured from an area of 400 m^2.

To establish the sample plots, a focal point was first established on the center of the clear-cut. From the focal point, four compass directions (1–360°) were randomly selected. Depending on the size of the clear-cut, either 30 or 50 m were walked to the randomly selected compass direction. At the end point of the 30/50 m line, a sample plot was established so that the end point became the north-east corner of the plot. If the shape of the clear-cut did not allow establishing four sample plots from one focal point, we used two focal points with two plots established from each point. The sample plots were not established on locations that distinctly differed from the surrounding clear-cut, such as on roads or on rocks. The sample plots also did not overlap or touch each other. If a plot was about to be placed on distinctly different ground or to touch another plot or the edge of the clear cut, a new compass direction was selected and the whole process was repeated until all four plots were appropriately placed.

On the 10 x 10 meters sample plots, we measured all pieces of dead wood which had a minimum large-end diameter of 2 cm and a minimum length of 20 cm. Only the pieces whose larger end was located inside the sample plot were measured. These pieces were measured as a whole regardless of the location of their smaller end. Stumps standing on the border of the sample plot were included. Individual pieces of dead wood that had sunk under the ground due to the mechanical treatment of the clear-cut or that were bound to the ground were not measured.

The dead wood pieces were divided into six different categories and measured accordingly; 1) branches, 2) logs and pieces of logs (also including tree tops), 3) stumps, 4) pieces of crushed stumps, 5) roots and pieces of roots, 6) standing dead trees (snags) and high stumps.

Of branches, logs, small standing trees and roots of regular shape, the diameter of both ends and length was measured. Of stumps, the height from the ground level and diameter of the whole stump at the cutting surface was measured. There were also some unbroken stumps that were pulled off the ground, being obviously leftovers from the forest fuel harvesting. These were measured in a similar way, estimating their height from the ground level. If stumps had been crushed so that their cutting surface had broken into wedges the diameter of a whole cutting surface was estimated as well as the proportion of the wedge (for example 1/3). Dead wood pieces that were difficult to measure accurately (due to their irregular shape) were weighed with an accuracy of 0.01 kg with a digital balance. The diameter of big standing dead trees was measured at breast height (1.3 m) and the height was estimated with a hypsometer.

In addition, we measured the decay stage of the dead wood pieces according to Renvall (1995). Based on the decay stage, we classified whether the dead wood originated from the pre-clear-cut period ("old dead wood") or from the current clear-cut or the post-clear-cut period (some fallen retention trees). Pieces representing decay stages 3–5 were interpreted to represent old dead wood. However, in the case of branches, roots and pieces of roots, that may decay faster than the larger-diameter dead wood, all pieces were classified as originating from the current clear-cut since there were no reasons to assume otherwise.

2.3 Calculations and Statistical Analyses

In total, more than 11 000 pieces of dead wood were measured. Based on the measurements taken in the field, we calculated the volume of different dead wood pieces. The volume of stumps was calculated with the formula of a cylinder ($V = \pi \times h \times r^2$, in which h = height and r = top diameter) and the volume of branches, roots, pieces of logs and small standing dead trees was calculated with the formula of a truncated circular cone ($V = 1/3 \times \pi \times h \times (r_1^2 + r_1 \times r_2 + r_2^2)$, in which h = length/height, r_1 = thick-end diameter, and r_2 = thin-end diameter). The volume of big standing dead trees and unbroken logs was calculated based on their DBH and height using the species-specific volume equations (Laasasenaho 1982).

The volume of weighed pieces of dead wood was calculated using the average density of the wood pieces. The value used was 509.5 kg/m^3. The average density was calculated by measuring the volume of 13 randomly chosen weighed pieces of dead wood. This measure was taken by sinking these pieces one at a time into a water tank and measuring the volume that it replaced.

The volume and composition of dead wood were compared between forest fuel harvested and control clear-cuts. If data followed normal distribution and group variances did not differ, we used independent samples t-test; otherwise Mann-Whitney U-test was used. We used SPSS 15.0 – for Windows software in the analyses.

Table 1. The volume (m^3/ha; means and standard deviations) of different dead wood types at the forest fuel harvested (FFH) and traditional clear-cuts and test statistics for the effects of forest fuel harvesting. Test statistics refer to independent samples t-test (t_{18}) or to Mann-Whitney U-test (Z, N1 = N2 = 10). Statistical tests were not performed considering snags due to the low number of their occurrences in the data.

Type of dead wood	FFH clear-cuts	Control clear-cuts	Test statistics	p
Total	26.0 ± 19.8	42.3 ± 29.5	Z = –1.663	0.096
Logs and pieces of logs	16.8 ± 18.9	20.8 ± 26.9	Z = –0.454	0.650
Stumps	2.29 ± 1.97	12.0 ± 3.74	t_{18} = 7.292	< 0.001
Branches	2.40 ± 1.50	3.97 ± 1.56	t_{18} = 2.306	0.033
Stump pieces	1.22 ± 0.79	1.40 ± 1.09	t_{18} = 0.310	0.760
Roots	3.00 ± 1.48	3.52 ± 2.72	t_{18} = 0.533	0.601
Snags and high stumps	0.33 ± 1.02	0.70 ± 2.10		
FWD	5.93 ± 2.67	9.67 ± 3.38	t_{18} = 2.749	0.013
CWD	20.1 ± 17.8	32.7 ± 27.9	Z = –1.512	0.131
CWD as defined by NFI	13.8 ± 17.0	15.6 ± 25.1	Z = –0.454	0.650
Fresh dead wood	21.3 ± 19.4	39.3 ± 30.5	Z = –2.268	0.023
Old dead wood	4.77 ± 5.44	3.01 ± 2.47	Z = –0.076	0.940

3 Results

3.1 Total Volume of Dead Wood

The total volume of dead wood was relatively high at both forest fuel harvested and control clear-cuts (Table 1). Moreover, the volumes are still likely to be underestimates because our stump measurements included only the above-ground part. At the forest fuel harvested clear-cuts, on average 72.0% (range 59–89%) of dead wood consisted of CWD (≥10 cm diameter) and 28.0% (range 11–41%) of FWD (<10 cm diameter) (Table 1). At the control clear-cuts, the proportion of CWD was 71.6% (range 50–88%) and the proportion of FWD 28.4% (range 12–50%) (Table 1). However, the volume of CWD that fulfilled the criteria used in the majority of dead wood studies and national forest inventories (≥10 cm diameter and ≥1.3m length; thus excluding stumps and most pieces of logs) was substantially lower (Table 1).

The total volume of dead wood tended to be lower at the forest fuel harvested clear-cuts than at the control clear-cuts and the volume of FWD was significantly lower at the forest fuel harvested clear-cuts than at control clear-cuts. The volume of CWD did not significantly differ between the forest fuel harvested and control clear-cuts (Table 1).

3.2 The Origin of Dead Wood

The majority of the dead wood was classified as fresh dead wood (decay stages 1–2). Fresh dead wood accounted for 82% of the dead wood volume at the forest fuel harvested clear-cuts and 89% at the control clear-cuts. This component of dead wood was likely to originate from the current clear-cut (e.g. residual logs, stumps and branches) or to be formed after the clear-cut (fallen retention trees). The volume of fresh dead wood was significantly lower at the forest fuel harvested clear-cuts than at the control clear-cuts (Table 1).

Old dead wood material that represented decay stages 3–5 accounted for 18% of the volume of dead wood at the forest fuel harvested clear-cuts and 11% at the control clear-cuts. This component consisted mainly of old logs. The volume of old dead wood did not differ between the forest fuel harvested and control clear-cuts (Table 1).

3.3 The Composition of Dead Wood

In the total volume of dead wood, logs and pieces of logs played the most important role forming on average 47% of the dead wood at the forest fuel harvested clear-cuts and 36% at the control clear-cuts (Fig. 2). The volume of logs did not differ between the forest fuel harvested and control clear-cuts (Table 1). Although CWD logs accounted for the majority of the volume of logs (76% at the forest fuel harvested and 61% at the control clear-cuts), most of the logs were of FWD (81% of the number of logs at the forest fuel harvested and 88% at the control clear-cuts). The number of FWD logs was significantly lower at the forest fuel harvested clear-cuts ($t_{18} = 2.339$, $p = 0.031$) and the volume of FWD logs tended to be lower at the forest fuel harvested clear-cuts ($t_{18} = 1.930$, $p = 0.070$).

At the forest fuel harvested clear-cuts, only 10% of dead wood consisted of stumps but at the control clear-cuts the proportion of stumps was 35% (Fig. 2). The volume of stumps was significantly lower at the forest fuel harvested clear-cuts (Table 1) being only 19% of that at the control clear-cuts. The average volume of branches was lower at the forest fuel harvested clear-cuts (Table 1) being only 58% of that at the control clear-cuts. The volume of roots and pieces of stumps did not differ between the forest fuel harvested clear-cuts and control clear-cuts (Table 1).

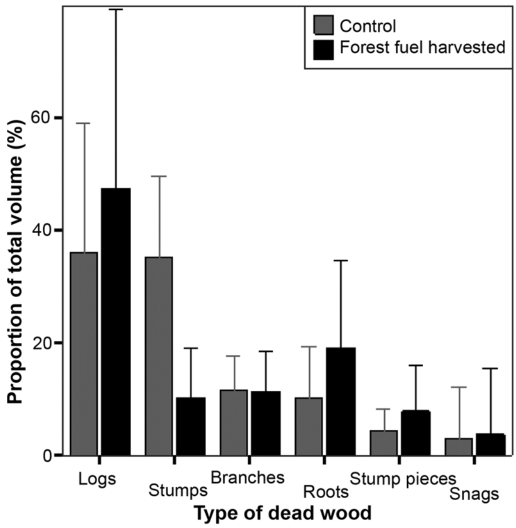

Fig. 2. The percentages (%) of different dead wood categories at the forest fuel harvested and control clear-cuts. Data presented are means and standard deviations.

4 Discussion

In this study, the volume of dead wood at clear-cuts was substantially higher than expected (26.0 m^3/ha at forest fuel harvested and 42.3 m^3/ha at control clear-cuts). However, if we had measured the volume according to the criteria of national forest inventories, the values would have been dramatically lower (13.8 and 15.6 m^3/ha, respectively) and roughly equal to those measured at clear-cuts in Sweden (Gibb et al. 2005). Therefore, it appears that the results of dead wood measurements are strongly affected by the accuracy of the method, and that the volume of dead wood at clear-cuts (and at the following early successional stages) is much higher than previously thought. The effect of neglecting pieces that are of <10 cm diameter and <1.3 m length is likely to be particularly strong at clear-cuts, because cut stumps, short pieces of logs and FWD are likely to comprise a substantially larger proportion of the dead wood on clear-cuts than in mature forests.

The smallest pieces of dead wood have frequently been neglected in the research focusing on the volume and diversity of dead wood in boreal forests (e.g. Siitonen et al. 2000, Lilja et al. 2005, Siitonen et al. 2009). However, FWD, such as small-diameter logs, branches and roots, had a substantial contribution to the total volume of dead wood: on average 28% of the dead wood was of <10 cm diameter and at some sites the proportion of FWD was even 50%. The volume of FWD, as well as the volume of branches which are the most important component of FWD, was lower at the forest fuel harvested sites.

So far there is still little evidence on the importance of FWD for biodiversity. FWD may not be a crucial resource for rare or endangered species but it could still be important for the more common species that nevertheless play a key role in the functioning of the ecosystem (Kryus and Jonsson 1999). Some of the common species may even be specialized on utilizing FWD (Küffer et al. 2008). FWD is an evenly spread resource and thus temporarily available everywhere at the clear-cut but small pieces of dead wood are likely to decay faster than large ones (Hyvönen et al. 2000, Holeksa et al. 2008). However, due to absence of long-term monitoring and modeling work it is difficult to predict the long term persistence of FWD on clear-cuts. The long-term importance of FWD for biodiversity should be more carefully considered in future studies, especially when investigating the effects of forest fuel harvesting.

It has been shown that FWD forms an important nutrient source on the clear-cuts after the needles, which are a nutrient-rich but short lasting resource, have decayed (Hyvönen et al. 2000, Thiffault et al. 2006). In some conditions, the removal of logging waste seems to negatively affect the growth of the next tree generation (Egnell and Lejon 1997, Jacobson et al. 2000). Considering the relatively high volume of FWD observed in this study, decreased nutrient status due to its removal appears likely.

A significant proportion of dead wood was formed by the above ground biomass of stumps, particularly at the control clear-cuts. In addition, our method of calculating the volume of stumps is likely to underestimate their volume, and their contribution to the total dead wood volume may be even higher than estimated here. The volume of stumps was dramatically reduced by harvesting and thus their importance in sustaining biodiversity in managed forests should be better understood before stump removal becomes a widespread practice. There seems not to be much species showing a preference for cut stumps (Hottola 2009), but the stumps are likely to provide an important resource in managed forests where e.g. large logs are virtually absent.

The majority of the dead wood at both forest fuel harvested clear-cuts (47%) and control clear-cuts (36%) consisted of logs. The category also includes tree tops and smaller pieces of logs and thus most of the dead wood pieces in the category were still of small diameter. However, the few large logs, that typically represented fallen retention trees, made a major contribution to the volume estimates. The volume of logs did not differ between the forest fuel harvested and the control clear-cuts, but there was a large variation among study sites. Large logs are typically scarcely distributed on clear-cuts, and the variation in the volume estimates was further increased by the small size of our sample plots (a large log of 1 m^3 volume would have made a contribution of 25 m^3/ha to the estimate).

The variation caused by large logs also explains the result that total volume of dead wood only tended to differ between the forest fuel harvested and control clear-cuts. However, the main aim of our study was to explore the volume and composition of those dead wood types that are likely to be removed in forest fuel harvesting (i.e. stumps, branches and small logs). The sample plots were designed to obtain realistic and detailed results for these particular dead wood types. The variation among study sites was notably lower in these dead wood categories, and forest fuel harvesting had distinct effects on these resources.

The volume of old dead wood was generally low at the study sites and did not differ between the forest fuel harvested and control clear-cuts. The volumes (4.7 m^3/ha at the forest fuel harvested and 3.0 m^3/ha at the control clear-cuts) are fairly typical for managed forests of southern Finland. However, the volumes before the clear-cut have probably been slightly larger, because some old dead wood is often destroyed during clear-cutting (Hautala et al. 2004) and because the oldest fraction of dead wood may have completely decayed during the five years between the clear-cut and our inventories. Forest fuel harvesting could potentially have a negative effect on the volume of old dead wood, because more activity on the clear-cut means more damage to the remnant dead wood. However, we did not find such a difference. This may be due to the initially low volume of dead wood and large variation, which together make it difficult to detect significant effects. In addition, forest fuel harvesting may not have so dramatic effects on the old dead wood as e.g. soil scarification (Hautala et al. 2004), and it is unlikely to lead to complete loss of the old logs, although they may degrade into smaller pieces during the activities.

To conclude, there is a high volume of dead wood available during the first years following clear-cutting. However, it is still only a small fraction of that formed by natural stand-replacing disturbances (Siitonen 2001a) to which saproxylic species preferring open habitats have adapted. Therefore, the dead wood on clear-cuts may not support substantial numbers of rare or red-listed species, but it is nevertheless likely to be an essential resource for those saproxylic species that are still common in managed forests. After forest fuel harvesting, the volume of dead wood is still relatively high, but there is an obvious reduction in the dead wood components that are the main targets of harvesting: stumps, branches and fine woody debris in general. This calls for detailed studies on the importance of stumps and branches for different saproxylic species groups.

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