Effects of forest fire on production of down woody debris in Aust-Agder county in Norway.

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Table of contents

Preface

This master thesis has been written at the Norwegian University of Life Sciences, at the Department of Ecology and Natural Resource Management, in the specialist field of forestry. It is part of a project managed by The Norwegian Forest and Landscape Institute. The work undertaken for my thesis has been of the greatest interest to me. I found it to be a fascinating experience to work in the forests that had burned, as it was very different to any forest I had ever visited before. It is also very motivating to be part of a project outside the university, specifically "Ecological effects of forest fires"at The Norwegian Forest and Landscape Institute.

Firstly, great thanks to my tutors associate professor Jon Frank at the Norwegian University of Life Sciences, and to scientist Per Holm Nygaard at The Norwegian Forest and Landscape Institute. They have inspired me by motivating and interesting debates, helped me find relevant literature, they have answered all my queries with great patience, and given me very constructive feedback and advice. I also want to thank Per Holm Nygaard, scientific engineer Roald Brean and scientist Harald Bratli at The Norwegian Forest and Landscape Institute for helping me with fieldwork. I want to thank The Norwegian Forest and Landscape Institute for their economic assistance. Finally, I need to thank the landowners, for allowing us to lay sample plots on their land.

I would also like to thank my family and friends for a lot of help during the writing of this paper. A special thanks to my mother-in-law Karin Bockelie for babysitting Sunniva, and my parents Øystein and Tone Vestmoen for helping me with fieldwork, babysitting Sunniva and proof-reading. Another special thanks to Stian Bockelie for helping me with fieldwork and for fixing my computer problems. And lastly a big thanks to Lisa McDowell, Patricia Dillon and Marte Qvenild for proof-reading.

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Abstract

Forest fires have played an important role in structuring the boreal conifer forest. Forest fires produce dead wood, which is important for biodiversity. Many species, including Red List species, are dependent on dead wood in general, and dead wood specifically from trees killed by forest fires. Human activities alter the natural forest cycle. Logging activities alter the forest by removing trees, and as a result much of the coarse woody debris (CWD) disappears. Fire suppression further reinforces this problem, as forest fires are effective producers of dead wood.

This thesis outlines the volume of down woody debris in forests that have been logged and burned (LB), logged but not burned (LNB), not logged and not burned (NLNB), and not logged and burned (NLB). Data was collected in Scots pine (P) and oak (O) dominated forests in the area around Mykland in Aust-Agder county in Norway. The thesis also connects the severity of the fire to the volumes found, and looks at down woody debris from before the fire and down woody debris created by the fire. Site index is also discussed. The sample plots were laid out in a random fashion, and the line intersect method was used to gather data on down woody debris.

NLBO has the highest mean value, followed by NLBP. The smallest mean value is found in NLNBP and LNBP. In most of the area that was logged and burned, the fire severity was medium or high, in most of the area that was not logged and burned, with Scots pine, the severity was high, while in most of the area that was not logged and burned, with oak, the severity was low. The smallest volume of pre-fire down woody debris was found in LBP, while the largest volume of pre-fire down woody debris was found in NLBO. The smallest volume of post-fire down woody debris was found in NLBO, while the largest volume of post-fire down woody debris was found in LB. The fire produced a lot of down woody debris in LBP, NLBP but not in NLBO. There is more down woody debris in areas with a higher site index. Apart from logging and the fire, the differences in down woody debris can be explained by the different topography, soil, tree species and so on. Previous forestry practice also affect the present down woody debris volumes.

Key words: forest fire, down woody debris, severity of fire, pre-fire down woody debris, post-fire down woody debris, Norway, line intersect method, Scots pine, oak.

1. Introduction

Forest fires have always existed where there has been anything to burn (Kimmins 2004). Regional and local fire patterns vary. In total, most of the fire activity is found in the tropics (Dwyer et al. 2000a), with half of the fires detected on the African continent and over 70% within the tropical belt (Dwyer et al. 2000b).

Forest fires are regarded as an ecological factor that has strongly influenced the boreal coniferous forests (Esseen et al. 1997; Granstöm 2001; Gundersen & Rolstad 1998; Wein 1993). In a Norwegian landscape there have always been forest fires, and it is even possible to date fires back 370 000 to 700 000 years ago (Lauritzen et al. 1990).

Forest fires produce dead wood (Tinker & Knight 2000), which is important for biodiversity (Esseen et al. 1997; Siitonen 2001). Human disturbances, like logging activities, remove trees and as a result much of the coarse woody debris (CWD) disappears (Esseen et al. 1997; Tinker & Knight 2000; Östlund et al. 1997). “Decreased abundance and diversity of decaying wood have probably negatively affected more species than any other consequence of forest management in Fennoscandia” (Esseen et al. 1997 :35).

Interest in quantity of dead wood also relates to the atmospheric carbon cycle issues (Næsset 1999). Sustainable forest management can reduce CO_2 emissions, as forests function as global carbon sinks (Luyssaert et al. 2008). If a forest replaces itself after a fire, the net carbon storage through the fire cycle is zero (Kashian et al. 2006). Hence, forest fires will not be a problem with regards to atmospheric carbon balance in the long run, as long as the forest is allowed to re-grow.

Historically, foresters regarded CWD as a potential substrate for pest species, but this has recently changed. Now the focus in forest management planning is on the minimum levels that are needed to maintain biological diversity, in combination with a financial sound harvesting strategy (Jonsson & Kruys 2001). These minimum levels are becoming even more important as logging waste is removed from the forest to support the growing bio fuel industry (Erajaa et al. 2010; Riffell et al. 2011).

One of the goals of the Norwegian government is to stop the loss of biological diversity within 2010, and Norway has signed the Rio convention (Nordeng 2002). About 48% of the species on the Norwegian Red List of 2006 have habitats in forests, or in relation to forests. About 60% of the Red List species are dependent on deciduous forest or deciduous trees, while 40% live in conifer forest or conifer trees. Older forests, with a natural character and a lot of CWD in different stages of decomposition, are important for 20% of the Red List species (Kålås et al. 2006). Dead trees are important for biodiversity because many species depend on dead wood (Kuuluvainen 2000; Siitonen 2001). Saproxylic species are species that are dependent on woody material from wounded or dead trees everywhere where wood occurs. In the Nordic countries there are about 7500 saproxylic species (Jonsson & Siitonen 2011), and in Norwegian forests there are about 4500 species who live in or on dead wood, or who live off other species dependent on dead wood. Many of these are specialists, that is, they live in or on special niches. Many insects need CWD in different stages of decomposition to survive in the forest, and as a result, a variety of dead wood is a key substrate (Ehnström 1997). Down dead wood is necessary for 360 Red List species, which is approximately 22% of all forest Red List species. Among these there are 217 species of fungi, 132 species of insects, and a number of mosses.

It is generally accepted that many rare or endangered species are dependent on the particular conditions present after a fire (Skogsstyrelsen 1995), and that forest fires are important for species diversity (Esseen et al. 1997). Approximately 40 of the forest species on the 2006 Red List are fire dependent or fire profiteers (Ødegaard 2006). The Red List of 2006 contain 30 species with burns as main habitat, and about 60 of the threatened and near threatened species (mostly beetles) in the Red List of 2010 live on forest fire sites (Kålås et al. 2006; Kålås et al. 2010).

Among plants and animals some are dependent on, benefit from or are impaired by fires. These are called fire specialists, fire profiteers and fire losers, or fire-dependant and fire-related species (Esseen et al. 1997). Many of the plants and animals seen as fire dependent might actually really be fire tolerant, that is, fire might just be one of several possible factors that will set off the same response in the species.

Some plants have adapted to survive fire. Fire-resistant bark, reduced flammability of tissue because of high foliar moisture and low resin or oil content, protected buds and rhizomes are all strategic developments. Frequent or fire/heat induced flowering, seed production and seed dispersal or heat induced germinating are others (Kimmins 2004). One example is pine (fig. 1), who historically dominated areas that burned regularly. In some areas the fires are of low intensity, and the pines here often have tissue insulation from deadly temperature provided by thick bark, large and protected buds, relatively thick needles, deep rooting habit, and a crown structure that helps to disperse the heat, leading to less crown scorch. Self-pruning and lower branch shedding because of competition or fire, add to crown fire prevention. In areas with high severity fires the pine species often either store a seed bank in serotinous cones, or they recover after the disturbance by sprouting. Pines in areas with moderate fire intensity may do a combination (Fernandes et al. 2008). Larger trees should be able to survive more intense fires mainly because of thicker bark and higher position of the foliage (Beverly & Martell 2003; Kobziar et al. 2006; Ryan & Reinhardt 1988). Groven and Niklasson (2005) observed several fire scars on the trunk of Scots pine (*Pinus sylvestris*) trees, hence one may deduce that these trees survive fires. Zackrisson (1977) also found Scots pine trees that had survived several fires. Linder et al. (1998) found that tree mortality after a forest fire decreased with increasing diameter up to DBH $\geq$ 50 (diameter breast height), and then it increased again. Sidoroff et al. (2007) found a decrease in mortality as stand age grew, and with increasing bark thickness.

Figure 1. Survival of Scots pine after a forest fire (Photo: Synne M. Vestmoen 2009).

Geranium bohemicum (fig. 2) are rare, but often found on fire sites. *Geranium bohemicum* has heat-induced seed germination, so the fire must be deep-burning for the seeds to sprout

(Granstöm 2001). However, there are several sightings outside areas that have burned, so it may not be 100% dependent on fire to get the high temperatures the seeds need to sprout.

Figure 2. *Geranium bohemicum* on a fire site (Photo: Synne M. Vestmoen 2009)

Some plants have evolved in the opposite direction, like Lodgepole pine (*P. contorta var. latifolia*) (Despain 2001). They burn easily, creating severe fires that destroy everything that grows in the area. These species sprout and grow back fast, winning the competition for space and nutrients (Kimmins 2004).

Forest fires affect many aspects of the forest. The flow of energy and nutrients is different, and the microclimate change. The soil pH generally increases, while the stream water pH may decrease, altering the water system which influences plants and animals (Kimmins 2004). The fire in Froland, Aust-Agder, Norway, led to acidification, and pH values as low as 4.4 have been recorded (Høgberget 2010).

The fires in boreal forests are infrequent, and the fire season is short. The interval between wildfires varies (Niklasson & Granstrom 2000; Wallenius et al. 2005). Zackrisson (1977) found a mean interval before fire suppression of 80 years, but the mean interval since the last fire occurred is approximately 155 years. Wallenius et al. (2004) found a mean interval of 63 years. Engelmark (1984) found that the most common frequency interval was 81-90 year, but because of outliers the mean interval was 110 years. Groven & Niklasson (2005) found a mean interval of 24.6 years between 1511 and 1759, but these fires had been deliberately lit for agricultural purposes. After 1759 they found only three fires, the last one in 1822, reflecting the increased value of timber and the increase in mining activity.

Forest fires fluctuate throughout the year. Most of the fires occur in April, May and June, with the majority in May (Mysterud et al. 1997), or spring/early summer (Groven & Niklasson 2005). After the snow has melted, but before the new vegetation has grown in, with its high water content, the landscape is generally drier, and more prone to forest fires (Mysterud et al. 1997).

The size of fires in boreal forests varies. In Canada and Russia larger fires are more frequent than in Scandinavia. In Norway the average size is less than five daa, and very seldom larger than 1000 daa. Most of the fires are in unproductive forests (Mysterud et al. 1997), that is, the production is less than 1 m^3ha^{-1} timber per year.

Forest fires may be ignited by lightening (Granström 1993), volcanoes, or other natural sources. Humans may start forest fires to clear land, to create favourable conditions for game, or for tactical reasons and so on (Esseen et al. 1997; Granström & Niklasson 2008; Groven & Niklasson 2005; Hjelle et al. 2010; Wallenius et al. 2004).

Forest fires vary with forest types within the boreal zone. The ASIO model (Angelstam & Rosenberg 1993) categorises the forest into four different classes depending on how often they burn. The forests in the A ("aldri") category never burn, such as bogs. The forests in the S ("sjelden") category sometimes burn, and in the I ("iblant") category we find forests that infrequently burn. These are moist, often with deciduous trees. Dry pine forests classified in the O ("ofte") group often burn. Esseen et al. (1997) noted that pine forests burn more frequently than spruce forests.

A stand-replacing disturbance, like a fire, can kill most of the trees. These trees constitute most of the CWD for the next few decades (Siitonen 2001). The ecological effects vary with time of year, quantity, condition and distribution of the fuel, the climatic and geological conditions, the severity, intensity and rate of speed of the fire, the vegetation and the soil. The type of fire, ground-, surface- or crown-, has different effects on the ecology (Granstöm 2001; Kimmins 2004). Natural barriers in the landscape shape the fire progress, and create fire refuges, as well as areas that are more or less affected by the fire. These variations can be seen long after the fire, in the mosaic of the landscape (Esseen et al. 1997).

There have been calls to allow forest fires to revert to a natural frequency and intensity (Kuuluvainen 2000; Linder et al. 1997; Ryan 2002), with human intervention only when human life and possession is in danger (Esseen et al. 1997; Simberloff 2001). A more natural fire cycle may result in smaller fires that are easier to control. Species profiting from fires could experience reduced stress levels. However, there are also problems related to this. In Norway today a forest fire will usually be near humans. It is also difficult to know what the natural fire cycle is like, as it has been influenced by humans for so long. Species may be adapted to a cycle influenced by humans, and not a natural cycle (Granstöm 2001).

In Norway there is no tradition for proscribed burning, but there are rules with regards to handling an area that has burned. After a small fire in older forests a maximum of 0.5 ha has to be left untouched for ten years. After a large fire the area has to be evaluated by professionals who make a decision as to the level of protection (Levende Skog 2006, requirement section 5).

The government in Sweden have decided to increase the amount of CWD in the forest by 40% in the next 10 years (Miljödepartementet 2001). There are several problems with this, cost being one, knowledge regarding the critical value level of CWD is another. Information regarding quantity, composition and distribution across a landscape is also meagre (Ekbom et al. 2006). It has been suggested that it might be more effective to increase the volume of CWD in connection with high-quality habitats, that is, managed forests outside protected areas with more than 20 m^3ha^{-1} of CWD (De Jong & Almstedt 2005).

The amount of old forest and dead wood in Norway is increasing. However, the quantity of dead wood is not increasing evenly in the various types of woodlands and forests, nor in different geographical regions (Larsson & Hylen 2007). Although there is an increase, the quantity is still much below what one finds in areas which resemble virgin forest (Ødegaard 2006). At the end of the 1990s the average amount of down dead wood in productive Norwegian forests was $5.7m^3ha^{-1}$, and in total there was 43 million m^3 (Larsson & Hylen 2007). In Aust-Agder 4.37 m^3ha^{-1} of down woody debris was found in productive Scots pine dominated forests, while 3.26 m^3ha^{-1} was found when considering all Scots pine dominated forest in the area for the years 1994 to 1998 (data from the National Forest Inventory database). This is about 10-20% of the amounts present if the forest had been undisturbed by humans (Levende Skog 1998).

This thesis compares the quantity of down woody debris in the forests around Mykland in Aust-Agder County, in burned, not burned, logged and not logged areas, separating Scots pine and oak dominated forests, one year after the fire. A connection will be made between the severity of the fire and the amount of down woody debris found in the burned areas. The volume of down woody debris pre- and post-fire is compared to find the forest fire's ability to produce dead wood. The effect of site index on down woody debris is also included.

2. Materials and methods

2.1 Site description

Froland is a municipal area in Aust-Agder County. The area is dominated by large areas of forest, and there are two rivers cutting through it, Nidelva and Tovdalselva. Mykland, where the fire started, is situated at 58°37′56″N 08°16′27″E. The area is dotted with small lakes and swamps, and the landscape is hilly. There are two larger lakes, Myklandsvatnet and Saurdalsvatnet.

Figure 3. Map of Norway with study site marked.

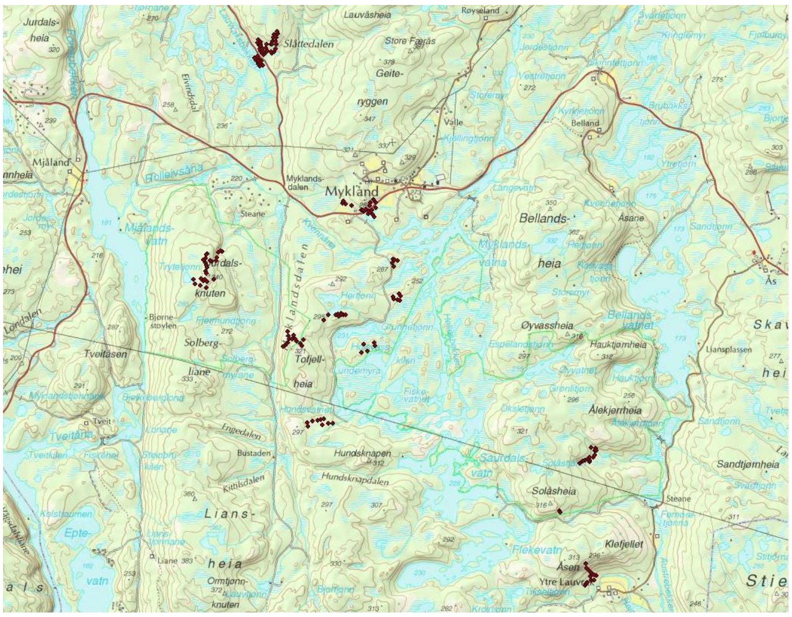

Figure 4. Map with all plots.

The vegetation zone is mainly boreonemoral with a small part southern boreal (the north eastern section), and the section is 02 markedly oceanic (Fremstad 1997; Moen 1998). The annual mean temperature for the period 1961-90, recorded at Nelaug meteorological station at Åmli at 175 meters above sea level, is 5.4 degrees Celsius (Meteorologisk institutt 2011). The total for the year in 2008 is more than the average, but the distribution, with little rain in May and June made the forest extremely dry (tab. 1).

Table 1. Monthly and annual precipitation in mm at Nelaug meteorological station, average for 1961-1990, and actual for 2008 (Meteorologisk institutt 2011).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
1961-90	102	67	75	53	80	75	91	108	124	141	128	95	1139
2008	255	100	175	117	29	67	77	175	105	188	101	62	1451

The quality of the forest was mapped before the fire, hence it is well documented. Seventy-four percent of the area is productive forest, 5% is unproductive, and 21% are lakes and bogs (data from AT plan). The forest is dominated by Scots pine at 97%, with stands of a variety of ages and cutting classes, and mainly middle and poor site indices. The site index F14 cover 24.9%, F11 cover 46.2%, F8 cover 24.2% and F6 site index cover 3.1%. Only 1.7% is F17 and 0.01% is F20. Before the fire 1.1% of the forest was in cutting class 1, 35.3% in cutting class 2, 25.1% in cutting class 3, 11.6% in cutting class 4, and 23.6% in cutting class 5. Only 2% of the forested area is Norway spruce (*Picea abies*), and 1% is deciduous trees. There are some old trees in the area, mainly oak (*Quercus spp.*), because these were not logged.

Most of the forest soil in the fire area is classified as Cambic Arenosol, but there is also Haplic Podzol, Folic Histosol and Lithic Leptosol (FAO-Unesco 1990). The bedrock is granite and gneiss of Proterozoean age (Sigmond et al. 1984), with some rock outcrops. In the eastern/ south-eastern area there is banded gneiss, resulting in some localities with more nutrient-rich vegetation types. Mostly, the soil is shallow but there are also ravines and slopes with deeper soil (fig. 5).

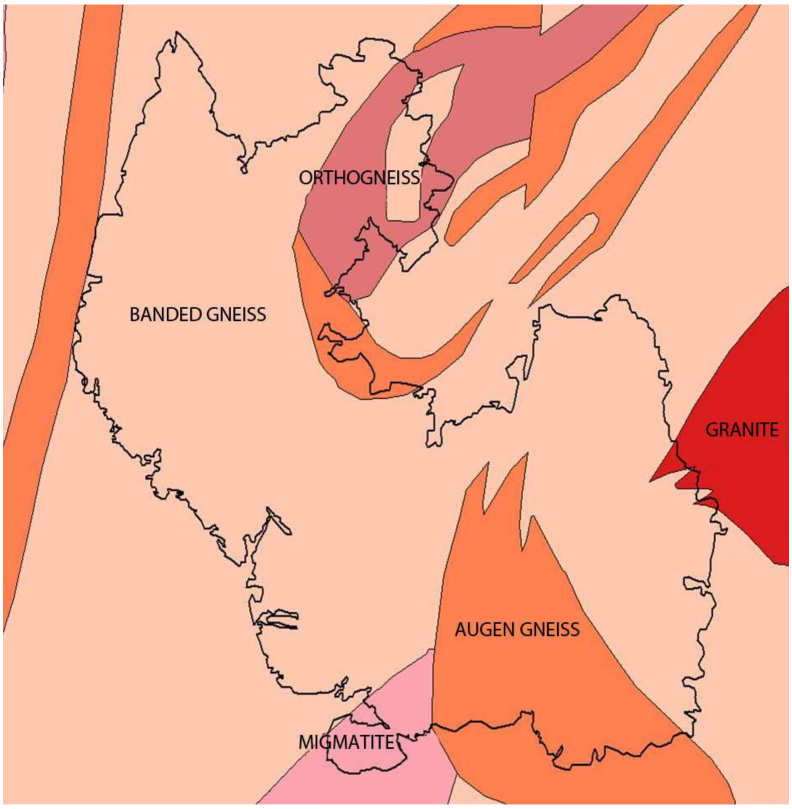

Figure 5. Map of the underground bedrock in the area (Sigmond et al. 1984).

2.2 The forest fire

Studies show that, historically, there were probably numerous forest fires in the area, and that the fires became smaller and rarer after the beginning of the 17th century. The forest industry was very active during the 17th and 18th centuries. More recently, there was lots of activity between 1940 and 1960, decreasing until today (Storaunet et al. 2008).

The forest fire in Froland on the 9^{th} to the 14^{th} of June 2008 was the biggest fire in Norway for more than 100 years. About 26 000 daa forest was burned down, and the estimated loss of value for the 12 forest properties was approximately 21.5 million Norwegian kroner (Skogbrand 2009). The fire was ignited by sparks from a forestry machine and the fire spread rapidly because the ground was dry, and it was windy. The area is sparsely populated, but seventy people were evacuated from their homes, and several cabins burned down.

The fire produced a lot of dead wood, from Scots pine, which is rare in Norway (Storaunet et al. 2008). Two areas have been protected (figures 6 and 7); 7137 daa at Myklandsvatna nature reserve and 3479 daa at Jurdalsknuten nature reserve (Brandrud et al. 2010; Storaunet et al. 2008).

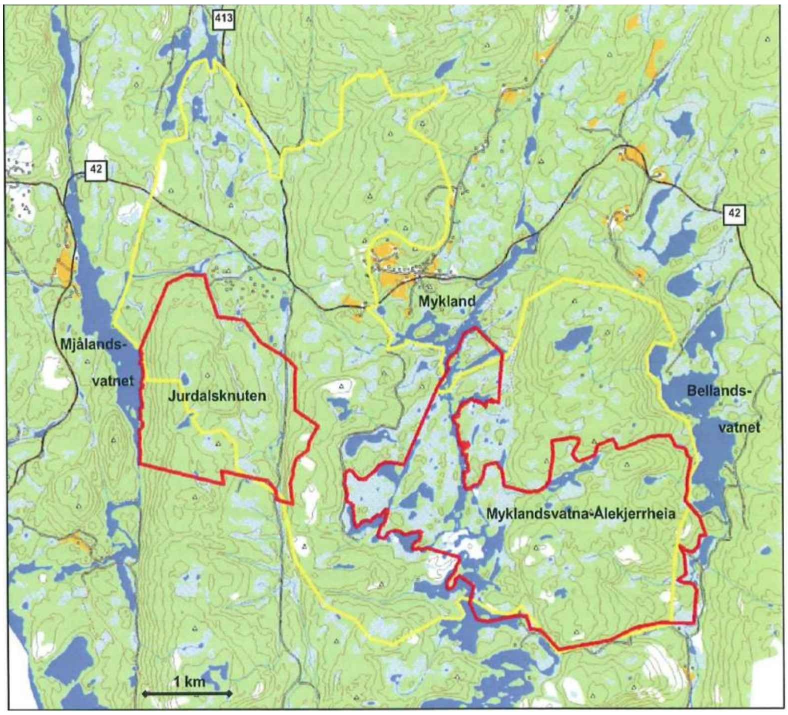

Figure 6. Map of the total area affected by the fire (yellow line), and the protected area (red line).

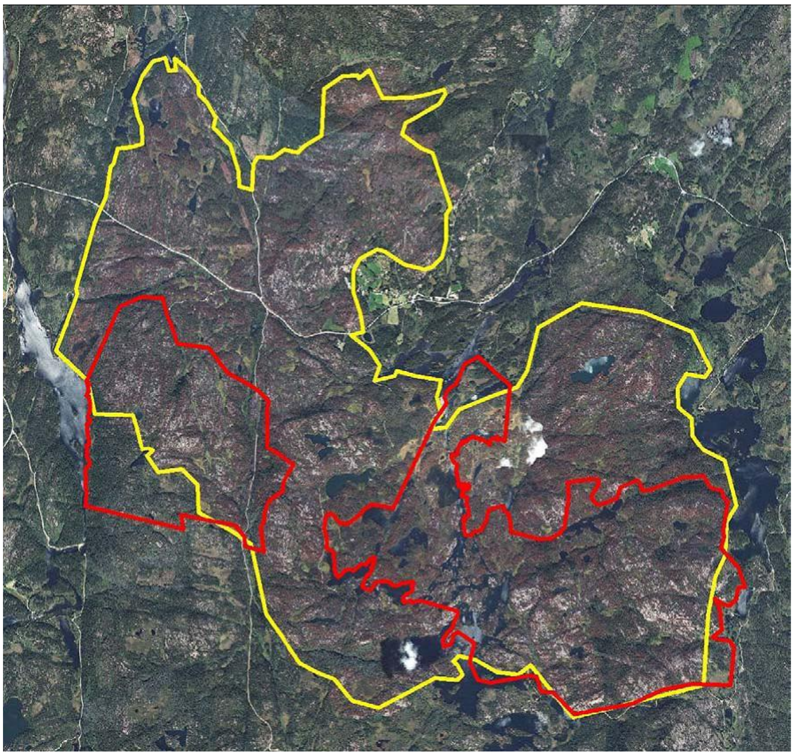
Figure 7. Aerial photograph of the total area affected by the fire (yellow line), and the protected area (red line).

The areas with shallow soil and Scots pine were heavily affected by the fire, and a lot of the bedrock is now exposed, while the smaller areas with deeper soil and Norway spruce were only slightly affected. There are also areas with deciduous trees. The severity of the fire in the deciduous forest varies from location to location. Areas with oak, lime (*Tilia cordata),* and aspen (*Populus tremula)* were slightly burned, while the small areas with elm (*Ulmus glabra),* Norway maple (*Acer platanoides),* black alder (*Alnus glutinosa)* and English yew (*Taxus baccata*) were not burned. I have categorised the severity, that is, the degree of impact of fire on organic matter (Kimmins 2004) into five classes, low, low to medium, medium, medium to high and high. In the areas where the severity was low all living trees survived the fire, and the vegetation was intact. The only sign of fire was small amounts of soot on standing trees, stumps or rocks, and the surface of trees that were dead before the fire was black. Areas were the fire's impact was low to medium were similar, trees and plants survived the fire here also. There was more soot on standing trees, stumps and the ground, and the stems of trees that were dead before the fire were slightly burned, not just sooty. In the areas with medium severity the fire had felled some trees. These trees were either felled during the fire, or by the wind afterwards because the roots were weakened. The vegetation was affected, but there was an abundance of plants, mostly of pioneer species. CWD and down logs already on the ground were burned, but it was still possible to see that it had been a log. The medium to high areas had more trees felled by the fire, less vegetation, and logs already on the ground were almost destroyed by the fire. In the areas where the severity of the fire was high, often all trees had been felled, and most of the humus was obliterated. Re-vegetation in the area was dominated by pioneer species.

2.3 Field methods

2.3.1 The line intersect method

Estimating dead wood/ CWD in general was first used to estimate the fuel in a forest, but has since also been used to look at nutrient cycles and wildlife habitats. The line intersect method measures down woody debris that intersects with a chosen line (Van Wagner 1968; Warren & Olsen 1964).

Van Wagner (1968) offers six rules;

"1) Lay a line of known length across the area to be studied.

2) Record the diameter of every piece of wood intersected.

3) If the sample line crosses the end of a piece, tally only if the central axis is crossed.

4) If the sample line passes exactly through the end of a piece's central axis, tally every second such piece.
5) Ignore any piece whose central axis coincides with the sample line.
6) If the sample line crosses a curved piece more than once, tally each crossing.

Rules 4, 5 and 6 are obviously of slight practical importance, but are included to cover all possibilities. Piece length and crossing angle need not be recorded" (Van Wagner 1968: 20-21).

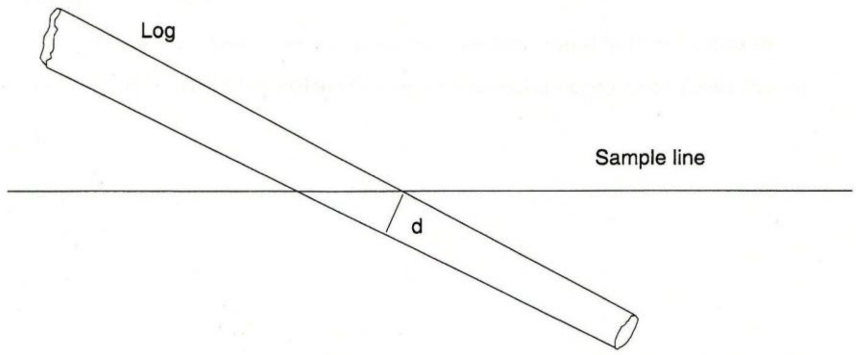

Figure 19. Example of sample line crossing a log (Larsen 1999: 1).

Formula used for finding volume of wood per unit area

$$V = \frac{\pi^2 \sum_{i=1}^{n} d^2}{8L}$$

Where
v = volume of wood per unit area (m^3ha^{-1})
d = piece diameter (cm)
L = length of sample line (m)

The pieces of wood must be cylindrical, horizontal and randomly oriented (Van Wagner 1968).

The method is dependent on “randomly oriented cylinders lying on a horizontal surface” (Van Wagner 1968: 22). In the field such conditions might not always be perfect, but not all shortcomings will affect the volume estimate. The presence of taper, axial asymmetry, minor tilts and curved pieces can be ignored. If the surface is sloped, the volume V should be multiplied by the ratio of the sloped area to account for a possible error. Error caused by a lack of randomly oriented pieces can be reduced by having sample lines in several directions (Van Wagner 1968). Ståhl et al. (2001) studied a collection of methods for assessing CWD, and the line intersect method had a good score. It is ranged as performing well with regards to efficiency and robustness for measurement errors, and intermediate for simplicity. It does not perform well when it comes to contextual information, but this can be corrected by noting additional information while in the field. Even though there are possible sources of error, the method can be trusted. It has been thoroughly tested, and it is robust as long as there are enough observations (Van Wagner 1968). The National Forest Inventory uses this method in their day to day work collecting data, which is one reason why this method was chosen for this work.

2.3.2 Field work

The field work was done between May 2009 and September 2009, the summer season the year after the fire, using the line intersect method. A total of 161 circular plots of 250m^2 were placed in the forest. The plots have a diameter of 17.84 metres. The lines were placed south-north, and east-west, crossing in the middle. All down woody debris longer than one meter in length and larger than 10 cm in diameter was recorded. The diameter was recorded using a calliper (fig. 18).

Figure 18. Recording diameter using a calliper (Photo: Per Holm Nygaard).

The plots were placed randomly in four main forest treatment types, logged and burned, logged but not burned, not logged but burned, and lastly, not logged and not burned. In the area that had not been logged, plots were placed in both Scots pine dominated forest and oak dominated forest, thus making up six different categories. To make sure the plot positions were random the centres were picked on the map on the GPS while not looking. The position was rejected if roads, lakes and large areas of bare rock dominated. Between each measured circle there was always a buffer of at least one circle. On each plot the severity of the fire, the vegetation type and the soil type, as well as topography, was registered. The dead wood was measured, and the degree of decay and tree species was also recorded. Whether the down woody debris was a result of the fire or not was also noted. Mostly this was an easy distinction to make.

2.4 Vegetation

The vegetation belongs to the *Cladonio-Pinetum* association, with some minor areas of *Vaccinio-Pinetum* (Kielland-Lund 1973). The sample plots are laid out in both logged and not-logged, and burned and not-burned areas. Seed tree felling was used in the logged areas. The sample plots in the logged areas are all in Scots pine dominated forests, while the sample plots in the not-logged areas were laid out in both Scots pine and oak dominated forests. The forest with Scots pine and Norway spruce are in cowberry-bilberry woodland, while the deciduous forest range from poor bilberry-oak forest to rich low-herb and oak forest, and elm-lime forest (Brandrud et al. 2010). In this work the focus is on tree species and field layer species.

In the cowberry-bilberry woodland species commonly found were Scots pine, *Vaccinium myrtillus*, *Calluna vulgaris*, *Vaccinium uliginosum* and *Vaccinium vitis-idaea*. In some areas Norway spruce, *Juniperus communis*, *Molinia caerulea*, silver birch (*Betula pendula*), *Avenella flexuosa* and *Luzula pilosa* were found. The ground is colonized by *Marchantia polymorpha*, *Funaria hygrometricia* and *Ceratodon purpureus*.

Figure 8. Logged, not burned, cowberry-bilberry woodland (Photo: Synne M. Vestmoen).

Figure 9. Logged and burned, cowberry-bilberry woodland (Photo: Synne M. Vestmoen).

Figure 10. Not logged, not burned, cowberry-bilberry woodland (Photo: Stian Bockelie).

Figure 11. Not logged and burned, cowberry-bilberry woodland (Photo: Synne M. Vestmoen).

In the small-fern woodland I found Norway spruce, *Vaccinium myrtillus*, *Dryopteris phegopteris*, *Gymnocarpium dryopteris*, and *Oxalis acetosella*. There was also rowan (*Sorbus aucuparia*), silver birch, downy birch (*Betula pubescens*), *Anemone nemorosa* and *Oxalis acetosella*.

Figure 12. Not logged, not burned, small-fern woodland, English yew valley (Photo: Synne M. Vestmoen)

Figure 13. Not logged, not burned, small-fern woodland (Photo: Synne M. Vestmoen).

In the low-herb woodland Norway spruce, rowan, Norway maple, hazel (*Corylus avellana*), Scots pine, *Viola riviniana*, *Carex digitata*, *Fragaria vesca*, *Oxalis acetosella, Vaccinium myrtillus, Veronica officinalis, Pteridium aquilinum, Hepatica nobilis, Melica nutans, Avenella flexuosa, Rubus idaeus* and *Vaccinium vitis-idaea* were found, along with *Geranium bohemicum.*

Figure 14. Not logged, not burned, low-herb woodland (Photo: Harald Bratli)

Figure 15. Not logged and burned, low-herb woodland (Photo: Synne M. Vestmoen).

In the bilberry woodland Norway spruce, *Vaccinium myrtillus*, *Vaccinium vitis-idaea*, *Avenella flexuosa* and *Luzula pilosa* were found in most plots. Scots pine, oak, *Juniperus communis*, *Veronica officinalis* and *Agrostis capillaries* were found in some areas.


Figure 16. Not logged, not burned, bilberry woodland (Photo: Harald Bratli).

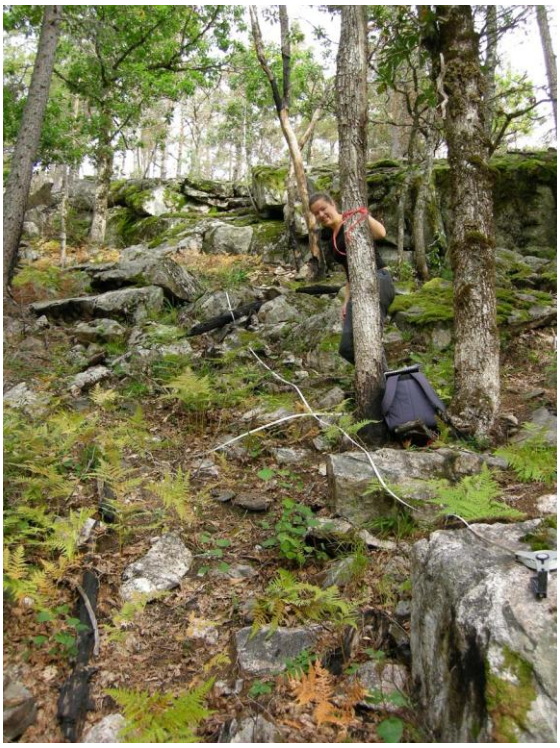
Figure 17. Not logged, burned, bilberry woodland (Photo: Harald Bratli).

In the area that was logged, not burned, the area that was logged and burned, and in the area that was not logged, burned, and where Scots pine dominated, all plots are in cowberry-bilberry woodland. The plots in the not logged, not burned, Scots pine dominated area were either in small-fern woodland or in cowberry-bilberry woodland. The plots in the area that was not logged, not burned, in oak dominated forests, were in small-fern woodland, low-herb woodland or bilberry woodland. The plots in the area that was not logged and burned, in oak dominated forests, were in small-fern woodland, low-herb woodland, bilberry woodland or cowberry-bilberry woodland.

2.5 Calculations and statistical methods

The data was entered into Microsoft Excel. The formula from Van Wagner (1968) was used to find volume m^3ha^{-1} of down woody debris. Descriptive statistics was done in Microsoft Excel. The volume and mean value were found in the different treatment classes. Due to the nature of the data, with several findings of no down woody debris, the non-parametric Kruskal-Wallis test was used (Conover 1980). This test is useful in cases where one cannot assume the data meets a normal distribution. The result is presented in a box-and-whisker plot (Tukey 1977), which show minimum, lower quartile, median, upper quartile, maximum and outliers.

3. Results

3.1 Volume of down woody debris

Firstly, volume per hectare was calculated using the formula in Larsen (1999).

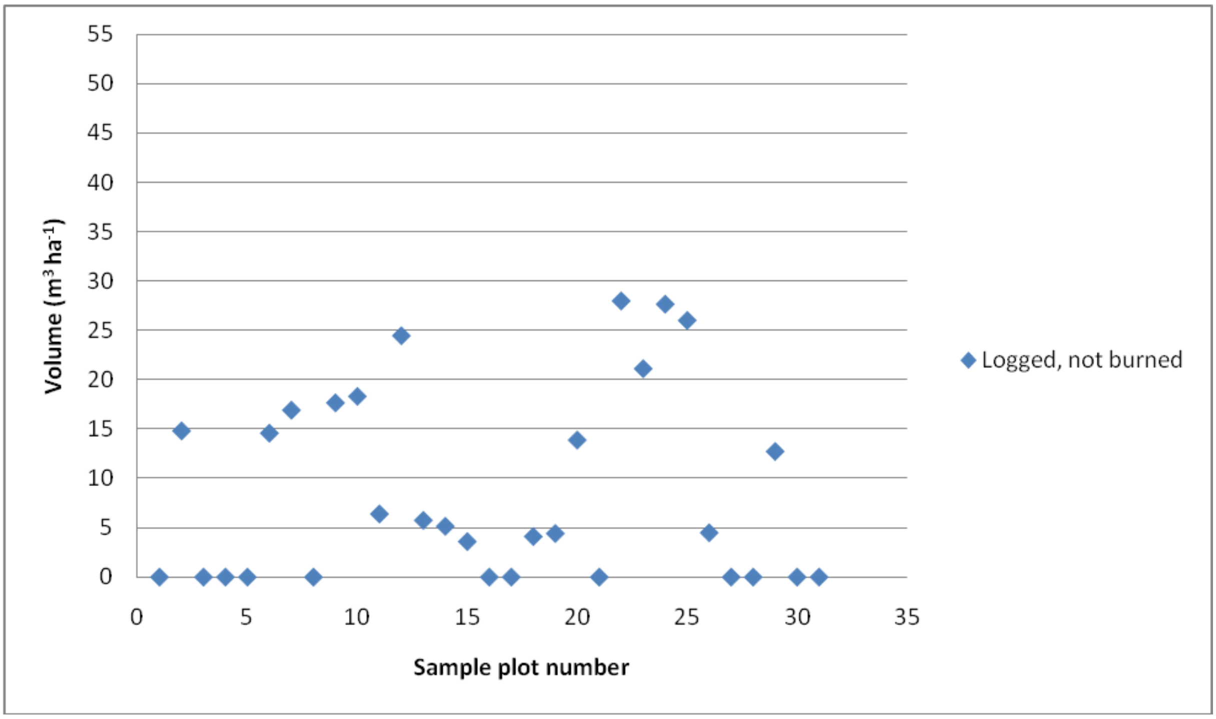

Figure 20. Scatter plot showing volume of down woody debris for each sample plot in the area that was logged, not burned and dominated by Scots pine forest.

In the area that was logged, not burned most of the fallen deadwood was either Scots pine debris from logging activity, or Scots pine seed-trees. The only exception was a few occurrences of silver birch, but this was also the result of logging activity. There were 31 sample plots. In 12 plots no down woody debris was found, while the volume in the remaining plots varies between 3.6 and 28 m^3ha^{-1} (fig. 20). The mean value is 8.7 m^3ha^{-1}.

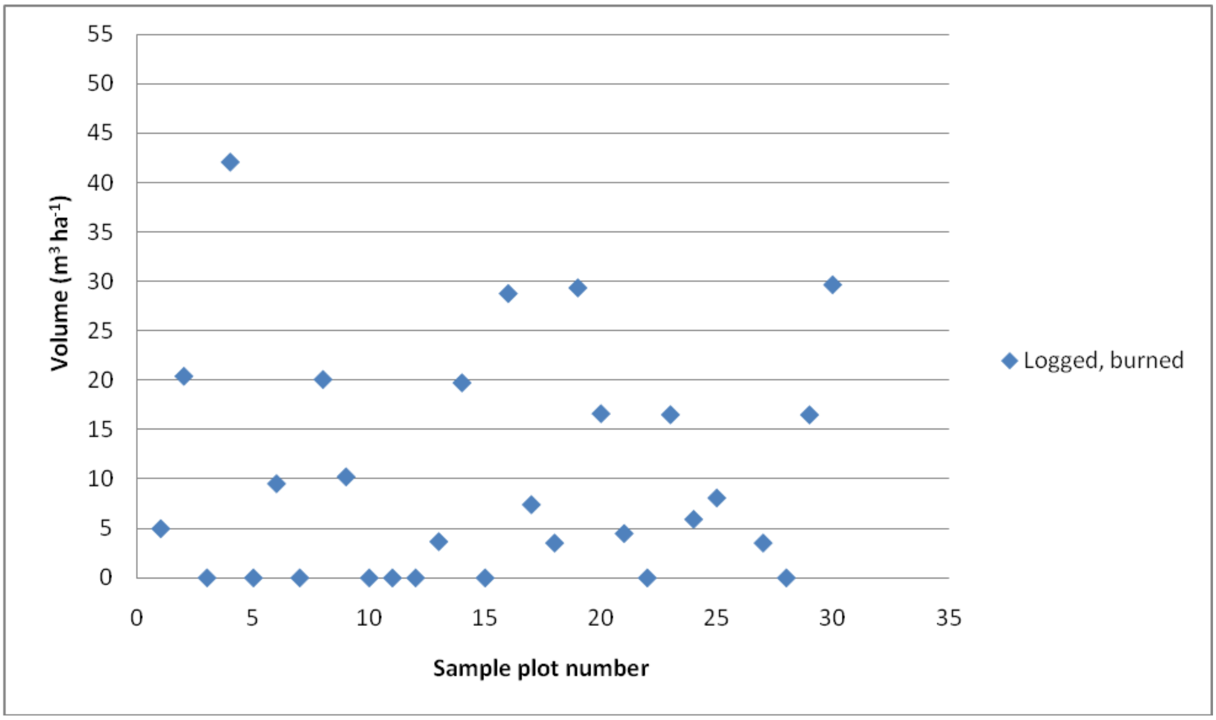

Figure 21. Scatter plot showing volume of down woody debris for each sample plot in the area that was logged and burned and dominated by Scots pine forest.

In the area that was logged and burned most of the fallen deadwood found was the result of logging activity, or wind throw of seed-trees, and again most of the down woody debris was Scots pine and a few silver birches. Some of the trees were dead before the fire. There were 30 sample plots. In nine of the plots no down woody debris was found, while the volume in the remaining plots varied between 3.5 and 42 m^3ha^{-1} (fig. 21). The mean value is 12 m^3ha^{-1}.

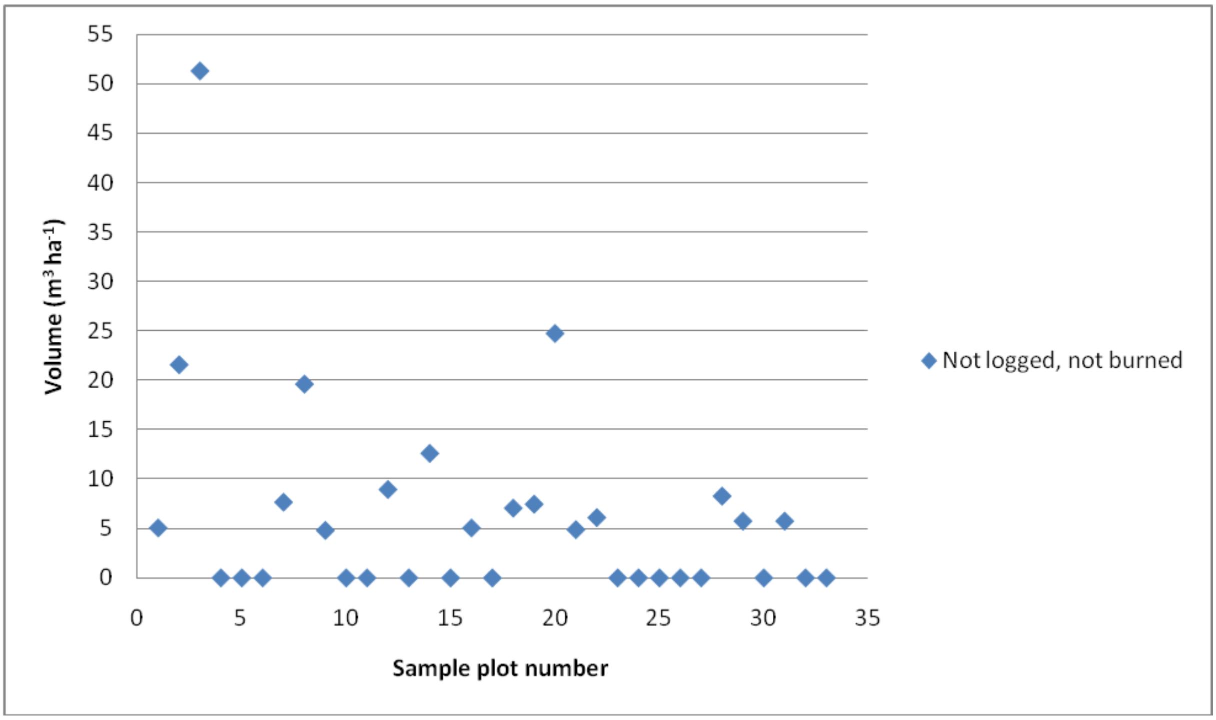

Figure 22. Scatter plot showing volume of down woody debris for each sample plot in the area dominated by Scots pine that was not logged, not burned.

In the area that was not logged, not burned, the down woody debris is mostly Scots pine windfall or debris from thinning, as well as some English yew and birch. There were 33 sample plots. In 16 plots no down woody debris was found. In the remaining plots the volume varied between 4.8 and 51.4 m^3ha^{-1} (fig. 22). The mean value is 6.3 m^3ha^{-1}.

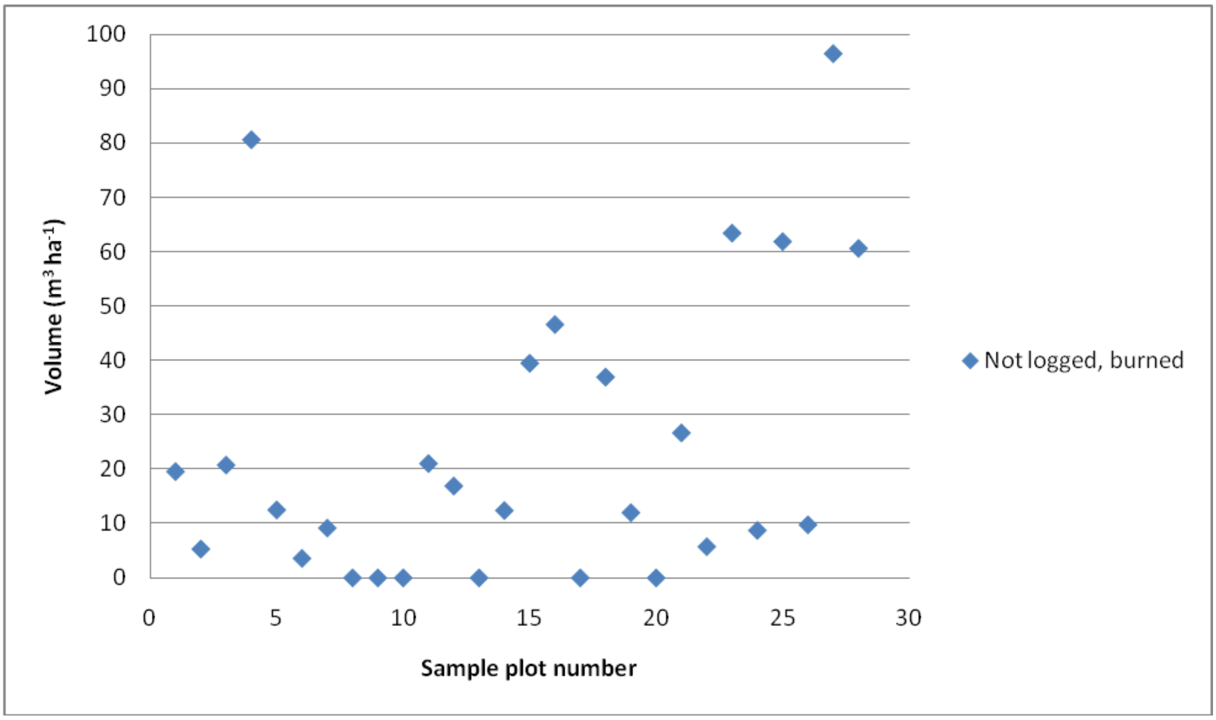

Figure 23. Scatter plot showing volume of down woody debris for each sample plot in the area dominated by Scots pine that was not logged and burned.

In the area that was not logged and burned there were several tree species found, mostly Scots pine, but also a few Norway spruce, silver birch and aspen. The down woody debris found was mostly killed by the fire. There were 28 sample plots, and 6 of these did not contain any down woody debris. In the other plots the volume varied between 3.6 and 96.5 m^3ha^{-1} (fig. 23). The mean value is 24 m^3ha^{-1}.

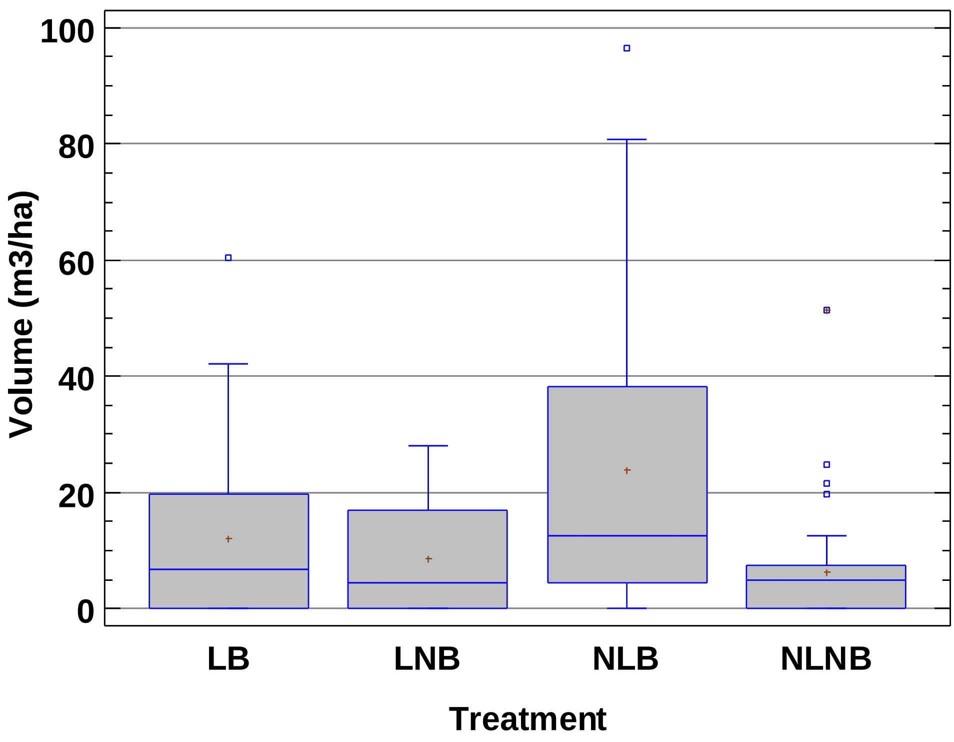

Figure 24. Box-and-Whisker Plot showing minimum, lower quartile, median, upper quartile and maximum volume, as well as outliers for down woody debris for the four treatment types in Scots pine dominated forest. LNB (logged not burned), LB (logged and burned), NLNB (not logged, not burned), NLB (not logged, burned).

The medians are 57.5 for LNB (logged not burned), 63.8 for LB (logged and burned), 48.8 for NLNB (not logged, not burned) and 78.3 for NLB (not logged, burned). The P-value is 0.0087, which is less than 0.05, hence there is a statistically significant difference among the medians at the 95% confidence level, and the null hypothesis must be rejected. The median for NLB is significantly different from the others (fig. 24).

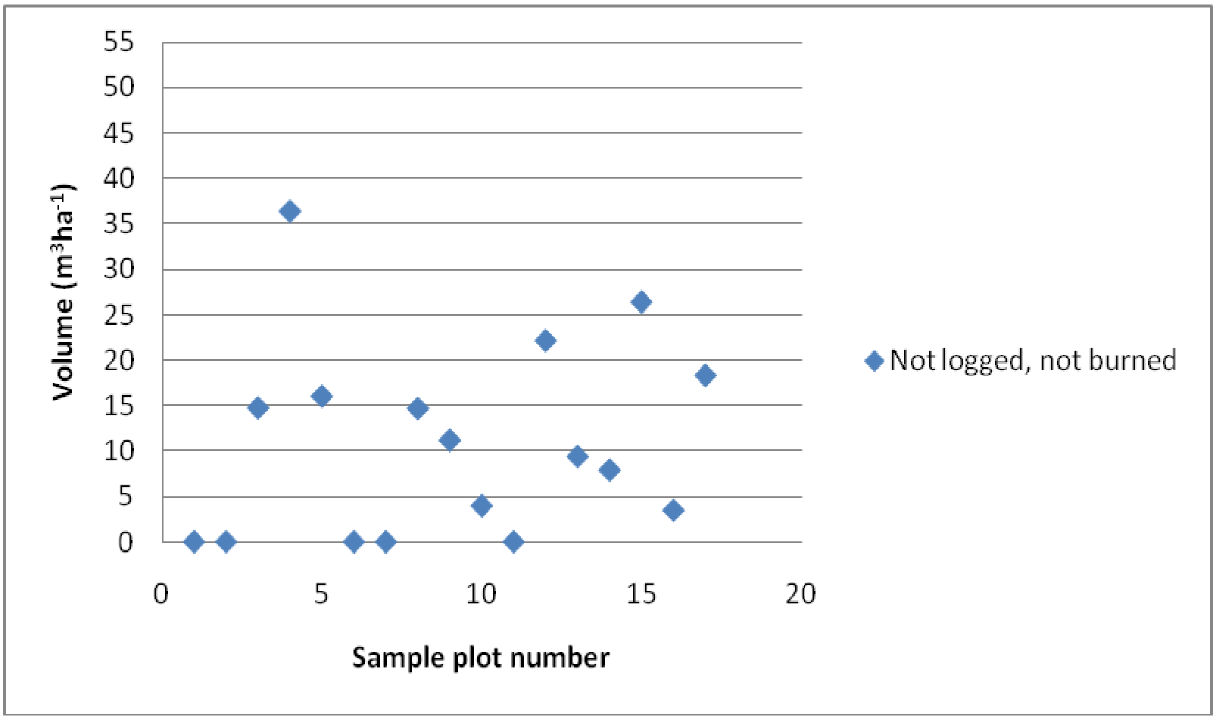

Figure 25. Scatter plot showing volume of down woody debris for each sample plot in the area dominated by oak that was not logged, not burned.

In the area that was not logged and not burned, and dominated by oak, there were several tree species found, mostly oak, but also some Norway spruce, goat willow (*Salix caprea*), aspen and Scots pine. The down woody debris found was all a result of trees dying and falling to the ground in a natural cycle. There were 17 sample plots, and 5 of these did not contain any down woody debris. In the other plots the volume varied between 3.5 and 36.3 m^3ha^{-1} (fig. 25). The mean value is 10.8 m^3ha^{-1}.

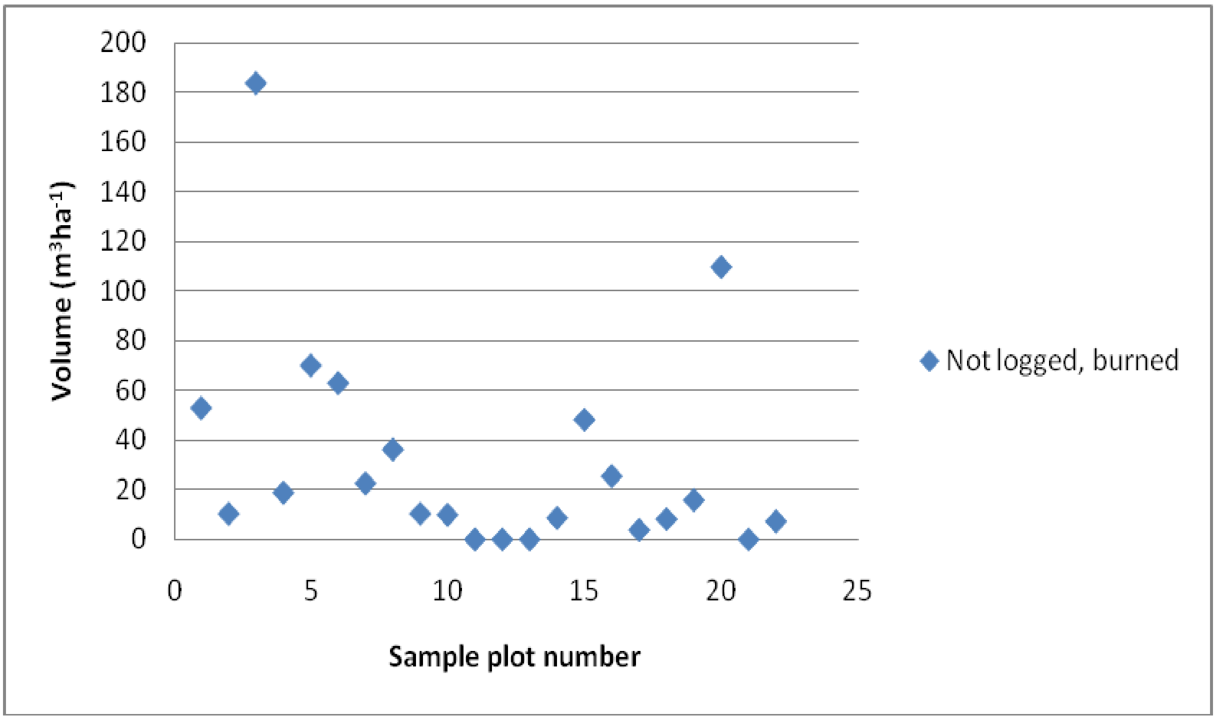

Figure 26. Scatter plot showing volume of down woody debris for each sample plot in the area dominated by oak that was not logged, burned.

In the area that was not logged and burned, and dominated by oak, there were several tree species found, mostly oak, but also aspen, goat willow, birch, lime, hazel and Scots pine. The woody debris found was a mix of down woody debris covered in moss already on the ground before the fire, and trees that had died before the fire, and been felled by the fire. There were 22 sample plots, and 4 of these did not contain any down woody debris. In the other plots the volume varied between 3.8 and 183.5 m^3ha^{-1} (fig. 26). The mean value is 32 m^3ha^{-1}.

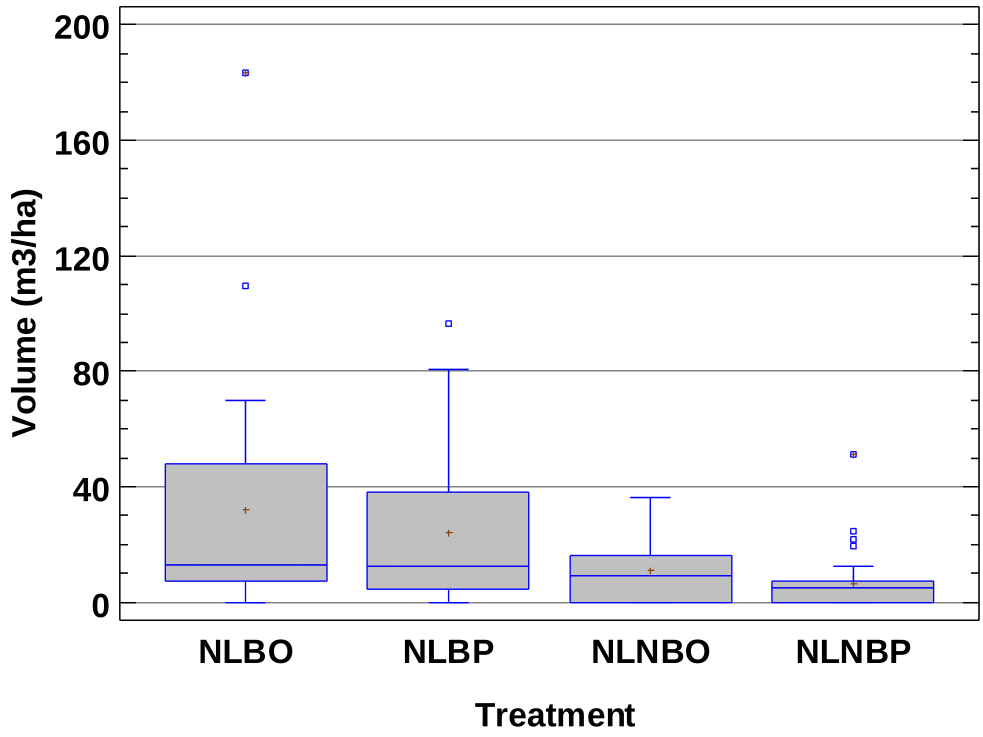

Figure 27. Box-and-Whisker Plot showing minimum, lower quartile, median, upper quartile and maximum volume, as well as outliers for down woody debris for the not-logged forest. NLNBO (not logged, not burned, oak dominated forest), NLBP (not logged, burned, Scots pine dominated forest), NLBO (not logged, burned, oak dominated forest), NLNBP (not logged, not burned, Scots pine dominated forest).

The median for NLNBO (not logged, not burned, oak dominated forest) is 48.9, NLBP (not logged, burned, Scots pine dominated forest) is 60, NLBO (not logged, burned, oak dominated forest) is 62.6 and NLNBP (not logged, not burned, Scots pine dominated forest) is 35. The P-value is 0.00095, which is less than 0.05. There is a statistically significant difference among the medians at the 95% confidence level, and the null hypothesis must be rejected. NLNBP is significantly different from the others (fig. 27).

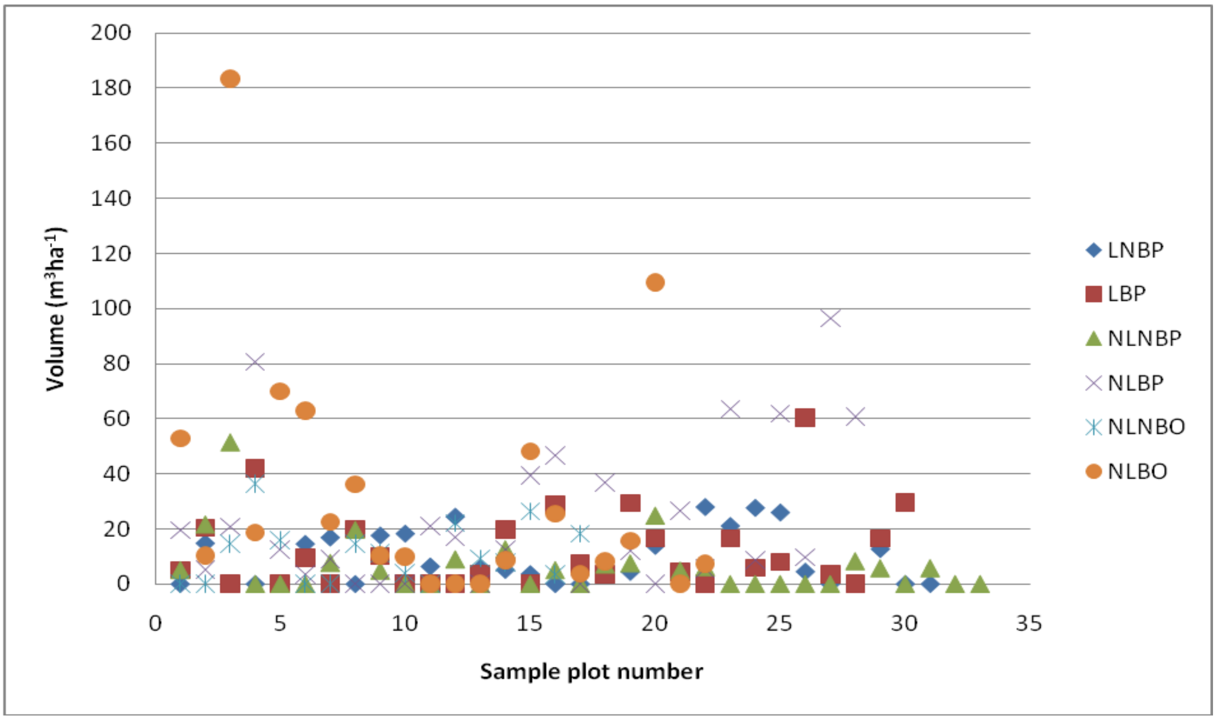

Figure 28. Scatter plot showing volume of down woody debris for each sample plot in the Scots pine and in the oak dominated area. The six different treatments are indicated. LNBP (logged not burned, Scots pine dominated forest), LBP (logged and burned, Scots pine dominated forest), NLNBP (not logged, not burned, Scots pine dominated forest), NLBP (not logged, burned, Scots pine dominated forest), NLNBO (not logged, not burned, oak dominated forest), NLBO (not logged, burned, oak dominated forest).

Figure 28 shows all plots in all categories in both Scots pine and oak dominated forest. The figure illustrates the differences between areas that were logged or not logged, and burned or not burned. The plots in NLBO and NLBP differ from the rest with regards to the amount of down woody debris, while the NLNBP stand out due to the number of plots where no down woody debris were found.

3.2 Severity of fire and amount of down woody debris

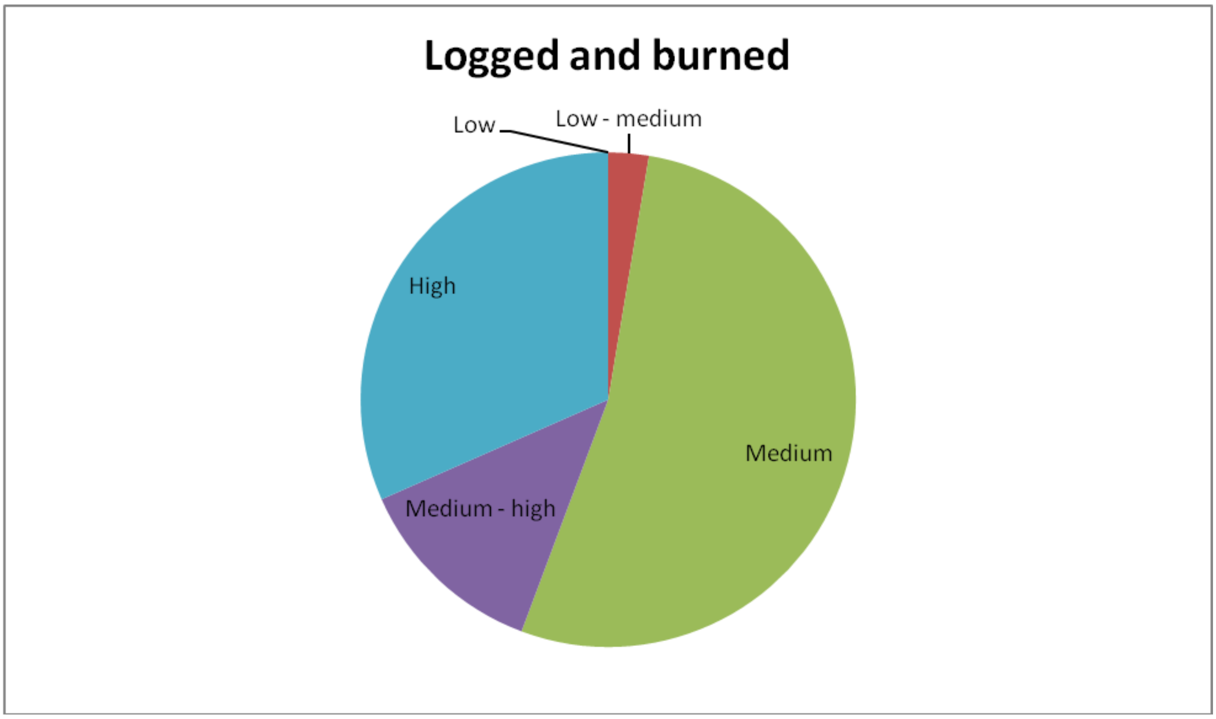

Figure 29. Relative volume of down woody debris by the severity of the fire, Scots pine dominated forest.

Figure 29 illustrates how the severity of the forest fire and the relative volume of down woody debris relate in LB. In the area where the severity of the fire was low, 0% of the dead wood was found. Three percent of the down woody debris was found where the severity of the fire was low to medium, 53% of the dead wood was found where the severity was medium, 13% of the dead wood was found where the severity of the fire was medium to high and 31% where the severity was high.

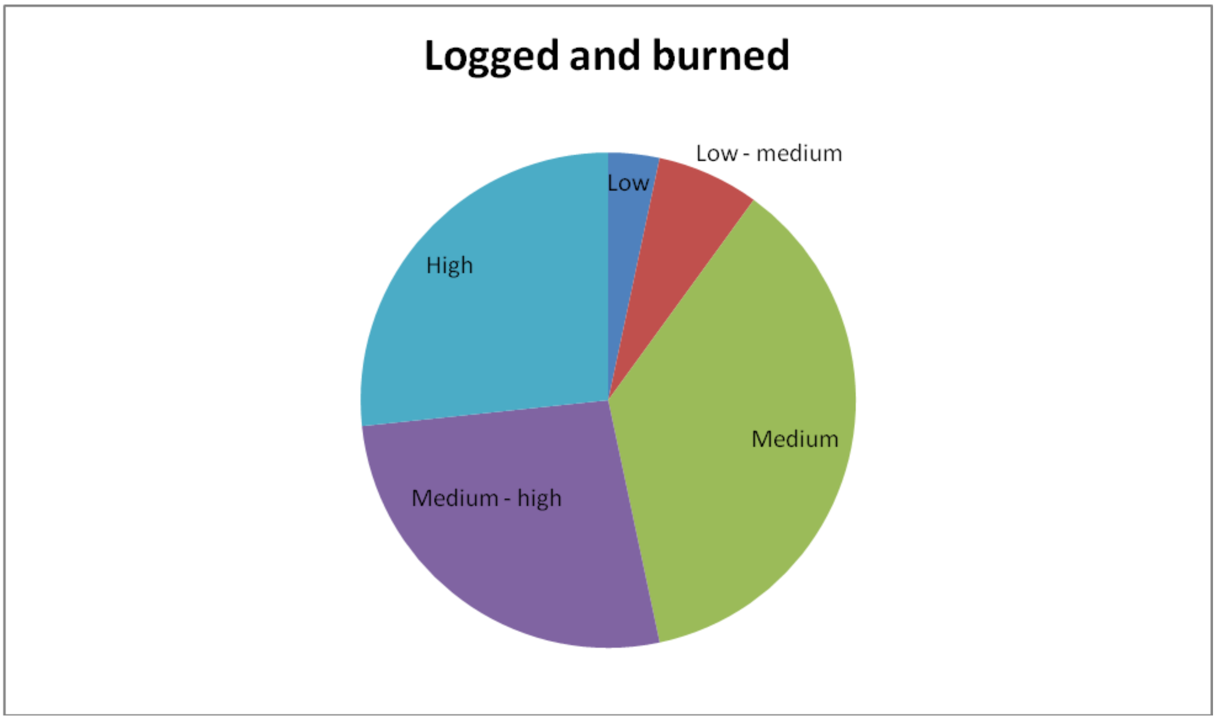

Figure 30. Number of plots by severity of fire, Scots pine dominated forest.

Figure 30 explains the distribution of the plots by the severity of the fire, in the area that was logged and burned. In total there were 30 plots. On one of the plots the severity of the fire was low, two plots were low to medium, 11 plots were medium, eight plots were medium to high and eight plots were high. The fire was severe in most of the area that was both logged and burned.

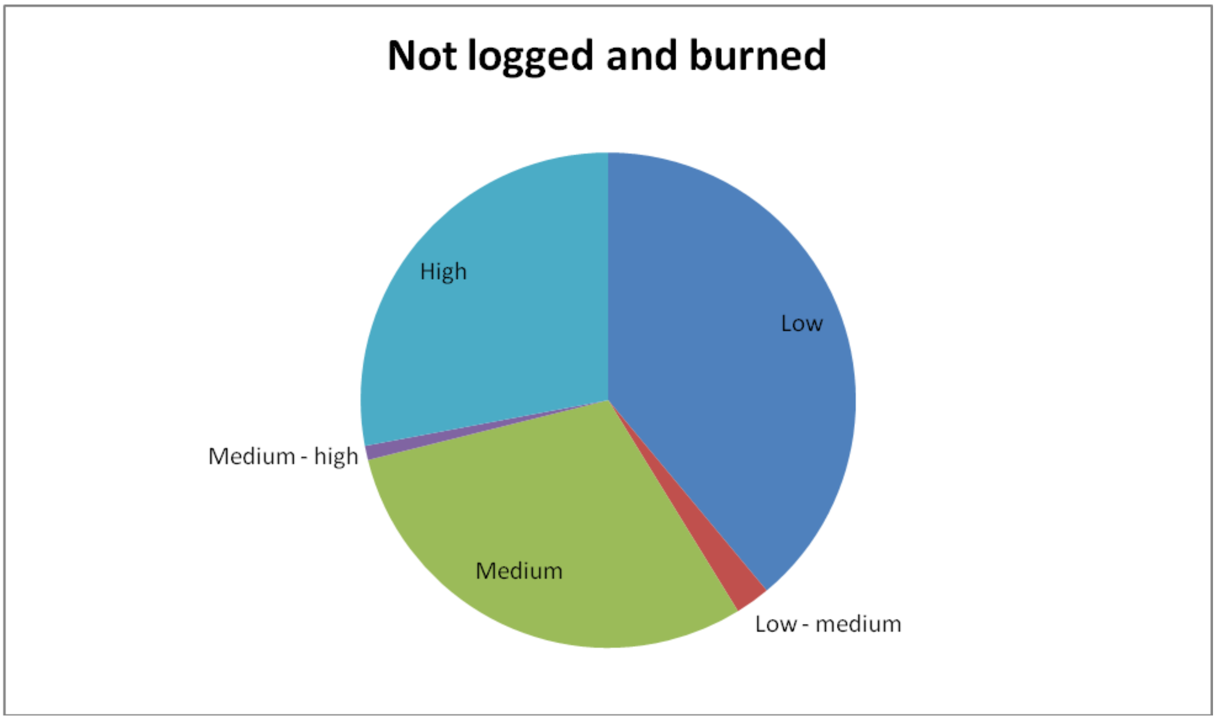

Figure 31. Relative volume of down woody debris by the severity of the fire for all plots in NLB, both Scots pine and oak dominated forests.

Figure 31 presents the relationship between the severity of the forest fire and the relative volume of down woody debris in NLB. In the area where the severity was low, 39% of the dead wood was found. Where the fire had been low to medium, 2% of the down woody debris was found. Thirty percent of the dead wood was found where the severity was medium, 1% of the dead wood was found where the severity of the fire was medium to high and 28% where the severity of the fire was high.

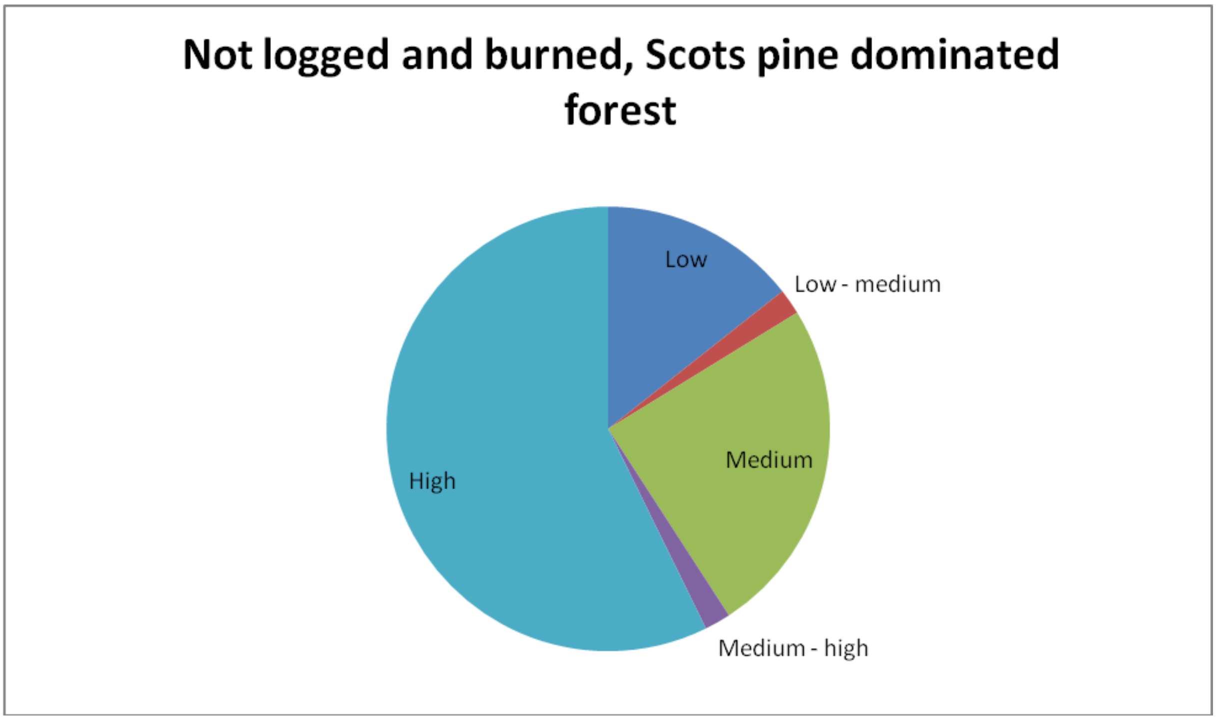

Figure 32. Relative volume of down woody debris by the severity of the fire.

Figure 32 presents the relationship between the severity of the forest fire and the relative volume of down woody debris in NLBP. In the area where the severity was low, 14% of the dead wood was found. Where the fire had been low to medium, 2% of the down woody debris was found. Twenty-five percent of the dead wood was found where the severity was medium, 2% of the dead wood was found where the severity of the fire was medium to high and 57% where the severity of the fire was high.

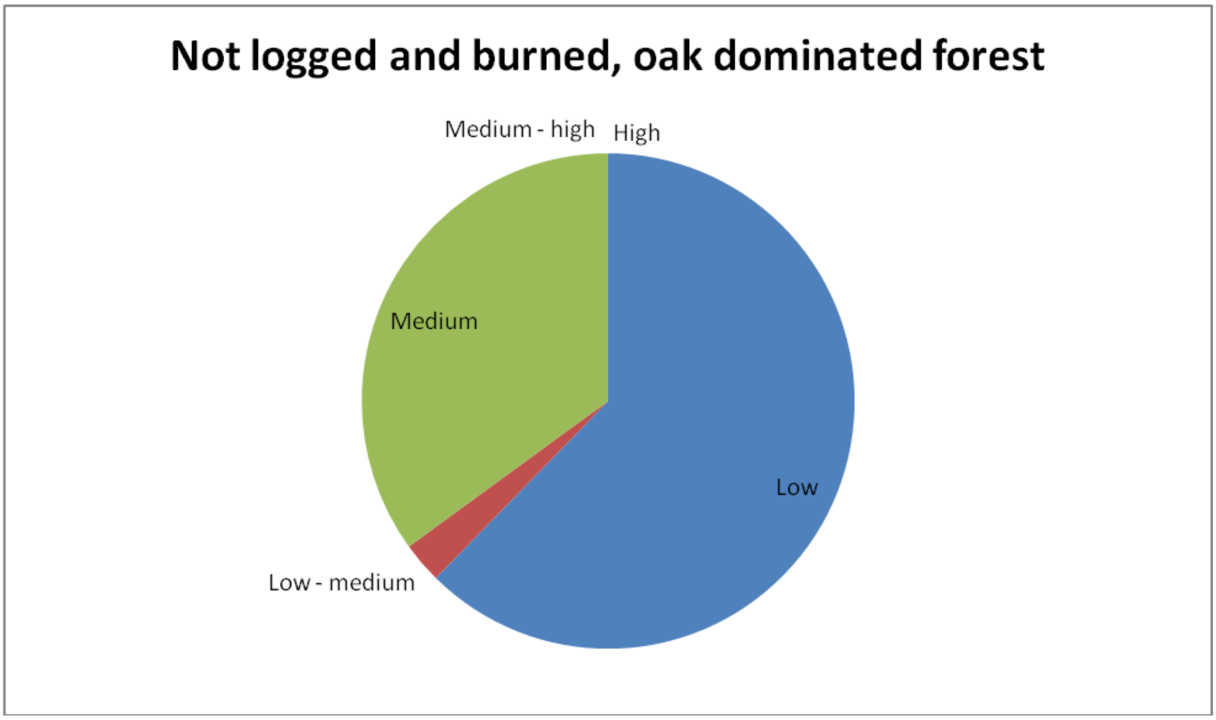

Figure 33. Relative volume of down woody debris by the severity of the fire.

Figure 33 presents the relationship between the severity of the forest fire and the relative volume of down woody debris in NLBR. In the area where the severity was low, 62% of the dead wood was found. Where the fire had been low to medium, 3% of the down woody debris was found. Thirty-five percent of the dead wood was found where the severity was medium, no dead wood was found where the severity of the fire was medium to high and where the severity of the fire was high.

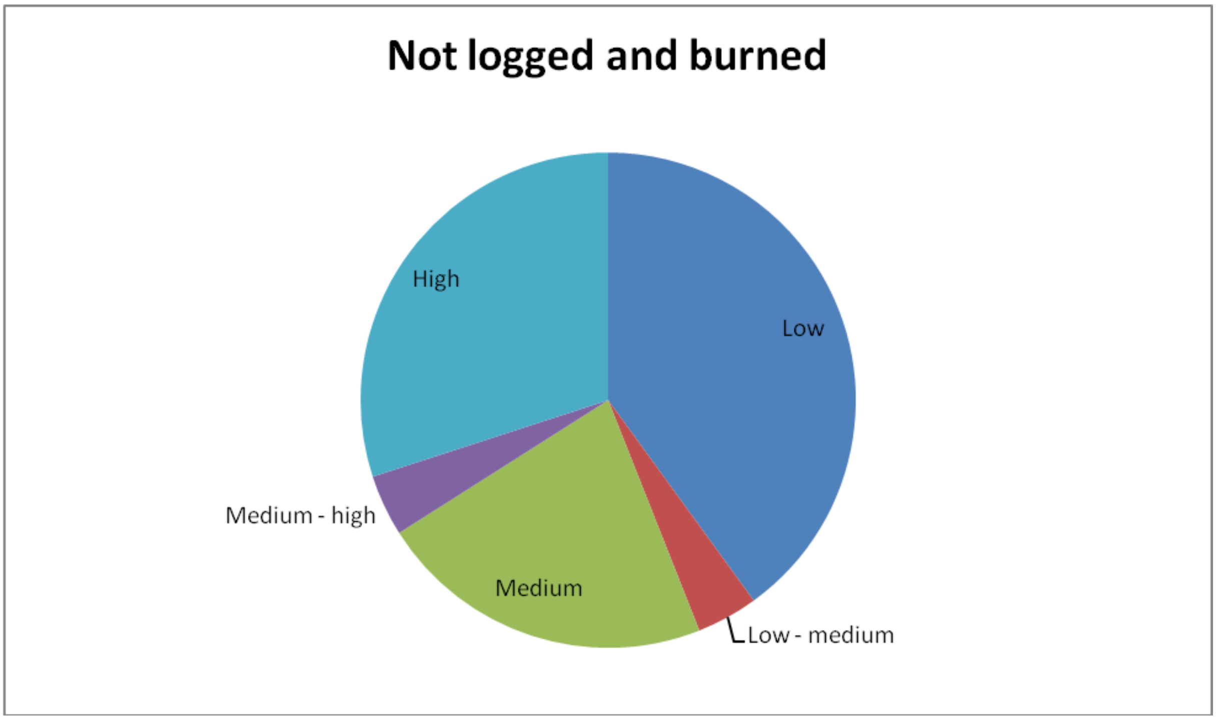

Figure 34. Number of plots by severity of fire, including all plots in both Scots pine and oak dominated forests.

Figure 34 demonstrates how the severity of the fire and number of plots correspond in NLB. In total there were 50 plots. In 20 of the plots the severity of the fire was low, two plots were low to medium, 11 plots were medium, two plots were medium to high and in 15 plots the severity was high. Thus, the severity of the fire in the area that was not logged and burned is varied.

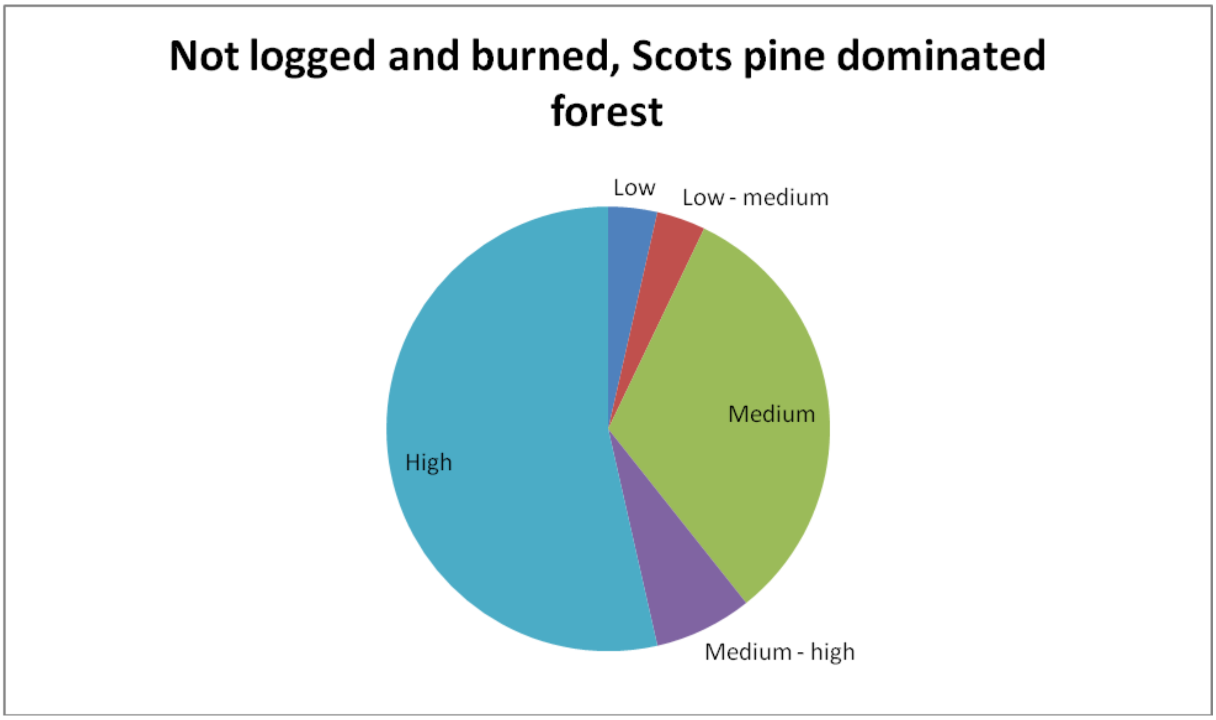

Figure 35. Number of plots by severity of fire, in Scots pine dominated forest.

Figure 35 demonstrates how the severity of the fire and number of plots correspond in NLBP. In total there were 28 plots. In one of the plots the severity of the fire was low, one plot was low to medium, nine plots were medium, two plots were medium to high and in 15 plots the severity was high. Most of the plots in this category were placed in an area where the fire was severe.

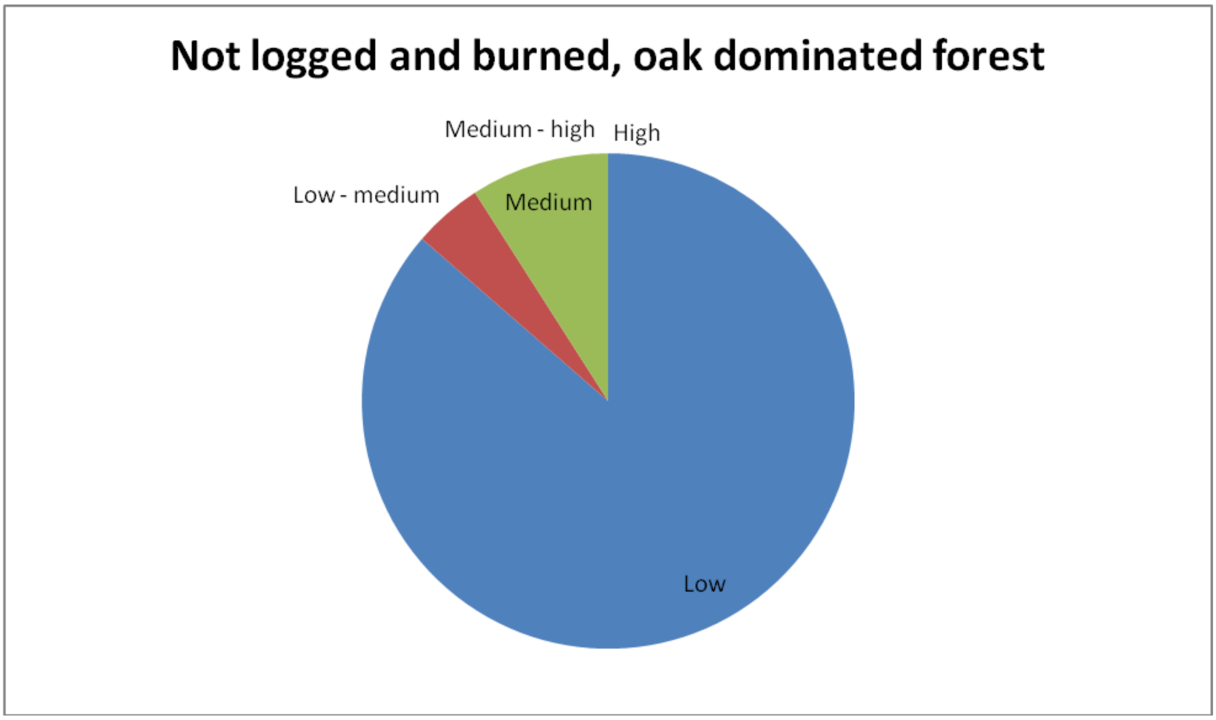

Figure 36. Number of plots by severity of fire, in oak dominated forest.

Figure 36 demonstrates how the severity of the fire and number of plots correspond in NLBO. In total there were 22 plots in areas with rich vegetation types. In 19 of the plots the severity of the fire was low, one plot was low to medium, two plots were medium, zero plots were medium to high and in zero plots the severity was high. Most of the plots in this category were placed where the severity of the fire was low.

3.3 Down woody debris before and after the fire

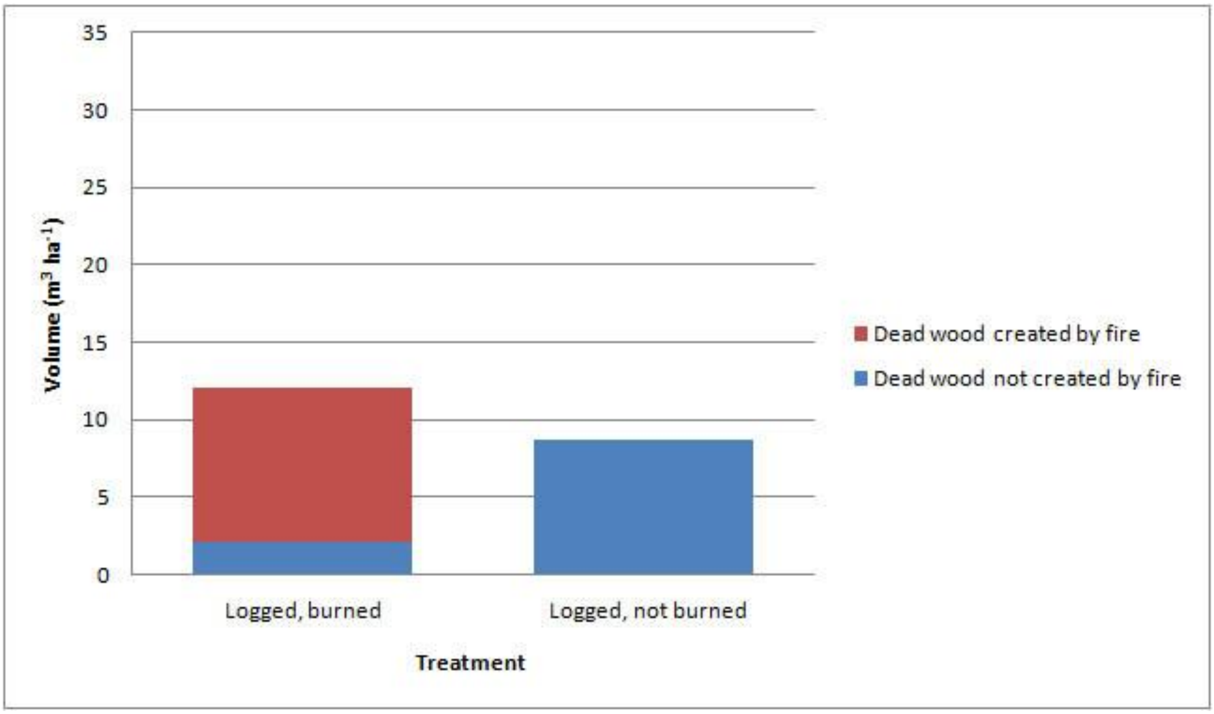

Figure 37. Volume of down woody debris before the fire versus the volume created by the fire, in the area that was logged. All plots were placed in Scots pine dominated forest.

When comparing the areas that were logged, most of the pre-fire down woody debris is found in the area that was not burned. In the area that was affected by the fire, there was little down woody debris from before the fire but a significant volume was created by the fire. In total, the volume is larger in the area affected by the fire than in the area not affected by the fire (fig. 37), pointing to forest fires as an effective producer of dead wood. As noted before, most of the down woody debris found in these areas was logging waste and windfall (seed trees).

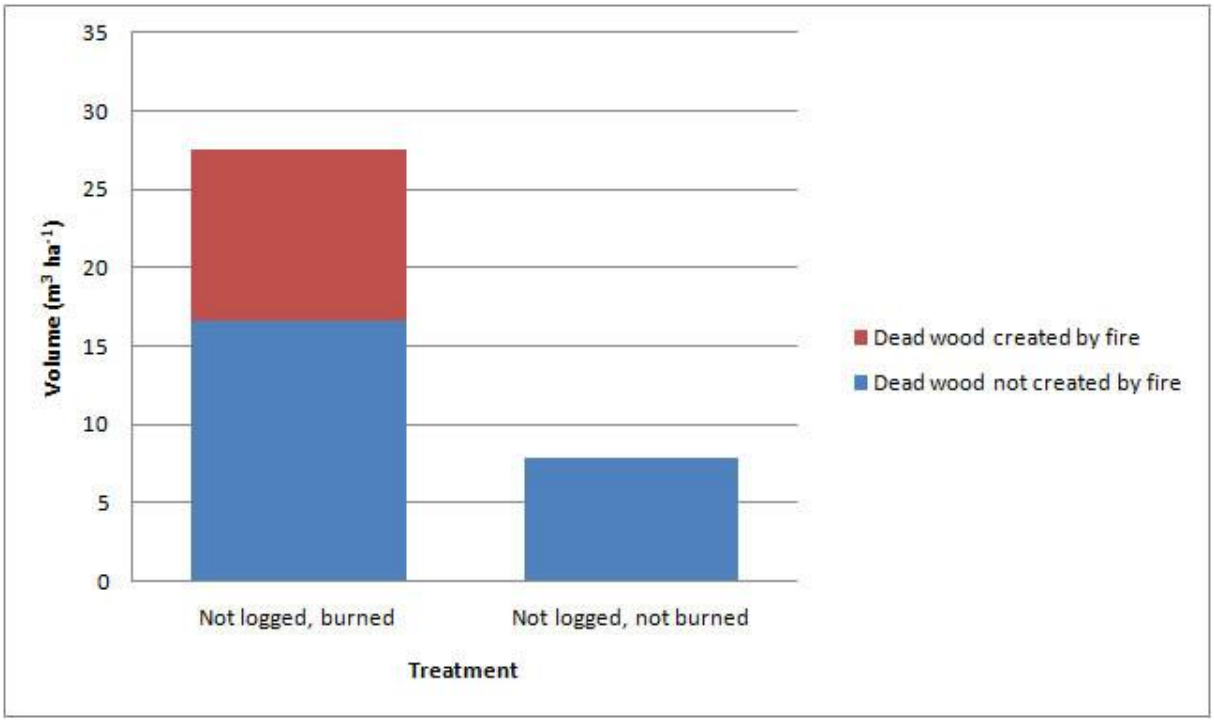

Figure 38. Volume of down woody debris before the fire versus the volume created by the fire, for the area that was not logged. All data for both the Scots pine dominated and the oak dominated area have been included.

The area that was not logged and burned contained a higher volume of down woody debris than the area that was not logged and not burned, both pre- and post forest fire (fig 38). Several tree species were found here. Remnants of previous forestry activity varied.

The area that was not logged and burned contained more down woody debris than the area that was logged and burned, both in relation to what was there before the fire, and in total. However, the volume produced by the fire is similar. In the areas that were not burned the volume of down woody debris was more or less the same (fig. 37 and fig. 38). Note that all plots in areas that were logged were in Scots pine dominated areas, while the plots in areas that were not logged are placed in both Scots pine and oak dominated areas.

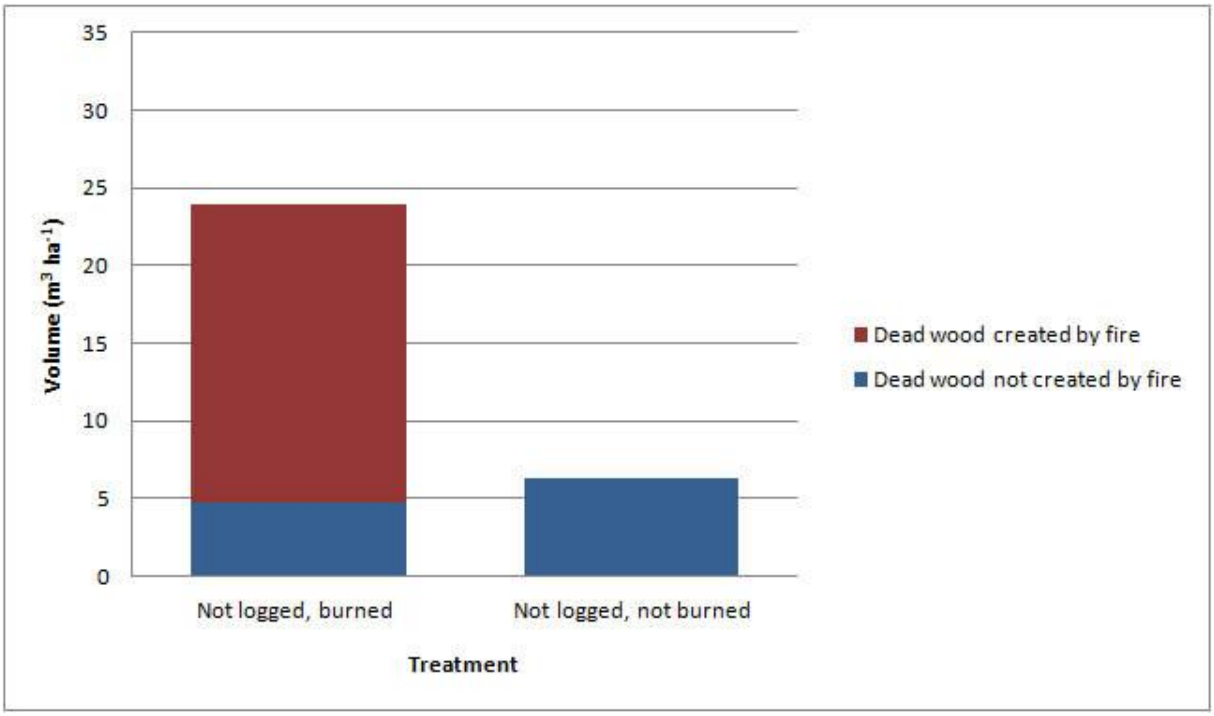

Figure 39. Volume of down woody debris before the fire versus the volume created by the fire, in the area that was dominated by Scots pine.

The forest that was not logged and burned is mostly Scots pine, with some deciduous trees, mostly aspen and birch. Most of the down woody debris was created by the fire. The forest that was not logged and not burned is a managed Scots pine forest. The down woody debris is either waste from a thinning or remnants from the last logging (fig. 39). The fire in these areas was severe.

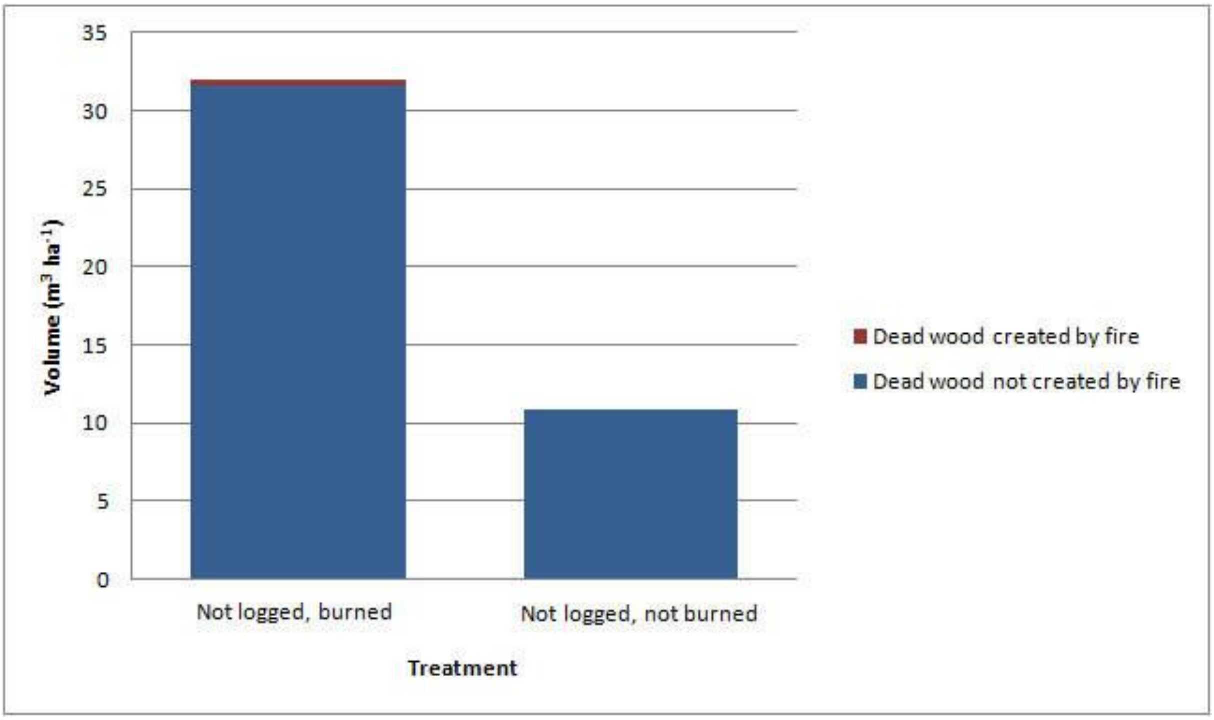

Figure 40. Volume of down woody debris before the fire versus the volume created by the fire for the area that was not logged and dominated by oak.

In the area dominated by oak, there was a larger volume of down woody debris than in the area dominated by Scots pine, both pre- and post forest fire. The areas in this figure were mostly unmanaged deciduous forests and fire refuges. The severity of the fire was low in most of the area that was burned (fig. 40). As a result the fire did not destroy the down woody debris already present, and neither did it create much new down dead wood.

There was more down woody debris in the oak dominated forest compared to the Scots pine dominated forest. There was also more down woody debris where there has been a forest fire, compared to where there has not been a fire, when contrasting the two areas with Scots pine and the two areas with oak.

3.4 Site index

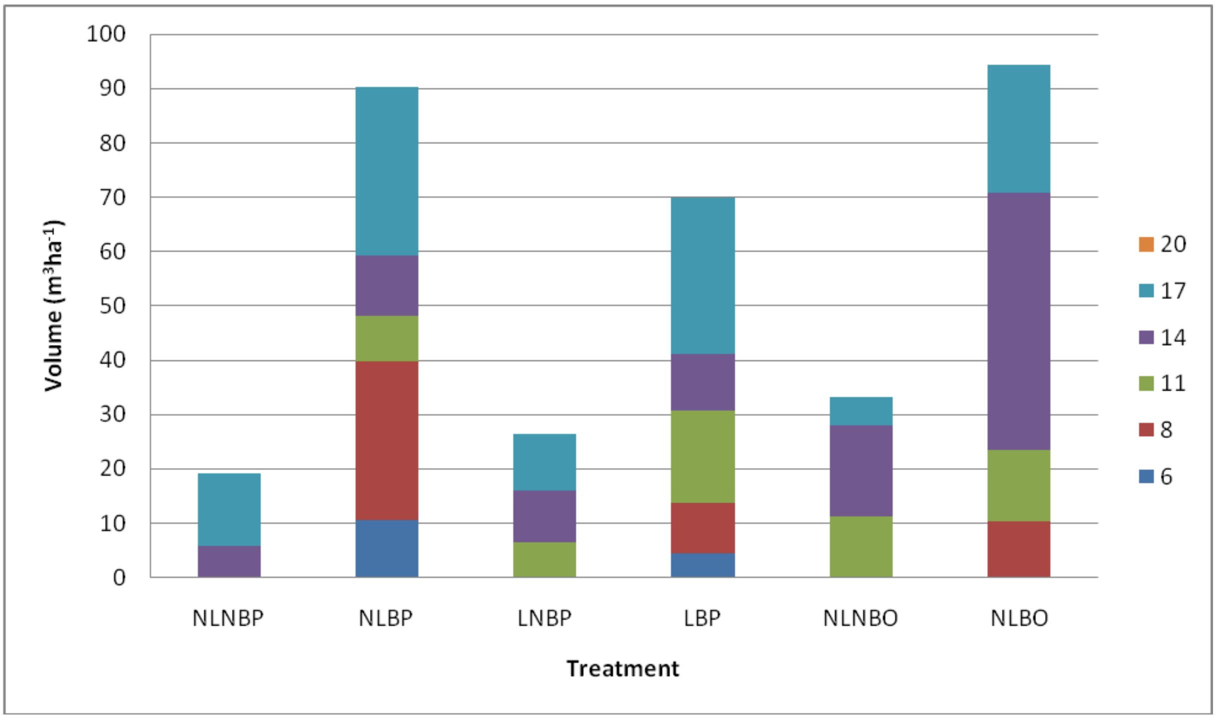

Figure 41. Volume of down woody debris for each site index and each treatment type. NLNBP (not logged, not burned, Scots pine dominated forest), NLBP (not logged, burned, Scots pine dominated forest), LNBP (logged not burned, Scots pine dominated forest), LBP (logged and burned, Scots pine dominated forest), NLNBO (not logged, not burned, oak dominated forest), NLBO (not logged, burned, oak dominated forest).

Figure 41 shows the distribution of down woody debris for the different site indices and the different treatment types. Site index 6 is only found in the area that was not logged and burned and in the area that was logged and burned in the Scots pine dominated areas. Site indices 14 and 17 are represented in all treatment classes. All treatment classes but NLNBP have plots in areas with site index 11, and site index 8 is represented in three of the treatment classes. There is a trend for larger volume of down woody debris in the higher site index classes.

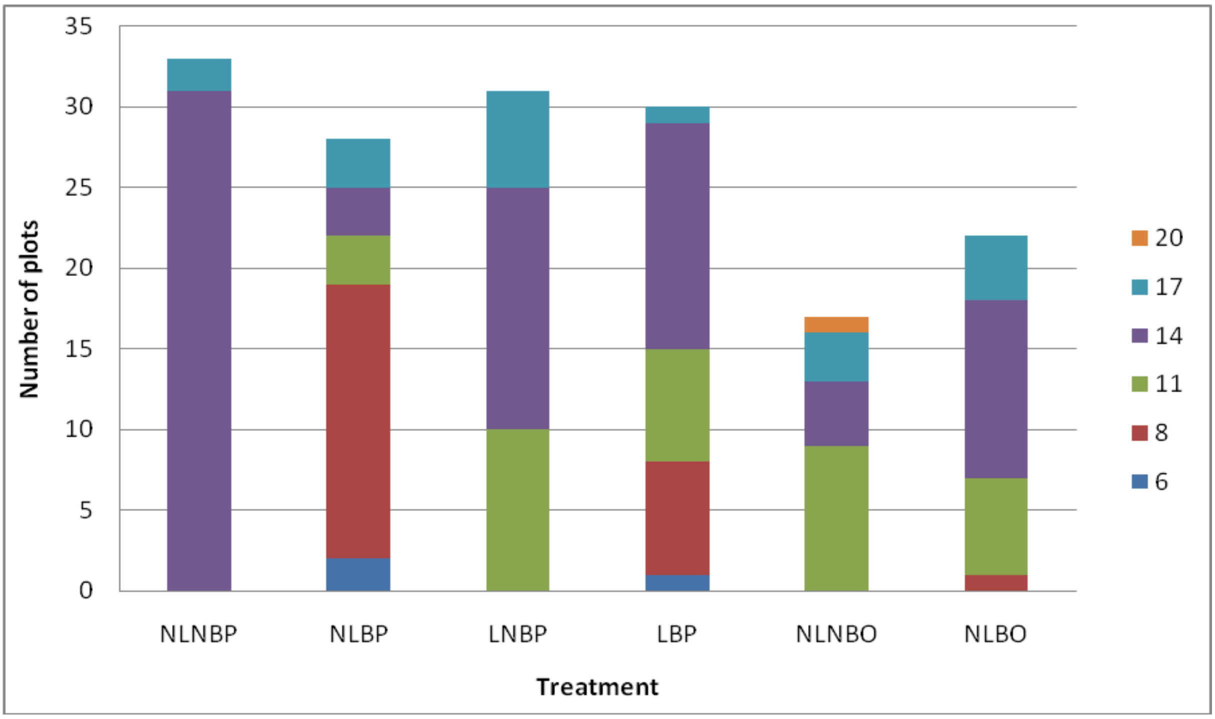

Figure 42. Number of plots for each site index and each treatment type. NLNBP (not logged, not burned, Scots pine dominated forest), NLBP (not logged, burned, Scots pine dominated forest), LNBP (logged not burned, Scots pine dominated forest), LBP (logged and burned, Scots pine dominated forest), NLNBO (not logged, not burned, oak dominated forest), NLBO (not logged, burned, oak dominated forest).

Figure 42 illustrates the dispersal of plots by site index and treatment type. There are 161 plots in total. Seventy eight plots, which is just under half of the plots, are placed in areas with site index 14. There are 35 plots on site index 11, 25 plots on site index 8 and 19 plots on site index 17. There are only 3 plots on site index 6 and 1 plot on site index 20.

4. Discussion

4.1 Volume of down woody debris

In the Scots pine dominated area the volume of down woody debris found in the plots in the not logged and burned area varied between nil and 96.5 m^3ha^{-1}, and the mean value is 24 m^3ha^{-1}. In the area that was logged and burned the volume varied between nil and 42 m^3ha^{-1}, with a mean value of 12 m^3ha^{-1}. The logged and not burned area had volumes varying from nil to 28 m^3ha^{-1}, and a mean value of 8.7 m^3ha^{-1}. Volumes in the area that was not logged and not burned varied between nil and 51.4 m^3ha^{-1}, and the mean value is 6.3 m^3ha^{-1}.

There are many studies that look at the amount of CWD in Scots pine (or Scots pine mix) boreal forests in Fennoscandia, both in unmanaged and managed forests, and in areas affected by forest fires or where one cannot find remnants of fires (Ekbom et al. 2006; Karjalainen & Kuuluvainen 2002; Linder et al. 1997; Pedlar et al. 2002; Rouvinen & Kuuluvainen 2001; Rouvinen et al. 2002a; Siitonen 2001; Uotila et al. 2001). Ekbom et al. (2006) found that mean volume of CWD in mixed trees managed stands in the central-boreal region in Sweden is 13.8 m^3ha^{-1}, while in unmanaged stands it is 27.5 m^3ha^{-1}. This area had been affected by frequent fires in the past, but these ended around 1900. Karjalainen & Kuuluvainen (2002) found a mean volume of 42.7 m^3ha^{-1} of down woody debris in their reserch area in Vienansalo wilderness in Russian Karelia with old-growth pine dominated forests. There is evidence to suggest fires in the area were mainly low-severity fires, and that the pine trees survived. Linder et al. (1997) found that the volume of dead logs in the Scots pine dominated plots ranged between 28 m^3ha^{-1} and 50 m^3ha^{-1} in protected areas with natural forests in northern Sweden. They found either no remnants of fires, or only fires from before 1888. Rouvinen & Kuuluvainen (2001) found 42.7 m^3ha^{-1} of downed logs on a stand-replacing fire site from the early 19th century and 35.2 m^3ha^{-1} of downed logs on a surface fire cite from 1906, in a mature Scots pine forest in eastern Finland (Karelia area). Rouvinen et al. (2002a) look at volumes of CWD and down logs on several locations in Finland. The data from Häme in south-western Finland was the most interesting in this paper, as this area has a long history of forest utilization. They compared how the amount of fallen CWD in old Scots pine forests varied with human impact, that is natural, selectively logged and managed stands. In natural stands a mean of 20 m^3ha^{-1} of fallen CWD was found, in selectively logged stands the mean was 18.7 m^3ha^{-1} and in managed stands a mean of 4.5 m^3ha^{-1} was found. In managed stands, man-made CWD made up about one-third of the total volume of CWD. Siitonen (2001) found that the average volume of CWD in old Scots pine forests in the south- and middle boreal zone of Fennoscandia varied from 60 m^3ha^{-1} to 120 m^3ha^{-1}, and there was about 70 m^3ha^{-1} in the northern boreal zone. The quantity of CWD constituted 18% to 37% of the total volume. There is some data for younger deciduous forests post fire, and the volume of CWD here seem to be lower than in old-growth stands on similar sites. Uotila et al. (2001) measured down dead wood in eastern Finland and Russian Karelia. In mesic managed forests they found 1.6 m^3ha^{-1} on clear cuts, 14.3 m^3ha^{-1} in mature and 42.4 m^3ha^{-1} in overmature forests. In mesic semi-managed forests they found 34.2 m^3ha^{-1} in burned, 28 m^3ha^{-1} in mature and 49.1 m^3ha^{-1} in old-growth forests. In sub-xeric managed forest they found 22.1 m^3ha^{-1} on clear cuts, 48.4 m^3ha^{-1} in mature and 31.8 m^3ha^{-1} in overmature forests. In sub-xeric semi-managed forests they found 56.5 m^3ha^{-1} in burned, 45.8 m^3ha^{-1} in mature and 36.4 m^3ha^{-1} in old-growth forests. Pedlar et al. (2002) studied different forests in Ontario, Canada, and found that CWD levels were significant higher in mixed (160.8 ± 15.4 m^3ha^{-1}) and deciduous (105.3 ± 14.1 m^3ha^{-1}) forests compared to conifer forests (17.8 ± 4.6 m^3ha^{-1}). The CWD was mostly downed logs of a variety of sizes and decay stages. One year after a fire, in a mixed forest, they found 342.6 ± 60.6 m^3ha^{-1}, which was significantly more than mature mixed forest (160.8 ± 15.4 m^3ha^{-1}) and a recent clearcut (112 ± 35.1 m^3ha^{-1}). Most of the CWD after a fire was standing, in the early stages of decomposing, while in clearcuts it was mostly small pieces of logging waste.

Most of the findings in these studies are substantially larger than mine, for example there should be around 30 m^3ha^{-1} in the area that was not logged and not burned as well as in the area that was logged and burned, and about 40 m^3ha^{-1} in the area that was not logged and burned. There are more down woody debris in the area that was logged and not burned compared to the equivalent in the literature studied. Ekbom et al. (2006) and Linder et al. (1997) studied forests in Sweden, while most of the studies on CWD were from Finland, mainly Finnish Karelia. Pedlar et al. (2002) studied forests in Canada. Often the papers report from areas further north, with different site indices, and different management histories. The fires seemed to be very different, and always further in the past. Also, most of the forests studied in the literature are old-growth forests, often also unmanaged forests, while the forest in my study is younger and managed. Thus the results in the literature cannot be compared directly to the results in the burned or not burned categories in this thesis. Topography may especially have an effect on the short term mortality rates in trees (Rouvinen et al. 2002b), as topography influences fire severity and the exposure to wind. Forestry activity or lack thereof, frequency of disturbances, severity of fire, accessibility, moisture, quantity of exposed bedrocks, site productivity, decomposition rate, latitude, altitude, vegetation type and other human activity all contribute to the varying degrees of CWD found in the forests. A short average fire return interval reduces the amounts found (Siitonen 2001).

At the end of the 1990s, the average amount of down dead wood in productive Norwegian forests was 5.7 m^3ha^{-1}, and in total there was 43 million m^3 (Larsson & Hylen 2007). In Aust-Agder 4.37 m^3ha^{-1} of down dead wood was found in productive Scots pine dominated forests, while 3.26 m^3ha^{-1} was found when considering all Scots pine dominated forests in the area for the years 1994 to 1998 (data from the National Forest Inventory database). In relation to the data from the National Forest Inventory, this difference compared with my data may be explained by the forest fire, the recent logging, or the fact that dead wood volumes are increasing in general (Larsson & Hylen 2007). The method for calculating down wood may also play a part, as the method used in this thesis is different from the method used to find the other results. Data from the National Forest Inventory using this method is unpublished, hence the difference is not yet known.

Among the plots in this study situated in Scots pine dominated forests, there are differences from one area to another. A mean volume of 24 m^3ha^{-1} was found in the area that was not logged and burned. Jönsson & Jonsson (2007) found that the woodland key habitats in their study had a larger volume and greater diversity of CWD compared to mature and overmature managed stands. However the woodland key habitats had a lower volume and density than selectively logged semi-natural forests and old-growth forests. They conclude that previous forestry practices have had a large impact. One must expect the areas that were not logged and burned to have been modified by human activity in the past, even if they have not been logged now, and this may play a part in the volumes of down woody debris found. The presence of MiS areas ("Miljøregistrering i Skog" /Environmental inventories in forest) also influence the volume of down woody debris, as these areas are areas that have been protected because of the biological diversity present, and hence not logged. There are several possible reasons why some areas were not logged. Size of timber and accessibility were contributing factors, but so were the density of trees, and the fact that large sections of the area were protected. Lastly, some areas were potentially too small for there to be a financial incentive to transport logging machinery there.

The areas that were logged and burned in the Scots pine dominated forest had a mean volume of 12 m^3ha^{-1}. They also often, but not always, had easier access from forest roads. Approximately 40% of the seed trees that had been left after the seed tree logging in the burned area fell over in the first year (Nygaard 2010), making up a lot of the down woody debris. Monsanto & Agee (2008) found that units that had been salvage logged had lower log biomass than unsalvaged units, except for the most recently burned site, where salvaged stands had higher log biomass. In my study, the data show that the logged stands had a lower volume of down woody debris than the not logged stands, one year after the fire. The discrepancies between the study by Monsanto & Agee (2008) and my study may be due to differences in study sites and tree species. Monsanto & Agee studied CWD in general, while my study focuses on down woody debris, which makes a difference.

The areas that were logged and not burned in the Scots pine dominated forest had a mean volume of 8.7 m^3ha^{-1}. These areas were all long-term managed Scots pine forest. The down woody debris was mainly residue from logging and windfall of seed trees. Gulbrandsen (1980) found that the total logging residue after a final felling amounted to 5,5% of the standing volume. Hence, in a managed forest significant amounts of dead wood is decomposing on logging sites. A mean volume of 8.7 m^3ha^{-1} is higher than the mean in Norwegian forests (Larsson & Hylen 2007, data from the National Forest Inventory database).

In the not logged and not burned area, in the Scots pine dominated forest, a mean volume of 6.3 m^3ha^{-1} was found. The most recent activity in this area was thinning. Thinning of managed stands reduces the amount of CWD in the mid-succession stage, and short rotations result in little dead logs of large diameters (Siitonen 2001). There are a significant number of plots without any findings in the area that was not logged and not burned, underlining the limited amount of dead wood in a managed Scots pine forest in this area.

Ekbom et al. (2006) and Siitonen (2001) found that unmanaged areas contained about twice as much volume of CWD as managed stands, and that the difference between natural and managed stands are the largest right after a disturbance (Siitonen 2001). Most of the plots in this study were placed in areas that had been managed, but the area that was not logged and burned was the least managed. A mean volume of 24 m^3ha^{-1} compared to the mean volume of 12 m^3ha^{-1} in the area that was logged and burned in my study is in agreement with the results of Ekbom et al. (2006) and Siitonen (2001).

Data was also collected in oak dominated forests, but only in not logged forests. Data was collected in both burned and not burned areas. NLNBP has a mean value of 6.3 m^3ha^{-1}, NLBP had a mean value of 24 m^3ha^{-1}, NLNBO had a mean value of 10.8 m^3ha^{-1} and NLBO had a mean value of 32 m^3ha^{-1}. The areas dominated by oak contained more cubic metres per ha of down woody debris compared to the equivalent dominated by Scots pine. Relatively, there are more dead wood in deciduous forest than in conifer forest (Levende Skog 1998). Deciduous trees have different roots compared with, for example, Scots pine, resulting in the fire affecting the various tree species' roots in different ways. In the studied area the soil in the deciduous forests is deeper, which makes it less susceptible to drought, and also less susceptible to severe fires. In the areas dominated by Scots pine the down woody debris was mostly supplied by the fire, while in the areas dominated by oak, there was a mixture of down dead wood because of the fire and down dead wood that had fallen over because the trees age and die. The variety in the data may partly be explained by spatial variations.

Creating CWD in young managed forests may be a way to eliminate the negative effects of logging and other forestry practices on dead-wood associated species. This might add to the effect of protecting forests, not come instead of it (Kouki et al. 2001). Jönsson & Jonsson (2007) call for more burned wood within the woodland key habitats, as this type of substrate is rare. Controlling the amounts of down woody debris can be used to manage fires for ecological restoration purposes (Lilja et al. 2005). Hence, protecting a forested area is not enough with regards to the quality of dead wood, one also has to make sure that there is enough variation within the substrate. Allowing for old forests and forest fires are tools to create this variation.

4.2 Severity of fire and amount of down woody debris

Figure 28 illustrates the link between the severity of fire and the amount of down woody debris found in the area that was logged and burned. Most of this was found in areas where the severity of the fire was medium to high. Mitchell et al. (2009) found that fuel reduction treatments always reduced fire severity in the forests they studied (the east Cascades ponderosa pine (*Pinus ponderosa)* forests, the west Cascades western hemlock (*Tsuga heterophylla*) and Douglas-fir (*Pseudotsuga menziesii*) forests, and the Coast Range western hemlock-Sitka spruce (*Picea sitchensis*) forests in the Pacific Northwest). Smirnova et al.

(2008) examine forest fire intensity, that is, the energy produced by a fire in an area, during a period of time. A moderate intensity fire creates a smaller volume of CWD compared to a high intensity fire. On the other hand, Boulanger et al. (2011) analysed fire severity in connection with the snag falling rate for spruce species. One may expect a severe fire to increase the snag falling rate, as exposed roots lead to windfall. However, a severe fire slowed the snag falling rate compared to lightly burned trees. This is probably because lightly burned trees decompose faster, and are hence more susceptible to stem breakage. However, one may argue that this study is invalid in the context of this thesis, as Boulanger et al. study spruce species 17 years after the fire. In my study more plots are placed in areas where the severity of the fire was medium to high, hence it is logical that a larger relative volume of down woody debris was found here. Another possibility is that logs that were only lightly burned had been removed in the post-fire logging.

Results for the not logged and burned areas include data from both Scots pine dominated forests and oak dominated forests. When including all the data, one notices that the amount of dead wood found and number of plots laid out are more evenly spread out, compared to the data for logged and burned. Most of the plots where the severity was high were in areas dominated by Scots pine, while a low severity characterised the oak dominated forest. The areas dominated by oak mostly had a richer ground vegetation, and they seemed moister. This difference partly explain the larger amount of down woody debris recorded in the oak dominated area.

4.3 Down woody debris before and after the fire

Lilja et al. (2005) conducted experiments where they increased the amount of CWD in a managed Norway spruce stand. Down logs and logging waste were created by a cutting. The three levels of CWD left on the ground were 5 m^3ha^{-1} (corresponding to current levels of standing retention trees left on clear-cuts in Finland), 30 m^3ha^{-1} and 60 m^3ha^{-1}. Surplus logs were harvested and removed from the sites. Afterwards a prescribed burning was set. They found that the quantity and quality of CWD after the fire was dependent on the amounts of CWD in the forest before the fire. The most effective burning was achieved with the most CWD already present, while in a forest with no or little down woody debris the fire was not severe enough to kill standing trees. However, a prescribed burning differs from wild fires in producing down woody debris.

One explanation for the small amounts of down woody debris in the area that was logged and burned in figure 37, may be that the pre-fire down woody debris burned. Tinker & Knight (2000) found that approximately 8% of the downed woody debris was consumed by fire and an additional 8% was converted to charcoal, for an estimated loss of about 16% in Yellowstone National Park lodgepole pine forests. In a lot of this area the fire severity was medium, medium to high or high, supporting the assumption that the fire destroyed the down woody debris present before the fire.

When studying the figures representing the areas that were not logged, one notices how big the differences are between the Scots pine dominated forest and the oak dominated forest with regards to pre- and post fire volumes of down woody debris, as well as the differences in total volumes. The figure that compares forest that was not logged and burned, with forest that was not logged and not burned, in Scots pine dominated forests, compares less managed Scots pine forests with some birch and aspen with an actively managed Scots pine forest. The fire was severe, probably destroying a lot of the pre-fire down woody debris, explaining the slight difference in pre-fire down woody debris found in the two categories. The fire created little down woody debris in the forest dominated by oak. One reason may be that the severity of the fire was too low, not consuming pre-fire down woody debris, and neither creating much new down woody debris. In the oak dominated forests traces of logging activities were not visible, giving the forest a more natural dynamic, with trees dying and decaying in the forest to a larger extent than in managed forests. The areas that did not burn were either fire refuges or outside the fire boundaries.

4.4 Site index

There is generally more CWD in sites with a high productivity (Ranius et al. 2003). In my findings there is a trend that show that a larger part of the down woody debris was found in sites with medium or high site index. The volumes have been adjusted for the number of plots, however having fewer plots increases the chance of the plots not being representative, and therefore giving a wrong impression of the volume in the category. Site index 20 is represented by only one plot, and no down woody debris was found here, making it atypical of what one may expect in an area with high productivity. Only 3 plots represent site index 6, which weaken the validity of the results. In comparison, 78 plots represent site index 14, making the mean volume more reliable.

Conclusion

The aim of this thesis was to discover volume of down woody debris in the forest in Aust-Agder county in Norway, particularly in relation to a forest fire. The largest volume of down woody debris in the Scots pine dominated area was found in the not logged and burned area. Taking all data into consideration the largest volume was found in the not logged and burned, oak dominated area, while the smallest volume was found in not logged, not burned Scots pine dominated area. These results support other studies that found a higher volume of both down woody debris and CWD in less managed forests, and in forests affected by forest fires, as well as larger volumes found in areas with higher site indices. However, many studies found more down woody debris compared to this study. On the other hand, this study found more down woody debris compared to the last survey by the National Forest Inventory. This may be explained by differences in the forests, as well as differences in forestry practises, and differences in measuring methods. The severity was generally higher in Scots pine dominated forests compared to oak dominated forests, affecting the pre-and post fire levels of down woody debris. Where the fire was severe one may assume that more pre-fire down woody debris was destroyed, but also that the fire was a more effective producer of dead wood.

As knowledge of the importance of dead wood in forests grow, efforts are made to increase volumes, and data shows that general volumes of CWD in Norway are increasing. Two areas have been protected in Froland, leaving the post-fire dead wood in the forest, and also allowing trees to die and decay as time passes. The volume of CWD should increase, playing an important role in maintaining biological diversity.

There is a lot of information relating to forest fires in the world, as this information is seen as important. The information does not only relate to volumes found, or biological diversity, but also to human interference with natural cycles, management practices after forest fires, atmospheric carbon cycles and so on. However, there is not enough information on forest fires specifically related to Norwegian conditions. This must change, as a lot of the knowledge from other countries cannot be applied to Norway. The recent projects are a step in the right direction, but more information is still needed to help Norwegian scientists maintain biological diversity.

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