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Species richness and abundance of saproxylic beetles in power-line corridors: effects of different management practices

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Preface

The long and adventurous journey of learning, sampling and writing this thesis could not have happened without my enthusiastic, positive and helpful supervisors: Katrine Eldegard and Stein R. Moe. Thank you so much for the opportunity to write about my favourite insects, the beetles! I have sent you “hundreds” of drafts throughout the writing period, and I am so thankful for the comments I received. I want to thank Katrine especially, for the statistical support. Further on I want to thank both of you for letting me work during and after my thesis with field and lab work, with even more beetles!

Secondly I feel that it is important to thank Jenny Benum Lorange for being my best friend and for always being so happy and positive. Without you, my field work would have been hard to follow through. I want to thank you for driving, walking, measuring, carrying, tenting, singing along with The Wombats, memories and for the lovely car you owned and that we used. Even though the car broke down on our last visit to the last site. You also helped me a lot with insect sorting at the lab and without your help I would not be finished in time.

I want to thank Markus Sydenham for deploying the fly interception traps one month before sampling and Statnett for founding the project. I also want to thank Fredrik Stenersrød, my boyfriend, who carried traps with me, from the field to the storage, on our last sampling trip. Without you, I might never even have started on a bachelor in biology, and would certainly not complete this master degree in General Ecology at the Norwegian University of Life Sciences (NMBU). Also my parents, Annette and Gunnar Hermansen, have been great help with positive words, their lovely visits to Ås and for economical support. I also have to thank the incredible and fast working, Sindre Ligaard, who identified and categorised approximately 30.000 sampled beetles for my thesis. My very good friend Rannveig M. Jacobsen have helped me a lot with issues concerning my (frustrations of the) thesis, what would I do without you, thank you!

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Abstract

Beetles (Coleoptera) are a major component of forest biodiversity. Approximately 900 of the 3558 known beetle species in Norway are facultative or obligate saproxylic, that is, directly or indirectly dependent on dead wood. Saproxylic beetles are considered vulnerable in the Norwegian forest landscape, due to modern forestry practices that typically reduce the abundance of dead wood. Establishment and maintenance cutting of power-line corridors resembles clear-cutting of forest. However, after cutting, all the woody biomass is usually left behind in the power-line corridors, and thus dead wood accumulate in the corridors. The aim of this study was to investigate whether power-line clearings can provide suitable habitats for saproxylic beetles, and if abundance and richness was influenced by management practice. This was done by carrying out a large-scale field experiment at 19 sites in southeast Norway, with three different treatments ('cut' where the biomass was left in the treatment after cutting , 'cut and removed' where the biomass was removed from the treatment after cutting and 'uncut' where the trees were not cut). Beetles were sampled with flight interception traps: at each site, three traps were deployed in late spring in each treatment. The traps sampled beetles continuously throughout the summer 2013, and sampled individuals were collected once a month and brought to the lab for species identification. In total 29 298 beetles were sampled and identified to 856 species. 22 105 beetle individuals with 420 species were classified as saproxylic. Saproxylic beetle abundance was positively affected by the increasing amount of dead wood in 'cut and removed' and 'uncut', while in 'cut' treatments there was a threshold level. 7189 beetle individuals with 436 species were classified as not saproxylic. The abundance of not saproxylic beetles was low in all treatments, highest in 'cut' thereafter 'cut and removed' and lowest in the 'uncut' treatments. There were no specific correlations with increasing amount of dead wood in the treatments. Species richness of saproxylic beetles was high while not saproxylic species richness was low in all treatments. There were positive effects of sun-exposure for both saproxylic and not saproxylic beetles in 'cut' and 'cut and removed' treatments while in 'uncut' treatments the species richness was not affected by sun-exposure.

My results suggest that frequent cutting and no biomass removal of early successional forest in power-line corridors prevent the loss of dead wood dependent beetles.

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1. Introduction

Because of intense utilisation and deforestation the European forest cover is strongly reduced. Managed forests are generally known to have negative effects on biodiversity (Stenbacka et al., 2010). Boreal forest is the main vegetation type in Europe and high levels of forest management leads to concerns about forest biodiversity (Bengtsson et al., 2000). Norway has variations in climate, topography and geological structure and the variation in nature types, species and habitats are therefore high. In a geological perspective, the Norwegian forests are young and unstable. In the past 500 years humans have used nature for industrial and other financial purposes. (Framstad et al., 2002). Natural occurrence of for example fires, harsh weather (rain and snow storms) is the natural cause for the mosaic structures in Norwegian forests. (Framstad et al., 2002).

Biological diversity in Europe are not only high in living, standing forests but are also associated with dead wood (Lassauce et al., 2011). The Ministry of Climate and Environment in Norway decided in 2009 to prevent loss of biodiversity in nature (Naturmangfoldloven 2009). The main goal of this law is to improve management of Norwegian nature through sustainable use and conservation. Preservations of dead wood are important because the woody material host many organisms. Globally, there are four major orders of insects that live in decaying wood: gnats and flies (Diptera), wasps, bees and ants (Hymenoptera), termites (Isoptera) and dead wood is highly associated with beetles (Coleoptera) (Stokland et al., 2012, Lassauce et al., 2011). Fruiting bodies of fungi growing on the surface of a tree (often dying trees) are associated with many invertebrate species and the fruiting bodies are used by mature insects as a food source and for larva development (Siitonen, 2012). A tree trunk may get damaged by a forest fire and can provide many different microhabitats for many different organisms, such as cicadas (Hemiptera) that break the bark and use the sap underneath as a food source. Also fungi can destroy the phloem layer and make room for bacterial growth which kills the tree and again make room for insects to invade (Siitonen, 2012). Tree cavities are another option for several other microhabitats and the cavity may grow wider and deeper along with the attraction of organisms that inhabit these. This may again attract for example predators to the same cavity (Speight, 1989). Speight (1989) defined saproxylic species of invertebrates as species that are dependent, during some part of their cycle, upon the dead or dying wood of moribund or dead trees (standing or fallen), or upon wood-inhabiting fungi, or upon the presence of other saproxylics. In old trees a cavity may host saproxylic species such as beetles, for several hundreds of years.

Some saproxylic organisms thrive only in dead wood exposed to sun, whereas others inhabit the side of a tree lying in the shadows (Siitonen, 2012). The humidity on the forest floor created by shading fallen trees and branches are habitats that attract invertebrates that require humid and shaded environments (Siitonen, 2012). In dead wood there are also many other important microhabitats such as branches, roots, fire scars, bark, phloem, sapwood and heartwood. When trees and trunks decompose, different saproxylic species will concentrate on inhabiting the different decay stages and different parts of the dead wood (Speight, 1989, Siitonen, 2001). Saproxylic beetles are important for the forest recirculation of dying and dead wood, since they inhabit the dead wood and break down the wood fibre and release nutrients to the ground.

Of all the groups of insects that live in dead or decaying wood, beetles are the best known group (Stokland et al., 2012). Beetles are the largest order of invertebrates in Norway with 3558 known species. After the publication of the Norwegian 2006 Red List (Kålås et al., 2006), 54 new beetle species has been found (Kålås et al., 2010). Approximately 500 out of 3558 recorded beetle species in Norway are defined as threatened or regionally extinct (Kålås et al., 2010). Coleoptera inhabit a broad range of habitats, not just on land such as inside and outside flowers, trees and roots but also in fresh water and some in marine ecosystems. Coleoptera thrive in fresh or dead wood material in all stages of decomposition (Gullan and Cranston, 2010). Saproxylic beetles deploy their eggs inside the wood and the larva from this egg use the dead wood as shelter and food source. The obligate saproxylic beetles may spend only parts of their life or almost their whole lifecycle inside dead wood and would go extinct without access to dead wood materials (Stokland et al., 2012). Approximately 700 beetle species in Norway are obligate saproxylic and 200 beetle species are facultative saproxylic (Økland et al., 1996a). Facultative saproxylic insects use dead wood as a source for food or to complete a life cycle, but they also use other sources, like non-saproxylic mycorrhizal fungi. Without dead wood the amount of facultative saproxylic may decrease but not completely go extinct. Species that only visit dead wood and are not dependent on this resource, should not be defined as saproxylic species (in this paper called 'not saproxylic') and would not suffer a population decline if all dead wood materials were to be removed from the forest (Stokland et al., 2012).

Continuous-cover habitats, are often dominated by shade tolerant and long-lived plant species. These habitats are found from the tropic through temperate areas to boreal forests. In this forest type there might occur dead wood, but only in small scale, often not more than a few hectares at a time. Since the occurrence of dead wood may only be one dead standing tree, or only one log on the forest floor there might be a long distance between dead trees (50- 100 meters) (Stokland et al., 2012) and thus this habitat will not be favoured by saproxylic beetle species because some of these insects disperse their offspring in short distances (Ranius, 2006).

Modern forestry where they leave no woody material behind after cutting and use the dead wood to produce biofuel is a relatively new forest management. Because of the economically benefits, this forest management is considered to be the best management system. Plantation forestry means that there is not a natural selection of tree species or a natural choice of suitable plant materials in the area. It also often means that the trees before cutting are at same age and also the forest and forest floor are a monoculture with no dead wood on the forest floor, also called plantation forestry (Stokland et al., 2012). There are clear reasons for the hard criticism against clear-cuts considering the abundance of dead wood. Harvesting the forest and utilizing all its qualities to produce biofuel, control pest outbreaks and reduce waste are not a long term preservation of species richness associated with dead wood. Often, after clear-cuts, over 90% of the volumes of dead wood are being removed. Also the rotation time are shortened because the forest are being cut too young to produce any dead wood (Riffell et al., 2011, Stokland et al., 2012). One of the most important preservations of biodiversity in boreal forest is maintenance of the forest floor by leaving parts of trees (with diameter < 10 cm) and dead wood materials (with diameter > 10 cm) behind after cutting and let the woody material decay. The dead wood are a key habitat for many threatened species and often the only way to preserve insect species from going extinct (Ranius et al., 2003).

So far the biodiversity and conservation values of old forests have gained a lot of attention, including dead wood in old forests. Recently there has been increasing focus to the importance of conservation of early successional forest to conserve animal habitats and species (King and Schlossberg, 2014)**.** Natural disturbance dynamics includes significant numbers of early successional forests and the disturbances might be a key component in ecology aspects (Turner, 2010). Clear-cut is similar to stand- replacing habitats, in that, after a big disturbance has caused the whole forest to change dramatically from standing living trees to fallen dead trees. Usually these changes are made by natural disturbances, such as big storms or forest fires. Stand-replacing disturbance supply dead wood to the forest and thus give an open habitat with sun-exposure and an early (reset) successional effect (Stokland et al., 2012). After such a disturbance, the habitat has changed dramatically from shaded above-ground habitat with no woody material to a habitat with sun-exposure and a forest floor almost covered with dead wood. Now the shade-intolerant tree species may become an early successional habitat and be pioneers for a new closed and shadow dominated forest. In the meantime the dead wood increases the saproxylic beetles diversity (Stokland et al., 2012) and the successional change offer more diverse habitats with preferable properties for a lot more species than before because restricted resources such as light, humidity, and nutrients are now accessible (Swanson et al., 2010). Also in comparison to continuous-cover, stand-replacing has a higher amount of dead wood and thus saproxylic beetles prefer stand- replacing habitats because of the amount and the short distance between dead wood. In this paper the clear-cut are referred to ‘cut’ treatment.

An other type of human disturbance, which results in both early successional forests and considerable amount of dead wood, is establishment and maintenance of power-line corridors. Typically all the woody vegetation is being cut every 5-10 years, and the dead woody biomass is left behind in the corridors after cutting. The dead wood biomass includes twigs, branches and small tree trunks which has mostly a diameter less than 3cm after cutting. The dead wood is piled up in layers which lead to sun- exposed and dry wood at the top, as well as dark and moist wood underneath. In this study I carried out a field experiment with different levels of disturbances, i.e. different management practices. Clear areas under power-lines resemble clear-cuts, but differed from clear-cuts in that the vegetation is maintained in an early successional stage, whereas in clear-cuts, the aim is to re-vegetate the sites. Power-line clearings also differed from clear-cuts in that the dead wood biomasses are not removed after cutting. I focused on how different management regimes of power-line corridors affect saproxylic beetles and I used an experimental approach where the vegetation below the power-lines was ‘cut’, ‘cut with biomass removed’ (in this paper termed ‘cut and removed’) or ‘uncut’. The aim of the experiment was to investigate possible increases or decreases in diversity of beetle richness and abundance in response to three different forest managements in power-line corridors.

My predictions are:

1) Abundance and species richness of saproxylic beetles are higher in the ‘cut’ treatment because of higher amount of dead wood (Økland et al., 1996a).

2) Abundance and species richness of saproxylic beetles are relatively higher than not saproxylic beetles in ‘cut’ and ‘cut and removed’ treatments.

3) Sun-exposure was measured in ‘Cut’, ’ Cut and Remove’ and ‘uncut’ treatments to investigate if there was a relationship between sun-exposure and beetle abundance and species richness of saproxylic beetles.

4) Wide power-line corridor might provide the ‘cut’ treatment with higher amount of dead wood and might therefore host a larger number of saproxylic beetles than ‘cut’ treatment in narrow power-line corridor.

2. Methods

2.1. Study system and study area

All the sites were located in forest, mainly boreal forest. The most common forest type in my study was bilberry spruce forest (*Eu-Piceetum myrtilletosum*), which develops in moraine soil with poor nutrition. (Fremstad, 1997). The study system in the power-line corridor consisted of early successional stages of boreal coniferous or mixed coniferous forests with the Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and birch (*Betula* spp). Spruce and Pine have a huge variety in habitat preferences and grow in areas from dry-land to mire and wet-land. Pine prefers to grow in dry soil with rocky forest floor in areas with continental climate and a high fire frequency. Spruce prefers mesic-moist soil in areas with oceanic climate and low fire frequency (Esseen et al., 1997). There are three species of birch in Norway; silver birch (*Betula pendula*) which grows almost everywhere in Norway except in costal areas, white birch (*Betula pubescens*) grows all over Norway and on high altitude and dwarf birch (*Betula nana*) grows in mountains and in mire (Skogoglandskap 2014). Silver birch thrives in sun exposed areas with oxygen rich moist or dry soil (Eplante 2013). Because of the wide geographic distribution of the sites (Figure 1), there was considerable among-site variation in climate between the sites, with relatively warm inland areas in the south and colder mountains inland areas in the north. In Norway, almost all of the forested area is intensively managed and used for economical purposes, and the power-line corridors included in this study transacted managed forests.

2.1.1 Site selection and design

The 19 study sites were located in power-line corridors throughout south eastern Norway (Figure 1). The sites where chosen in collaboration with Statnett (the main electricity grid owner in Norway), in order to identify potential sites, that is, sites with extensive re-growth of trees in the corridors, and maintenance clearing planned by Statnett in the near future. My data in this thesis is a part of an ongoing project, which aims at increasing our understanding of how power-line corridor forest management impact the biodiversity.

The sites ranged from Lillehammer in north (latitude: 61.11 and longitude: 10.57) to Sarpsborg in east (latitude: 59.33 and longitude 10.43) and from Gol in west (latitude: 60.69 and longitude: 8.95) to Tønsberg in south (latitude: 60.82 and longitude: 11.28). The average temperature for 2013 in January was -7.1^{o}C. The warmest temperature was -2.9^{o}C and the coldest temperature was -9.7^{o}C. The average temperature in growth season 2013 (June, July and August) was 13.4^{o}C, the warmest temperature was on average 15.5^{o}C and the coldest was on average 10.8^{o}C. The average annual precipitation in 2013 was 765mm (ranged from 1034mm to 541mm).

2.1.2 Experimental design

We carried out a field experiment with three different treatments, corresponding to three different intensities of management (human disturbance). The three levels of disturbance were: 1) 'cut' (all the trees were 'cut', but not removed) 2) 'cut and removed' (all the trees were cut, and thereafter removed) and 'uncut' (no trees were cut) (Figure 2). In the treatment 'cut and removed', the removed biomass was stored at least 10 meters away from the outer border of the experimental area (Figure 2). The experimental areas in the narrow power-line corridors (single set of areal lines) measured 30 x 38 meters and in the wide power-line corridors (double set of areal lines) the treatments measured 30x 56 meters. The treatments were located at least 30 meters away from each other (Figure 3).

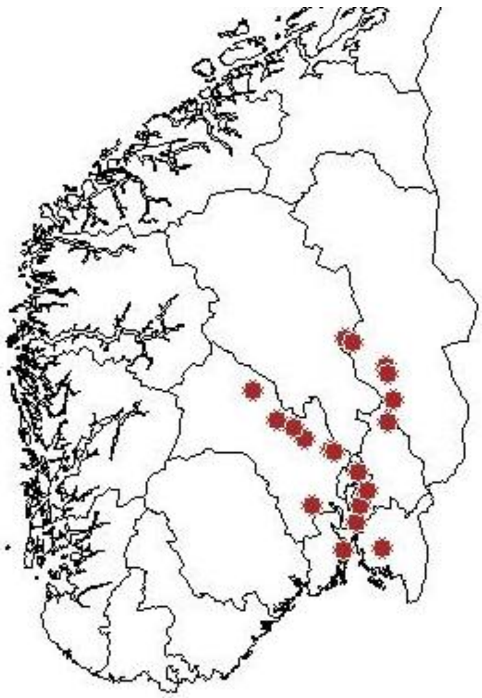

Figure.1 Geographical distribution of the 19 sites where the beetles were collected with flight interception traps (Figure 4).

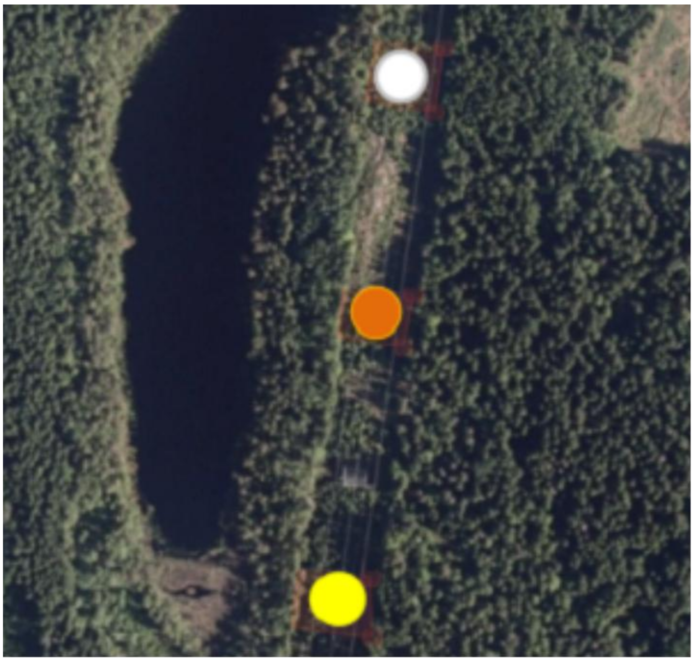

Figure 2. Areal photo of one of the study sites in a power-line corridor showing the three locations of three treatments in different colours (the photo was taken before the three treatments was carried out). 1) Yellow = cut and trees removed, 2) orange = cut and trees not removed, 3) white = uncut. Photo is taken from http://www.norgeibilder.no

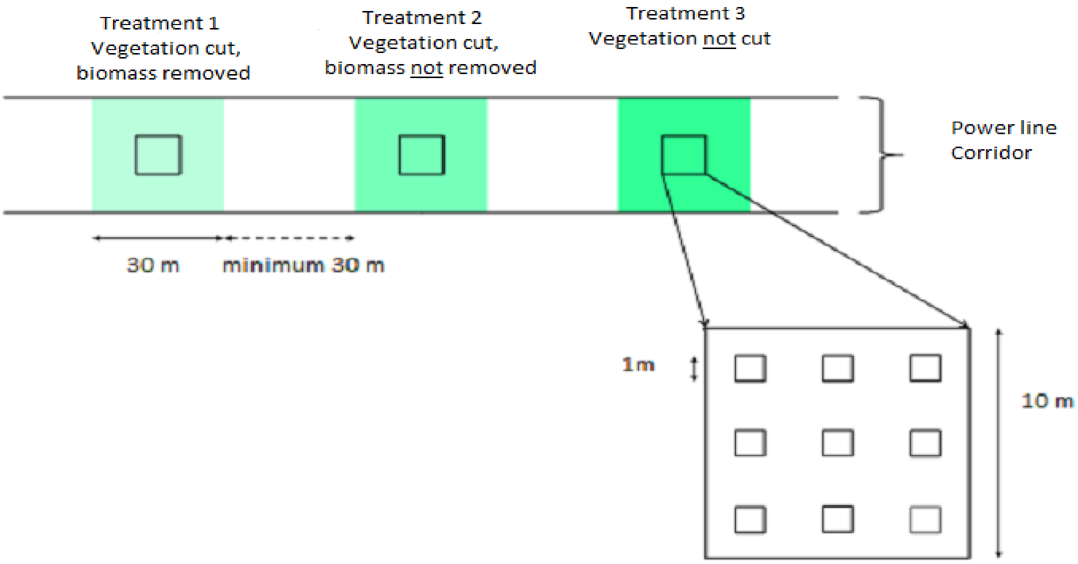

Figure 3. Figure showing how dead wood was estimate within the nine 1 x 1m quadrates (see section 2.2.1) and how the three treatments under power-line grids was conducted. In each treatment three interception traps were deployed to collect beetles (see section 2.2.2).

2.2 Data collection

Figure 4. One out of three flight interception traps in a wide power-line corridor (double set of areal lines). Photo: Fredrik Stenersrød.

2.2.1 Environmental variables sampled

Inside the nine plots shown in figure 3, the amount of dead wood was recorded by measuring the percentage of ground covered by dead wood by visual estimation, that is the summed percentages of freshly 'cut' dead wood covering the ground with a diameter >3cm, older dead wood covering the ground with diameter >3cm, stumps >3cm and cover of standing dead trees (trunk). The counts were done in nine 1m x 1m plots in each of the three experimental areas (Figure 3) in each of the 19 sites. Each plot was located approximately 5m from each other.

Aspect, slope and latitude of each plot were measured, and these were used to calculate Okes`s radiation index (RI), a simple measure of plot-scale local climate (Oke 1987). Narrow and wide corridors were measured with aerial photo.

2.2.2 Flight interception traps

19 sites each with 9 traps is a total of 171 interception traps deployed and distributed out in the power-line corridors (3 traps in each treatment at each site). The sites were distributed with 12 sites with 108 interception traps in narrow power-line corridors and 7 sites with 63 interception traps in wide power-line corridors. These traps were deployed in the end of May 2013 and emptied and refilled with preservation fluid once per month from June to September.

The trap setup is shown in the picture above (Figure 4). The trap was made of 3 bamboo sticks with a rope that tied the three ends together. The ends tied together made the top of the trap and one thin rope or thin steel wire tied two transparent plexiglas screens, measuring 370 x 210 mm, in a form of a cross. A funnel was tied up right under the plexiglas screens and the collection bottle was placed right underneath the funnel. The collection bottles were removable and filled with a mix of 50% green propylene glycol, 50% water and a few drop of detergent (Zalo, Lilleborg, Norway). This mix is used to preserve the insects that fall into the cup, Zalo is a washing detergent and was added to break the surface tension so that the insects that fall into the cup cannot survive and fly out again. The bottles also had drainage holes, to prevent loss of insects. The removable bottles were replaced once every month with new bottles with liquid mix. Strong tape covered the drainage holes on the collected bottles and a lid were put on before transporting the samples to the laboratory.

2.2.3 Laboratory material work and species identification

The samples collected were transported to the laboratory and sifted in to containers with 70% ethanol and 30% water. The containers were labelled with necessary information thereafter delivered to a beetle taxonomist (Sindre Ligaard) for species identification and categorisation. The species was then cheked agains a beetle species traits database (Tone Birkemoe and Anne Sverdrup-Thygeson, unpublished database) to find out which beetle species were saproxylic and which were not saproxylic.

2.3 Statistical analyses

For each site, data from the three interception traps in each of the treatments were pooled. To run my data analyses, I used R version 3.0.3 (R Core Team 2014).

Before statistical analyses, I carried out exploratory analyses as recommended by (Zuur et al., 2010). I checked for outliers in the response variables (abundance and richness) for each beetle group and treatment. No outliers were detected. Thereafter, I checked for potential co-linearity between the explanatory variables i) treatments (with three levels: 'cut', 'cut and removed' and 'uncut' and ii) width of power-line corridor (with two levels: narrow and wide), iii) cover of dead wood and iv) sun-exposure (radiation index). The variable 'dead wood cover' was highly skewed but not zero-inflated. All correlation coefficients between the explanatory variables were small (<0.5 and > -0.5). To investigate if the size of corridors influenced beetle abundance and richness I used the corridor width: narrow and wide as a variable. I included number of trap months in my models as an offset variable to correct for traps that were lost. Maximum trap months for each treatment were 12 months.

Because of overdispersion in the data set for Abundance (Pearson`s chi-quared/df = 20.06) when I fit a Poisson GLMM (generalized linear mixed model), I re-specified the model with a negative binomial distribution which did not give an overdispersion (Pearson`s chi-quared/df = 1.019). I used the package glmmadmb (Fournier et al., 2011) in R for these analyses. Explanatory variables were 1) 'cut and removed' 2) 'uncut' and 3) narrow power-line corridor. In my model I also checked if 1) saproxylic vs. not saproxylic interacted with narrow power-line corridors, 2) 'cut and removed' interacted with narrow power-line corridors and 3) 'uncut' interacted with narrow power-line corridors. Site was included as a random effect to account for among-sites variation. Through backward selection (Crawley 2013) for each response variable the effects of each variable was tested to see if they were statistically significant (P< 0.05) and in that case the variable was retained in the model. My final model included only significant terms (P< 0.05).

Data set for Richness did not fit a Poisson GLMM because of overdispersion (Pearson`s chi-quared/df = (1.9). Therefore I re-specified the model with a negative binomial distribution and used the package glmmadmb (Fournier et al., 2011) in R which gave no overdispersion (Pearson`s chi-quared/df = 0.89). Explanatory variables were 1) 'cut and removed' 2) 'uncut' and 3) radiation index. Site was included as a random effect to account for among-sites variation. Through backward selection (Crawley 2013) for each response variable the effects of each variable was tested to see if they were statistically significant (P< 0.05) and in that case the variable was retained in the model. My final model included only significant terms (P< 0.05).

3. Results

3.1 Beetle abundance and species richness

The total dataset included 29 294 individuals of saproxylic and not saproxylic beetles and identified to 856 species. The total set of 856 species included 420 species of saproxylic beetles and 436 species of not saproxylic beetles. In total 22 105 individuals were classified as saproxylic beetles and 7189 individuals were classified as not saproxylic beetles. The most common saproxylic beetle species sampled were *Scaphisoma agaricinum* with a total of 2 825 individuals, *Dasytes niger* with 1 564 individuals and *Pityogenes chalographus* with 1 163 individuals. There was not a huge difference in the total number of saproxylic versus not saproxylic beetles species, but the difference between the two groups in average number of abundance and richness per treatment and site was high: in treatment 'cut' the average numbers of beetle abundance was 640 (saproxylic) and 148 (not saproxylic) and average numbers of beetle species richness was 132 (saproxylic) and 46 (not saproxylic). In the treatment 'cut and removed' the average numbers of beetle abundance was 527 (saproxylic) and 139 (not saproxylic) and average numbers of beetle species richness was 132 (saproxylic) and 50 (not saproxylic). In the 'uncut' treatment the average numbers of beetle abundance was 367 (saproxylic) and 88 (not saproxylic) and average numbers of beetle species richness was 102 (saproxylic) and 35 (not saproxylic).

3.2 Effects of treatment on beetle abundance

The saproxylic beetle abundance in narrow and wide power-line corridors increased inside the 'cut' habitat treatment with as many as over 1000 individuals. The abundance of not saproxylic beetles in the same treatments was low (approximately 250 individuals).

The abundance of saproxylic beetles was considerably higher than the abundance of not saproxylic beetles, both in wide and narrow corridors (Table 1, Figure 7). There was a significant effect of the treatment, but the effects of treatment depended on corridor width (Figure 7). In narrow corridors, both saproxylic and not saproxylic beetles were most abundant in the 'cut' treatment. The abundance of saproxylic beetles was intermediate in treatment 'cut and removed', and lowest in treatment 'uncut'. In wide corridors, the abundance of saproxylic beetles was at its highest in the 'cut and removed' treatment, followed by 'cut', and thereafter 'uncut' with the lowest abundance. For not saproxylic beetles, average abundance was similar for treatments 'cut' and 'cut and removed', but the variation within the treatment 'cut and removed' was larger. The abundance of not saproxylic beetles was lowest in the treatment 'uncut', and this treatment also had the lowest within-treatment variation.

Table 1 Results from generalized linear mixed models with negative binomial distribution. Influence of treatments ('cut', 'cut and removed' and 'uncut') and corridor width on the total abundance of saproxylic vs. not saproxylic beetles. Reference levels are not- saproxylic (trait group), 'cut' (treatment) and wide (corridor width).

Explanatory Variables	**β**	**SE**	**Z**	**P**
Fixed effects				
Intercept	2.38	0.1	19.5	<0.001
Saproxylic vs. not saproxylic	1.59	0.09	18.0	<0.001
'Cut and Removed' vs. 'Uncut'	0.1	0.1	1.14	0.25
'Uncut'	-0.35	0.1	-3.3	0.001
Narrow power-line corridor	0.25	0.15	1.6	0.09
Saproxylic vs. not saproxylic: Narrow power-line corridor	-0.27	0.1	-2.47	0.01
'cut and removed': Narrow power-line corridor	-0.37	0.1	-2.7	0.005
'uncut': Narrow power-line corridor	-0.3	0.1	-2.3	0.02
Random effect				
Site	**σ**	**SD**	**Plots**	**Sites**
	0.047	0.2	114	19

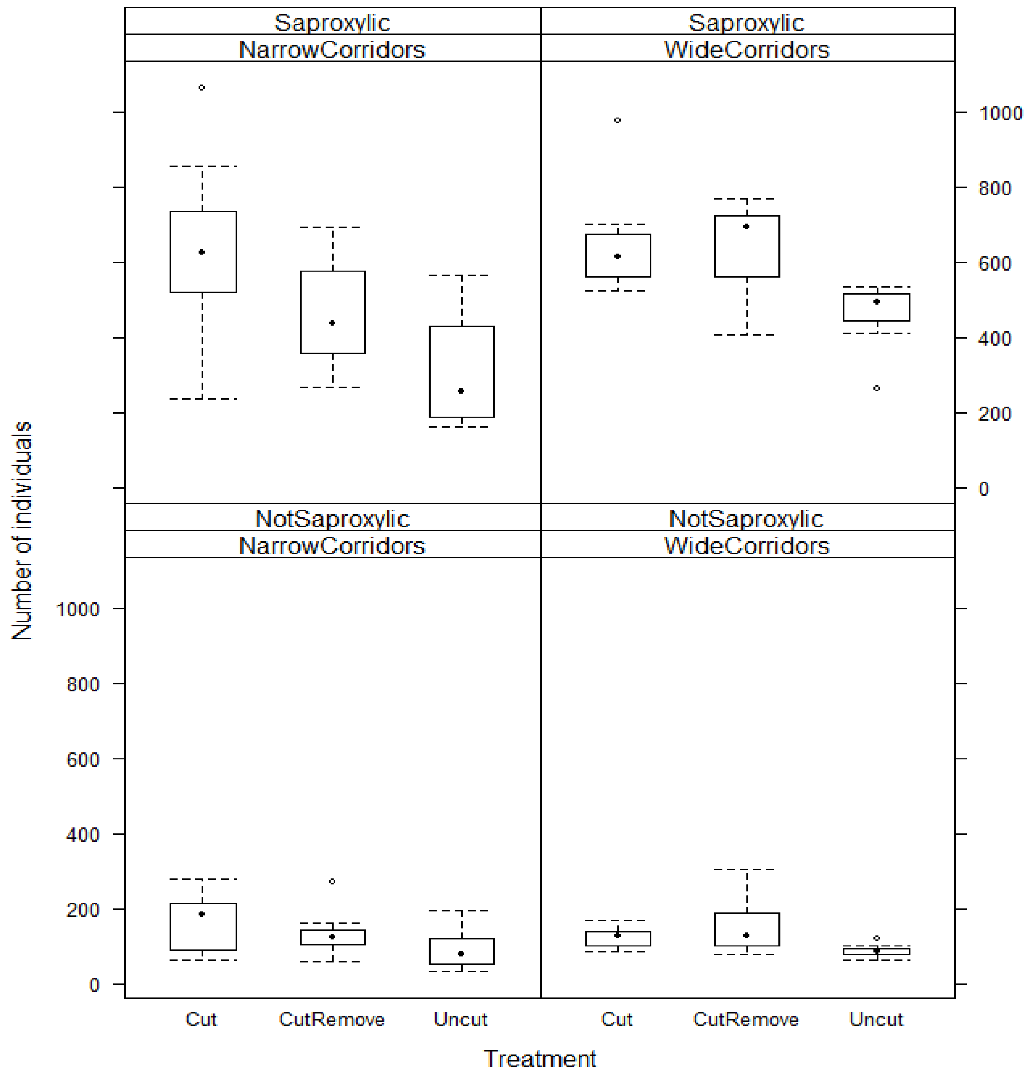

Figure 7. Box plot showing number of individuals of saproxylic and not saproxylic beetles in the three treatments in narrow and wide power-line corridors.

3.3 Effects of treatments on beetle species richness

The richness of saproxylic beetle species was considerably higher than the richness of not saproxylic beetle species for every treatment and sizes of corridor widths (Table 2, Figure 8). There was a significant effect of the treatments, but the effects of treatment depended on power-line corridor width (Figure 8). In narrow corridor width, both saproxylic and not saproxylic beetle species richness were highest in 'cut' and 'cut and removed' and lowest in the 'uncut' treatment. In wide corridor width, both saproxylic and not saproxylic beetle species richness were highest in 'cut and removed' and lowest in the 'uncut' treatment. The variation inside the beetle group of saproxylic and not saproxylic beetles was high in the 'cut and removed' treatment in wide corridor width. The richness of saproxylic and not saproxylic was intermediate inside 'cut' treatment in wide corridor width and the richness for not saproxylic beetles inside the ‘cut’ treatments in narrow corridor width was intermediate. The ‘uncut’ treatment had a negative effect on saproxylic beetle species richness in both narrow and wide corridor width and a positive effect in ‘cut and removed’ treatment for both saproxylic and not saproxylic beetles. The richness of not saproxylic beetles in ‘uncut’ treatment was smallest in both narrow and wide power-line corridor width.

Table 2 Results from generalized linear mixed models with negative binomial distribution. Influence of treatments (‘cut’, ‘cut and removed’ and ‘uncut’) and corridor width on the total species richness of saproxylic vs. not saproxylic beetles.

Explanatory Variables	**β**	**SE**	**Z**	**P**
Fixed effects				
Intercept	1.26	0.07	17.8	<0.001
Saproxylic vs. not saproxylic	1.03	0.03	31.6	<0.001
‘Cut and removed’	0.047	0.038	1.24	0.216
‘uncut’	-0.247	0.04	-6.14	<0.001
Radiation Index	0.257	0.108	2.37	0.018
Random effect				
Site	**σ**	**SD**	**Plots**	**Sites**
	0.033	0.18	114	19

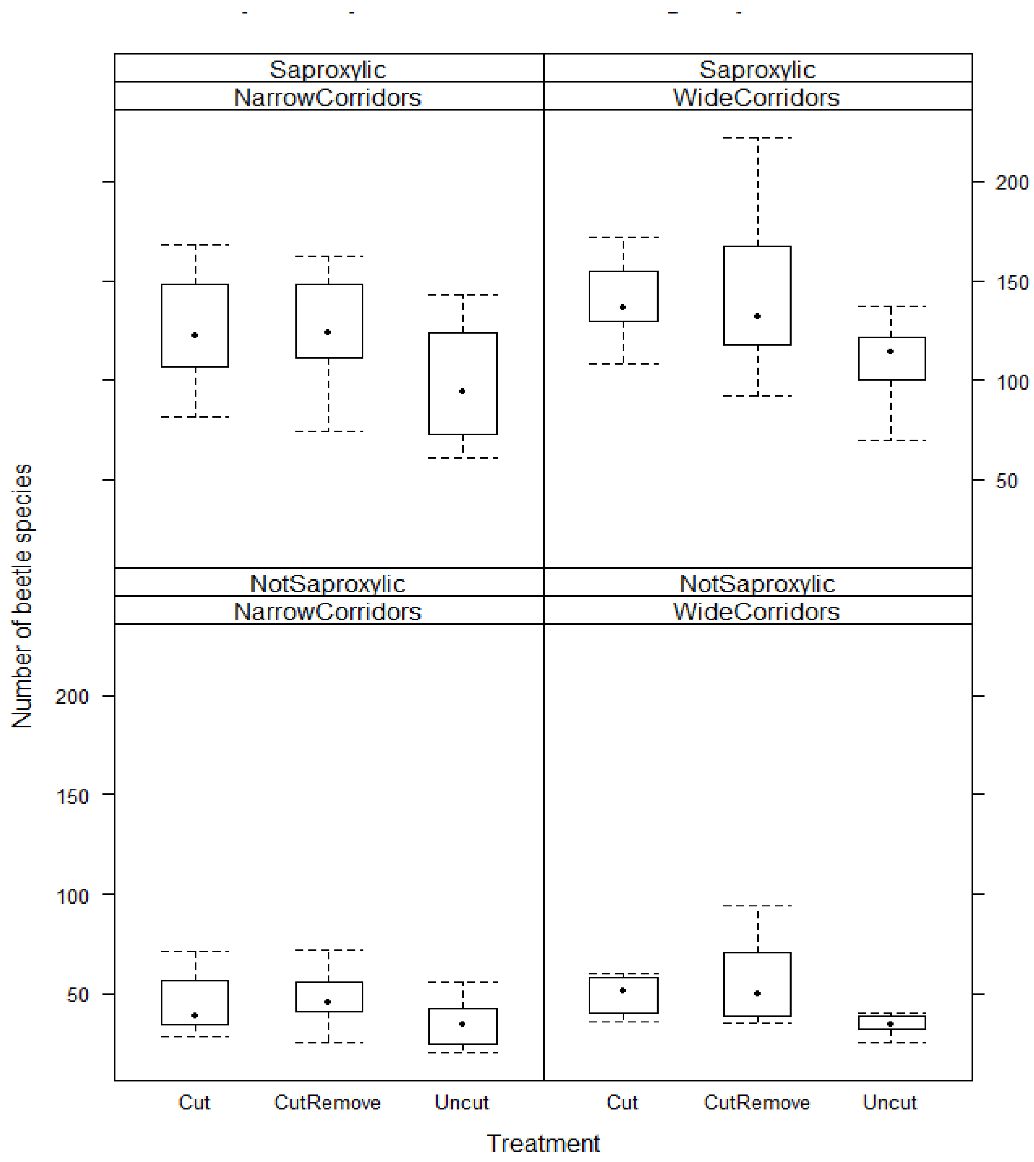

Figure 8 Box plot showing relations between number of saproxylic and not saproxylic beetles species in the three treatments in narrow and wide power-line corridors.

3.4 Effects of dead wood on beetle abundance

The amount of dead wood had no effects of abundance of saproxylic beetles in ‘cut’ treatment, but a threshold for the amount of dead wood (Figure 9). Further there was a positive effect in treatments ‘cut and removed’ and ‘uncut’. For the not saproxylic beetles there were no specific correlation with increasing amount of dead wood in any of the three treatments. I chose to use the same scale for saproxylic and not saproxylic to show the clear difference in their abundance. My results show that saproxylic beetles are much more abundant than not saproxylic beetles.

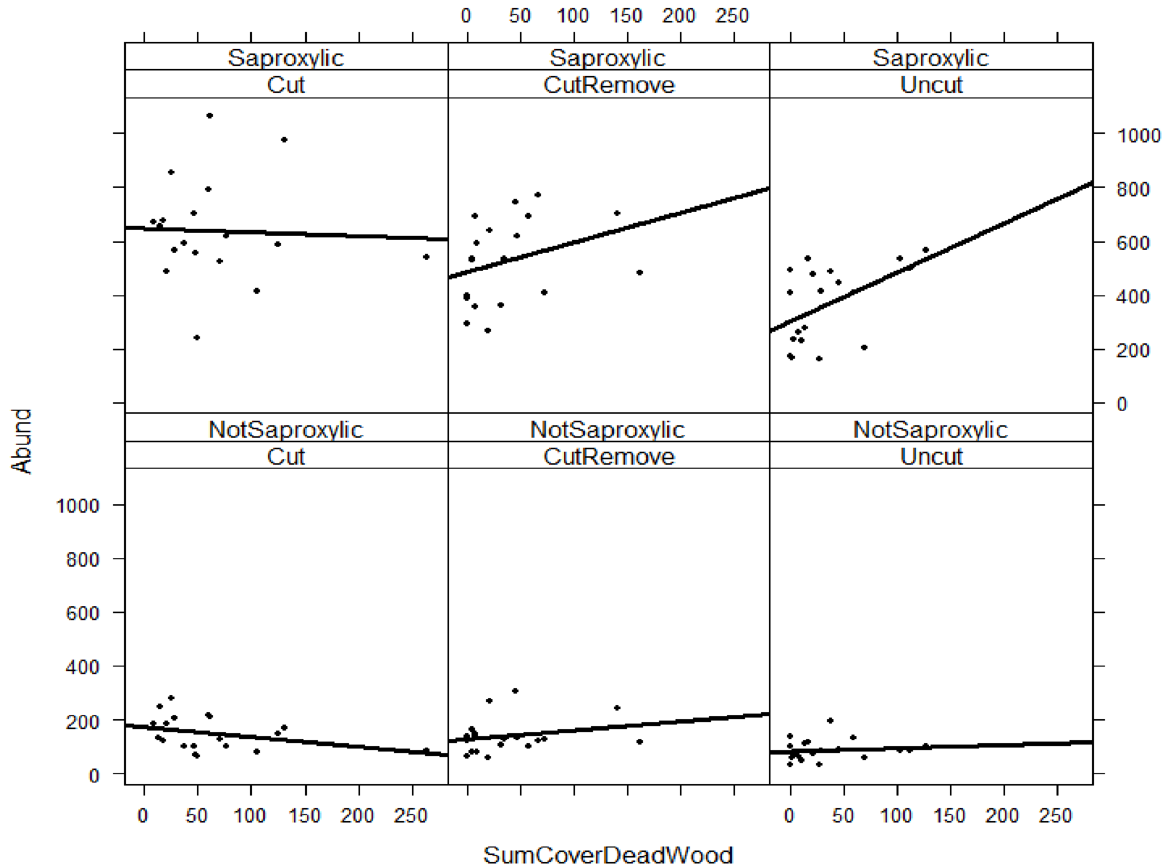

Figure 9: Shows the occurrence of dead wood in the three treatments ‘cut’, ‘cut and removed’ and ‘uncut’ and their relation with occurrence of saproxylic and not saproxylic beetle species.

3.5 Effects of sun-exposure on beetle species richness

Treatments ‘cut’ and ‘cut and removed’ show a positive effect of saproxylic and not saproxylic beetles to sun-exposure. The ‘uncut’ treatment did not show any effects for both saproxylic and not saproxylic beetles (Figure 10). Further the richness was higher for the saproxylic beetles in the three treatments than not saproxylic beetles.

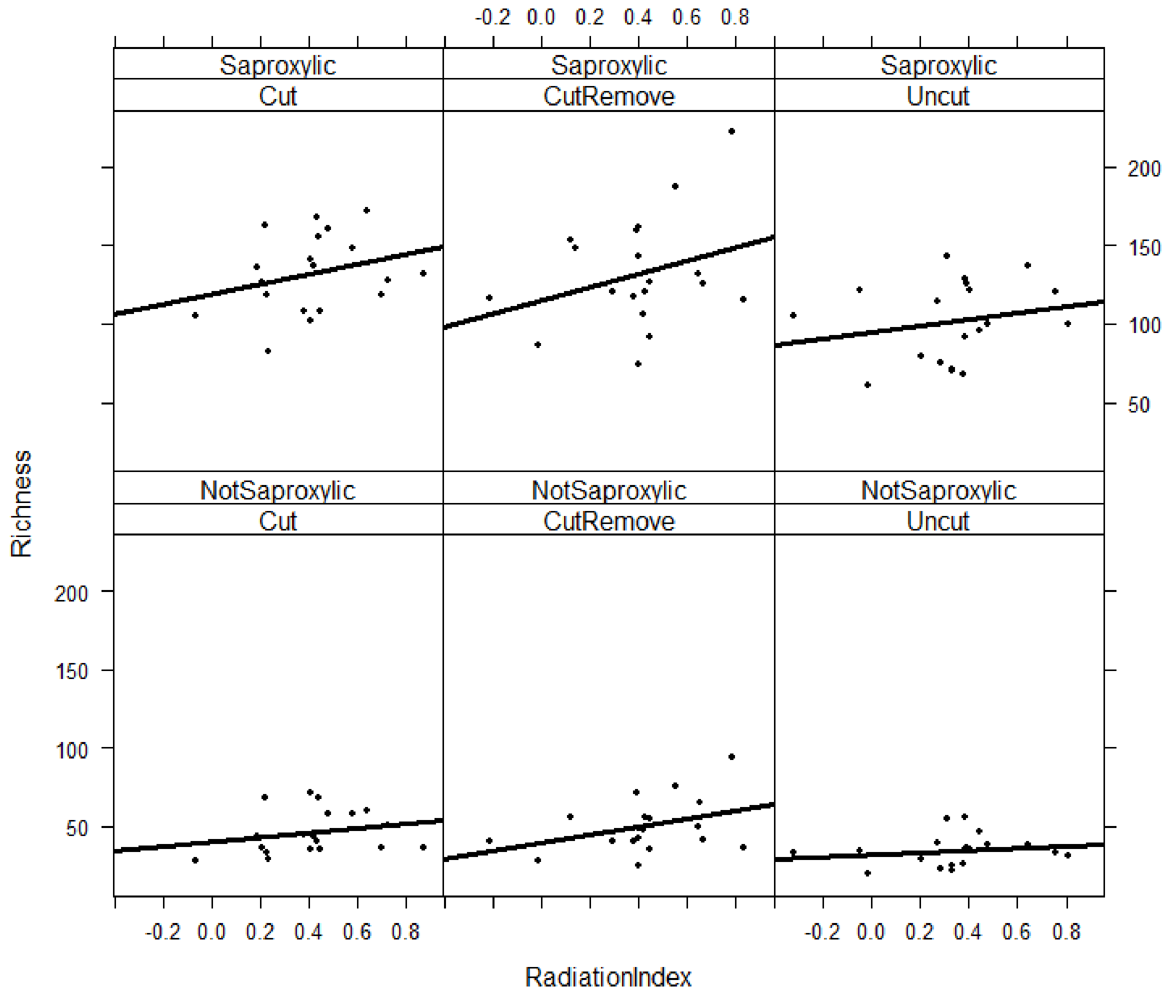

Figure 10: effect of saproxylic and not saproxylic beetles species richness to sun-exposure in ‘cut’, ‘cut and removed’ and ‘uncut’ treatments.

4. Discussion

4.1 Beetle abundance and richness

Saproxylic beetle abundance and species richness were higher than not saproxylic beetles in all three treatments. Other studies have also found that saproxylic beetles occur in higher numbers than not saproxylic beetles collected with flight interception traps in forest and clear-cut areas (Sverdrup-Thygeson and Birkemoe, 2009, Stenbacka et al., 2010). Cutting the forest in power-line corridors increased the amount of dead wood. Dead wood is important for saproxylic beetle abundance and species richness since it is an important factor and a key habitat for saproxylic species (Fridman and Walheim, 2000, Siitonen, 2001, Ranius et al., 2003, Ranius, 2006, Stenbacka et al., 2010, Lassauce et al., 2011, Stokland et al., 2012, Økland et al., 1996b). However, there are not many previous studies comparing the effect of forest disturbances under power-line grids, which the experiment was located in my study system.

The power-line corridors provide different habitats and different stages of succession than a forest, where the forests in 'cut' and 'cut and removed' are in early successional stages and the 'uncut' represent a later successional stage. The study of Gibb et al. (2006) showed that many saproxylic beetles are attracted to early successional forests in clear-cut areas. Jonsell et al. (1998) showed that sampled beetles favoured by sun-exposure was found on recently dead wood. Therefore, I assumed that this is why so many beetles in this experiment are collected in the sun-exposed treatments 'cut' and 'cut and removed'. The forests under the power-lines in the two managed treatments ('cut' and 'cut and removed') are frequently cut and the forests are therefore never growing old and can never develop into an older successional stage. By frequently cutting the trees inside the corridors, the forest might provide the treatments with different habitats and attract different saproxylic beetles with different stages of dead wood preferences. Therefore the clear-cuts are a good way to manage and protect the saproxylic fauna. For example Berg et al. (2011) found that the butterfly fauna increased in power-line corridors (comparable to early succession in my study) with increasing species richness and higher total abundance and, even the red-listed butterfly species increased compared to the treatments pasture, forest road verge and clear-cut. Forrester et al. (2005) showed that the rear Karner blue butterfly (*Lycaeides melissa samuelis*),was only found in managed early successional power-line corridors in New York because Lupine increased in response to the management and Karner blue butterfly preferably ovisposited in areas with high numbers of flowers because Lupine are a good food source for the larva.

4.2 Dead wood

Dead trees can be grouped into four stages of decay, with the approximation dependent on tree species and climate; dead< 2 years = trees where there still live bark beetles; dead 2-5 years = wood still firm, but bark is starting to loosen; dead 5-15 years = wood rotten and can be torn by knife; and dead > 15 years = wood very rotten and can be torn by hand (Esseen et al., 1992, Jonsell et al., 1998). In my study the trees in 'cut' treatment have been dead for less than 2 years and may still contain several species of bark beetles although it may differ with the tree trunk sizes. The wood that was cut in the power-line corridors was on average < 3cm in diameter. After the death of trees, in the early successional stage, the selection of fungi, rather than the tree species may be important for the beetles selecting habitats (as food source and nest site). Fungi that grow on specific tree species may be of higher importance because some beetle species are relatively specific in selecting habitats (Jonsell et al., 1998, Stokland et al., 2012). The treatment edges in the 'cut and removed' treatment, provide the removed biomass with shade and moist environment which may be a key habitat for fungi. The fungi grow in dead and moist wood after a few years of decay and may develop into fruiting bodies. The fruiting bodies attract certain beetles such as *Curtimorda maculosa* (Siitonen, 2012), of which 1067 individuals were collected in my experiment. In addition to regular cutting of relatively small trees in the corridors, a considerable number of larger trees along the forest edges are felled to prevent them from hitting the aerial lines. These trees are left to decay in the corridors and may have been dead for over 2 years. These trees may be a source for beetles that prefer older and larger dead wood with older fruiting bodies.

Allison et al. (2004) states that the defensive compounds, such as monoterpenes, that are produced in wood and foliage when damaged, are used as attractive kairomones for wood-boring beetles, including Cerambycids and that ethanol is released from trees exposed to stress or dying trees and from dead wood which also aggregate saproxylic beetles. Ethanol is produced under anoxic conditions and is excreted when for example wood-boring beetles attack the stem and gypsy moth caterpillars attack the foliage of oak trees so the transpiration is reduced and lead to hydration of bole and stem (Stephens et al., 1972, Montgomery and Wargo, 1983). The trees are cut in both 'cut' and 'cut and removed' treatments and may explain why I found similar amount of abundance and richness inside the two cut treatments because the beetles smell the ethanol in both treatments. The number of saproxylic individuals in narrow and wide power-line corridors increased inside the 'cut' habitat treatment with higher amount of dead wood. A possible reason can be that 'cut' treatments inside wide power-line contains more dead wood than narrow power-line corridors (Table A1 and A2) and therefore lead to a higher aggregation of beetles because of higher release of monoterpenes and ethanol.

To sum up, many saproxylic beetles are attracted to early successional forests in clear-cut area (Gibb et al., 2006) because most of the beetles that favoured sun-exposure was found on recently dead wood (Jonsell et al., 1998) and because defensive compounds such as ethanol in newly cut wood attracts saproxylic beetles (Allison et al., 2004). Therefore I assume that this was why most of the beetles in this experiment are collected in the sun-exposed treatments 'cut' and 'cut and removed'.

4.3 Power-line corridor treatments

I predicted that abundance and richness of saproxylic beetles would be higher in the 'cut' treatment than 'cut and removed' and 'uncut' treatments. I found that both 'cut' and 'cut and removed' had higher abundance and richness of saproxylic beetles than in the 'uncut' treatment. Based on the previous study by Sverdrup-Thygeson and Birkemoe (2009) I could predict to find much higher abundance and species richness of saproxylic beetles than not saproxylic beetles in clear-cut management versus unmanaged closed forest . Furthermore, Mikaelsen (2012) compared the occurrence of saproxylic beetles in forest versus power-line corridors and showed that there were higher numbers of saproxylic beetles in the power-line corridors than in the forest. However, the difference in abundance and richness between the saproxylic and not saproxylic beetles within each treatment were not large in my study. I would have thought that the abundance and richness of saproxylic beetles would be higher than for the not saproxylic beetles. The reason for this result can be that not saproxylic beetles are attracted to open landscape with sun-exposure similarly to the preferences by many mature saproxylic beetles (Siitonen, 2012).

The difference in abundance between saproxylic and not saproxylic beetles was larger for wide than for narrow corridors. One reason for the higher difference in wide than in narrow corridors between saproxylic and not saproxylic beetles might be because the wide corridors have a larger habitat containing higher numbers of dead wood than narrow power-line corridors. With a total of 1367 objects of dead wood counted in wide power-line corridors and a total of 1223 objects of dead wood counted in narrow power-line corridors (Table A1 and A2). A second reason could be that the larger habitats in the treatments provide a larger space with sun-exposure which attracts more beetles. The difference in abundance between the treatments was smaller for wide than for narrow corridors. A reason for this can be that the three treatments in narrow corridors provide small habitats compared with treatments in wide corridors. My results also showed that richness of saproxylic beetles in all three treatments was higher in wide than in narrow corridors. This may be because higher numbers of beetle species thrive in larger sun-exposed areas with access to more dead wood and because of the warmer condition the beetles get more active (Kaila et al., 1997) and easier to sample higher numbers of species.

The difference in abundance and richness of saproxylic beetles in both narrow and wide power-line corridors was higher in 'cut' and ' cut and removed' than in 'uncut' treatment. This result can unsurprisingly be that there are more dead wood in the ‘cut’ treatments than in the ‘uncut’ treatments (Table A1 and A2).

Abundance of saproxylic beetles in ‘cut’ treatments inside narrow power-line corridors are higher than in ‘cut and removed’ treatment. A reason for this might be because of the higher amount of dead wood inside the ‘cut’ treatment (Table A1) whereas the abundance are lower in ‘cut’ treatment than ‘cut and removed’ treatments inside wide corridor. This may be because wide corridors provide larger habitat with access to sun-exposure and because of the easier way of travel. The higher activity of beetles in sun-exposed habitats increases the chances of sampling higher numbers of beetle abundance in ‘cut and removed’ treatment.

Richness of saproxylic beetles in ‘cut’ versus ‘uncut’ treatment inside narrow and wide power-line corridors are approximately the same in numbers and this result may be because there are on average very similar numbers of dead wood samples (Table A1 and A2) and similar amount of sun-exposure (Figure 10) in the two treatments.

4.4 Dead wood cover

Abundance of saproxylic beetles increased along with increasing dead wood cover inside ‘cut and removed’ and ‘uncut’ treatments but not inside the ‘cut’ treatment (Figure 9).

Stenbacka et al. (2010) also found that occurrence of saproxylic beetles increased with increasing amount of dead wood. The effect of beetles depending on corridor width differs between saproxylic and not saproxylic beetles abundance and richness. Therefore the higher amount of dead wood inside the wide power-line corridors can apparently be the reason for the slightly higher numbers of abundance of saproxylic beetles in wide corridors than in narrow corridors.

The reason for the positive effect of increasing dead wood on ‘cut and removed’ and ‘uncut’ treatments may be that even though the biomass was removed from the ‘cut and removed’ treatment and even though the forest in ‘uncut’ treatment was not cut there was still dead wood present in both treatments (Table A1 and A2). Also the saproxylic beetles could have used the ‘cut and removed’ treatment to travel between preferable habitats because there were no obstacles left in the treatment. The same could also be the case for the similarity of abundance and richness of saproxylic and not saproxylic beetles in the ‘cut’ and ‘cut and removed’ treatments. The forest in ‘uncut’ treatment also included some dead wood (A1 and A2) and the biomass placed along the forest-power-line edges is a good semi shaded habitat for saproxylic beetles that do not prefer 100 % sun-exposure and prefer moist environments.

A possible reason for the not affected treatment ‘cut’ to increasing amount of dead wood may be that the cover of dead wood in ‘cut’ treatment was high enough and the amount of dead wood reached a threshold for the saproxylic beetles preference. My results showed that the ‘cut’ treatment on average had the highest amount of dead wood for all sites (Table A1 and A2). Abundance of not saproxylic beetles did not relate to amount of dead wood in this treatment.

4.5 Sun-exposure

In addition to dead wood as a key habitat, sun-exposed dead wood has also affected the results in my study. Species richness of saproxylic and not saproxylic beetles increased with increasing radiation index in all three treatments (Figure 10). Many other studies on sun-exposure in forest and sun-exposed dead wood also showed positive and similar results (Bílý, 1989, Kaila et al., 1997, Ranius and Jansson, 2000, Lindhe et al., 2005). Beetles are ectothermic and their activity are not controlled by inside temperature, but the outside climate (Sverdrup-Thygeson and Ims, 2002) and the high activity and mobility of beetles can be explained by the open, sun-exposed clear-cut area because of warmer conditions (Kaila et al., 1997, Gullan and Cranston, 2010) and due to the their attraction to sun exposed dead wood in 'cut' and 'cut and removed' treatments (Jonsell et al., 1998). There were not many studies of species mobility and the variation among the species could be high. In some 'cut' treatments the overall cover of dead wood was high and since the dead trees are piled up in layers the wood become both sun-exposed and dry on the top layers and humid in the shadowed bottom layers. Access to sun-exposure in the 'cut' and 'cut and removed' treatments does not only dry up the moist forest floor and the dead wood, but also improve growing conditions for flowers which are often found in early successional forests. In some 'cut' treatments where there were few trees to be cut and in every 'cut and removed' treatments there were patches where flowers could grow, some sites more than others depending on climate and altitude. The flowers attract several species of beetles such as the family Cerambycidae, *Leptura quadrifasciata (*sampled 104 individuals) (Bílý, 1989) and *Trichius fusciatatus* (sampled 101 individuals) which eats pollen as adults while larvae eats sapwood inside sun-exposed dead wood (MicÓ et al., 2008). In the 'cut' treatments where there are huge amounts of dead wood, flowers grew in the treatment edges.

The study of Jonsell et al. (1998) showed that beetles species found in early successional habitats with newly dead wood are more attracted to sun-exposure than are species occurring late in the succession. This definition of early successional habitat are comparable with the two cut treatments in my experiment and beetle attraction to early succession forest may explain why there are sampled much more saproxylic beetles in 'cut and 'cut and removed' treatments. The sun-exposure inside 'uncut' treatment was lower than for the two other treatments, but since the 'uncut' treatment are in early successional stage, the forest was not completely closed in all sites as in the older forest neighbouring the 'uncut' treatments. The differences in beetle species in the three treatments are due to their differences in habitat preferences.

To sum up, beetles are ectothermic (Sverdrup-Thygeson and Ims, 2002) and warmer conditions result in higher activity and mobility (Kaila et al., 1997, Gullan and Cranston, 2010) and due to the their attraction to sun exposed dead wood in 'cut' and 'cut and removed' treatments

(Jonsell et al., 1998) species richness of saproxylic and not saproxylic beetles in my results increased with increasing radiation index in all three treatments.
A study by Jonsell et al., (1998) showed similar results when he studied 542 red listed saproxylic species of invertebrates in Sweden. Of these species 25% preferred sun exposed sites and the highest proportion preferred sun exposed sites with early succession of dead trees than decayed trees. Species that inhabit and rely on newly dead wood do also favour sun-exposed areas such as in clear-cuts.

4.6 Interception traps

Saproxylic beetles fly to search for dead wood and food, therefore the interception traps are a useful trapping method (Økland et al., 1996b). The trap and trapping method are documented by Basset (1988). The disadvantage with interception traps may be that the collected beetles fly inside the 'cut' and 'cut and removed' treatments just because it is an easy place to travel that there are no obstacles such as in closed forest in the 'uncut' treatment. Therefore it may be a bias that even though the collected beetles are saproxylic, all of them may not hatch or use the treatment actively but rather move between their preferable habitats (Siitonen, 1994).

4.7 Recommendation of management

In Norway there are 706 beetle species nearly threatened or threatened listed in the Norwegian red-list (Kålås et al., 2010) and 129 of these red-listed species are depended on dead wood. If the desire is to prevent the loss of dead wood dependent beetles, leaving dead wood after clear-cut as done in the 'cut' treatments will be the best way for preserving abundance and species richness of saproxylic beetles. The clear-cut treatment with early successional habitat will eventually become a closed forest and include less dead wood; therefore the trees should be frequently cut.

4.8 In conclusion

My study indicates that power-line corridors can be an important habitat for many beetle species and that management practises influence the abundance and species richness, and under certain environmental conditions also affects the relationship between saproxylic and not saproxylic species. Leaving dead wood in clear-cuts had a clear positive effect for increasing habitats for saproxylic beetles preferring or indifferent to sun-exposure. Although some beetles preferred shade, sun-exposure increased the abundance and richness of saproxylic beetles in all three treatments. Not saproxylic beetles showed no effect of more sun light in the treatments. Saproxylic beetles showed stronger reactions to early-successional management than not saproxylic beetles. Even though there are a lot of negative effects of managed forests and clear-cuts my study showed that there are also some positive outcomes for saproxylic beetles that use early successional sun exposed dead wood as source for their lifecycle.

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Appendix

Table A1.Estimated objects of dead wood in narrow power-line corridor

Site	**'cut'**	**'cut and removed'**	**'uncut'**	**Total sum**
GOL	105	32	70	207
102	7	14	13	34
70	62	47	46	155
71	60	21	39	120
72	17	162	128	307
73	48	58	11	114
75	15	19	28	62
76	25	0	2	27
80	14	0	13	27
81	21	5	1	27
82	8	0	0	8
83	37	35	60	132
SUM	**419**	**393**	**411**	**1223**

Table A2. Estimated objects of dead wood in wide power-line corridors

site	**'cut'**	**'cut and removed'**	**'uncut'**	**total sum**
66	13	8	9	30
85	46	9	30	85
86	131	72	0	203
87	125	46	17	188
92	265	66	112	443
93	70	141	104	315
95	77	4	22	103
SUM	**727**	**346**	**294**	**1367**

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