High-stumps and Wood Living Beetles in the Swedish Production Forest Landscape

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Abstract

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The amount of dead wood in Swedish production forests is low compared to natural forests. This has resulted in a high proportion of red-listed and threatened wood living beetle species. Different actions are taken to increase the amount of dead wood and one such action is to artificially create high-stumps (snags), i.e. living trees cut between 3 and 5 meters height. This thesis focuses on whether high-stumps on clearcuts in southern Sweden increase beetle diversity. One study focus on whether a high-stump offers a different substrate compared to ordinary low-stumps. Another study investigates if beetle species are affected if the high-stumps are pre-rotten or not. Finally, the beetle species number and composition between high-stumps of spruce and birch in biodiversity hotspots and production forest (matrix), respectively. High-stumps have a somewhat different beetle species composition compared to low-stumps (normal cutting stumps), and several species were primarily associated with high-stumps. This justifies the making of high-stumps even though the amount of dead wood they add to a clearcut is low. The pre-rotten spruce high-stumps (infected by *Heterobasidion spp*.) had a negative effect on some beetle species and none of the analyzed species showed positive associations with *Heterobasidion spp*. This suggests that increasing the proportion of rotten spruce high-stumps could have a small but negative effect on beetle diversity. The number of beetle species did not differ between high-stumps on hotspot and matrix clearcuts, suggesting that concentrating high-stumps to hotspot areas will not benefit more beetle species. However, the amount of broadleaved forest in the surroundings of clearcuts was important for explaining species composition on high-stumps. The amount of coniferous forest only explained a small part of the beetle species composition, possibly because coniferous forests are dominating the entire forested landscape in southern Sweden. The high-stumps in these studies were four years old at most. This means that, as the wood decay progress, the properties of high-stumps change and potentially they become even more important.

Keywords: high-stumps, saproxylic beetles, *Coleoptera*, hotspot, matrix, *Picea abies, Betula,* species composition

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Till Mandisen, Linus och Semlan

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Appendix B, List of the Saproxylic beetles caught in study I & II

Papers I-IV

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. Abrahamsson, M. & M. Lindbladh (2006) A comparison of saproxylic beetle occurrence between man-made high- and low-stumps of spruce. Forest Ecology and Management 226: 230-237

II. Abrahamsson, M., Lindbladh, M. & J. Rönnberg. Influence of butt rot on beetle diversity in artificially created high-stumps of spruce. Forest Ecology and Management, Under revision

III. Lindbladh, M., Abrahamsson, M., Jonsell, M. & M. Seedre (2007) Saproxylic beetles in artificially created high-stumps of spruce and birch within and outside hotspot areas. Biodiversity and Conservation 16: 3213-3226

IV. Abrahamsson, M., Lindbladh, M., Jonsell, M. & M. Niklasson. Saproxylic beetle assemblages in artificially created high-stumps of spruce (*Picea abies*) and birch (*Betula pubescens/pendula*) on clearcuts – does the surrounding landscape matter? Manuscript

Introduction

Background

Southern Scandinavia has been dominated by forests since soon after the last glaciation, about 11,000 years ago. The degree of forest cover during mid-Holocene when the temperate deciduous forest was dominating is well debated (Vera, 2000). There is however an agreement that the forest cover decreased when agriculture was introduced in Northern Europe about 4000 BC (Berglund, 1991), and there is some evidence that these changes also affected wood-dependent species (Whitehouse, 2006).

Mans impact on the forests increased gradually, but in particular the early Medieval was a period of farm establishment and colonization in southern Sweden (Lagerås, 2007). During the 16th century there was an increased direct utilization when forest products were needed for fuel and for iron production (Lagerås, 2007). The following centuries were characterized by an even greater human impact on the landscape, for example by livestock grazing (Lindbladh & Bradshaw, 1998) and slash-and-burn cultivation (Larsson, 1989b). However, it is important to note that except from certain coastal areas, southern Sweden harboured rather extensive forests (Larsson, 1989a), and a large share were deciduous forests, also during the 17th to the 19th century(Lindbladh, Bradshaw & Holmquist, 2000). The so far limited decrease in forest area probably had an small effect on some species distributions, but the species richness was still most likely rather intact (Nilsson, 1992; Nilsson et al., 2005).

The big change for forest living species occurred when forestry activities started in the mid 19th century (Eliasson, 2002). The changes were intensified in the 1950's when clear-cutting became the dominant silvicultural method in combination with developed technique for timber felling and transport. The gradual intensification of forestry lead to four major changes that affected the biodiversity among wood living organism, (i) changes in tree species composition (ii), changes in stand composition (iii), habitat loss and habitat fragmentation and (iv) changes in disturbance regimes.

Changes in tree species composition

The transformation of the forests in Sweden from a natural or near natural stage to a production forest has had a severe impact on a large number of forest living organisms (Dahlberg & Stokland, 2004; Junninen, 2007; Økland, 1994; Schiegg, 2000; Siitonen & Martikainen, 1994). Tree species composition is maybe the most obvious change over the last century. The planting of spruce (Picea abies) has dominated regeneration of forest and led to a massive "sprucification" (Bjørse & Bradshaw, 1998) even in parts of Sweden that was outside the distribution range of spruce (Hesselman & Schotte, 1906). The amount of pine (Pinus sylvestris) and mixed coniferous forests have decreased, but the most significant reduction can be seen on the amount of broadleaf forests or mixed coniferous/broadleaf forests that have been replaced by coniferous monocultures (Bjørse & Bradshaw, 1998).

As a result, many species which are associated with broadleaved trees species or confined to broadleaved forests have decreased in numbers, population size and distribution. Examples of species that have been negatively affected could be found among wood living insects and woodpeckers (Carlson, 2000; Martikainen, Kaila & Haila, 1998; Nilsson & Baranowski, 1997; Wiktander et al., 1992).

Stand composition

Production forests today are almost entirely monocultures that are uniform and even aged. Natural forests are more stratified, often have several age classes and therefore have a richer substrate diversity (Nilsson, Hedin & Niklasson, 2001). Large and biologically old trees, for instance, are a rare in production forests of today, and this is affecting species from most organism groups (Jonsell, Weslien & Ehnström, 1998; Nilsson, Hedin & Niklasson, 2001; Odor et al., 2006; Uliczka & Angelstam, 1999). Old trees often have dead or dying parts or hollows which are important for many saproxylic (wood living) species, e.g. beetles (Dahlberg & Stokland, 2004; Palm, 1959; Ranius & Jansson, 2000).

Habitat loss and fragmentation

Habitat loss and habitat fragmentation are connected to both changes in tree species composition and stand composition, and are in some sense a result of these changes. Habitat loss is maybe the factor that has had the largest impact on wood living species (Martikainen et al., 2000; Nilsson & Baranowski, 1997; Siitonen & Saaristo, 2000). Many local populations have disappeared when the landscape changed. Habitat loss also occurs under natural conditions, for instance in connection with a fire, but under natural conditions populations were probably not as isolated as they are today. Today the habitat loss has led to that some species now are confined to certain areas, often referred to as hotspots, where the amount of suitable habitats still is sufficient (Nilsson, 2001). However, many species are restricted to these areas as they can not disperse to the next suitable patch. Habitat fragmentation affects many species and their distributions and fragmentation is often connected to habitat loss (Fahrig, 2002). Habitat fragmentation is a problem especially for species that are dispersal limited (Ranius & Hedin, 2001). The fragmentation occurs at different scales depending on which species or species groups that are in focus. For most wood living beetle species the dispersal ability is not well known. Species that are associated with long lasting substrates (e.g. large hollow oaks) or adapted to features in stabile habitats have been suggested to be dispersal limited (Hedin & Ranius, 2002; Jonsson, 2003; Siitonen & Saaristo, 2000). Species that utilise more common resources, like barkbeetles using fresh cambium, are often better at dispersing, also over longer distances.

Disturbance regimes

Another factor that has had a large impact on forest biodiversity is the altering and suppression of the natural disturbance regimes. Disturbances like wind and to some extent flooding are still acting in the forests, but fire that was an important disturbance regime until the late 18:th century, is almost absent in southern

Sweden today (Niklasson & Drakenberg, 2001). The suppression of forest fires, in combination with the uniform silvicultural management, has resulted in that the dead wood dynamics in the forests has changed and therefore is the input of dead wood low. Under natural conditions, fires created large volumes of dead and dying trees (Nilsson, Hedin & Niklasson, 2001). The burned sites were then subject to a succession of pioneer trees like birch, (Betula spp.), aspen, (Populus tremula) and pine. When the pioneer broadleaves died off, large amounts of dead and dying wood was created, providing habitats for many saproxylic species e.g. wood decaying fungi, insects and also birds like woodpeckers (Ås, 1993).

Dead wood

The silvicultural intensification the last couple of hundred years have created forests that are very different compared to natural forests. In southern Sweden (Götaland) there are today about 5 million hectare of forest land and about 900 million m3 of standing volume. 50 % of the volume is spruce, 28% is pine, 10% is birch and the rest is other broadleaved tree species (Anon., 2006). Since the 1920s the standing volume per hectare has doubled and is now about 180 m^3 per hectare (Anon., 2006). The amount of dead wood is strikingly different between a natural (or near natural forest) and a managed forest. In natural forests the volume of dead wood is typically between 40-130 m^3 per hectare depending on tree species and site conditions and could be up to about 200 m^3 after a disturbance (Siitonen, 2001). In the managed forest in southern Sweden the average is about 4 m^3 (Fridman & Walheim, 2000), hence the difference in volume is at least one order of magnitude higher in a natural forest. The quality of the dead wood also differs between these forest types, and the size of both lying and standing dead wood is just one factor that effects the fauna (Nilsson, Hedin & Niklasson, 2001).

The low amount of dead wood in Swedish production forests is one important explanatory factor for the high proportion of red-listed and threatened forest living species. Saproxylic beetles (beetles species that at some part of their life cycle are living of wood or associated with fungi associated with wood or preying on other species living on wood (Speight, 1989)), are perhaps the most negatively affected species groups. More than half of the species from these groups are red-listed (Gärdenfors, 2005). During the last decade the low volumes of dead wood and the effect it has on forest biodiversity have received more attention. This has resulted in different actions aiming at increasing the amount of dead wood in the production forest. One action is to leave dead or dying dead trees during clear-felling. Another action is to retain trees; to leave living trees that grow into the next generation, but that eventually die. Yet another action to benefit wood living organisms is to artificially create high-stumps (snags) from living trees by cutting them at between 3 and 5 meters height. These actions are mandatory when an estate is certified with FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest Certification schemes) (Anon., 2000a; Anon., 2000b).

High-stumps are probably the most common action when creating dead wood in Swedish forests today. Studies on created high-stumps have shown that they can host a diverse saproxylic fauna (Hansson, 1998; Jonsell, Nitterus & Stighäll, 2004;

Jonsell, Schroeder & Weslien, 2005; Lindhe & Lindelöw, 2004). These studies have also shown that high-stumps on clearcuts attract beetle species associated with fire (Hyvärinen, Kouki & Martikainen, 2006; Lindhe, Lindelöw & Åsenblad, 2005) and that high-stumps differ in beetle species composition compared to logs and lying wood (Jonsell & Weslien, 2003).

Studies published so far have considered different aspects of high-stump and beetle interactions regarding for instance tree species, diameter and fungal flora and they have often been conducted on a rather limited geographical area (Jonsell, Schroeder & Weslien, 2005; Jonsell & Weslien, 2003; Lindhe & Lindelöw, 2004). So far most studies have been conducted in the boreal zone whereas studies on high-stumps in southern Sweden are lacking. In southern Sweden there are other species to consider, both regarding beetles species and tree species. Furthermore, there is a need for landscape ecological studies on saproxylic beetles. Such studies can give valuable information on what factors that are important on larger scales and not just give information on specific substrates and associations.

Objectives

The first aim regards the justification of creating the high-stumps. The introduction of high-stumps started without any real empirical knowledge on their conservational value, but rather as a way of mimicking natural snags. This was based on the knowledge that natural snags often hosted a diverse saproxylic fauna. However, the additional volume of dead wood in the form of high-stumps on a clearcut is insignificant compared to the volume of the low-stumps (ordinary cutting-stumps) and considering the large volumes of low-stumps created each year it would be valuable to know to what degree the high-stumps and low stumps have a complementary or unique fauna. Furthermore, as low-stumps now are being increasingly harvested for bio fuel purposes information on species confined to low-stumps is also important from a conservation point of view.

The second aim regards spruce high-stumps with butt-rot. The highest value in a tree is usually in the first log. To reduce the cost for the forest owner, high-stumps are if possible created from trees of low quality, which for spruce often are rotten trees. If the proportion of rotten spruce high-stumps increases it could affect beetle and fungal communities associated with non-infected trees. It is therefore important to know if there is a difference in the fauna composition between infected and non-infected high-stumps.

The third aim regards high-stumps on a landscape scale. Knowing where conservation actions are most effective is desirable for both conservationists and forest owners. But also what type of action that should be considered is of importance. High-stumps are now being spread all over the forest landscape. However, it might be more effective to concentrate them to certain species rich areas where they might benefit more species. Further it is important from a conservational point of view, to know if the tree species of high-stumps have different species composition depending on the surrounding landscape.

The specific questions asked are

- Do spruce high-stumps have a beetle species composition complementary to the one found in low-stumps?

- Is there a difference between high-stumps made from spruce with butt-rot and without butt-rot regarding species number and species composition of saproxylic beetles?

- Are there differences in species composition and number of species on high-stumps depending on whether they are located; in a hotspot or in a production forest (matrix)?

- Do spruce respectively birch high-stumps have different species assemblages depending on the surrounding landscape?

Materials and methods

The study sites

The studies were carried out in the three south Swedish provinces Skåne, Halland and Småland. The study in paper one (I) was carried out in Småland and Skåne (figure 1.) The study in paper two (II) was done in Småland (figure 1.) and studies in paper 3 and 4 (III and IV) were done in Småland and Halland (figure 1.).

In paper I, on high-stumps and low-stumps, and paper II, on root rot, all included clearcuts had previously been dominated by Norway spruce (*Picea abies*) 80-90 years old and all were situated in a normal production forest landscape. In the first study (I) 16 clearcuts were chosen of which eight were newly cut and eight were three years old. On these clearcuts 128 high-stumps and 128 low-stumps were investigated. In the second study (II) 10 clearcuts and 4 high-stumps pre clearcut were included. These clearcuts were created in autumn/winter 2000 /2001. The studies in paper III and IV were conducted on 20 clearcuts (the same in both studies) confined to five regions across southern Sweden. Each region consisted of four clearcuts; two of them were located in hotspot areas and two in production forest and on each clearcut high-stumps were sampled. For the study in paper III,

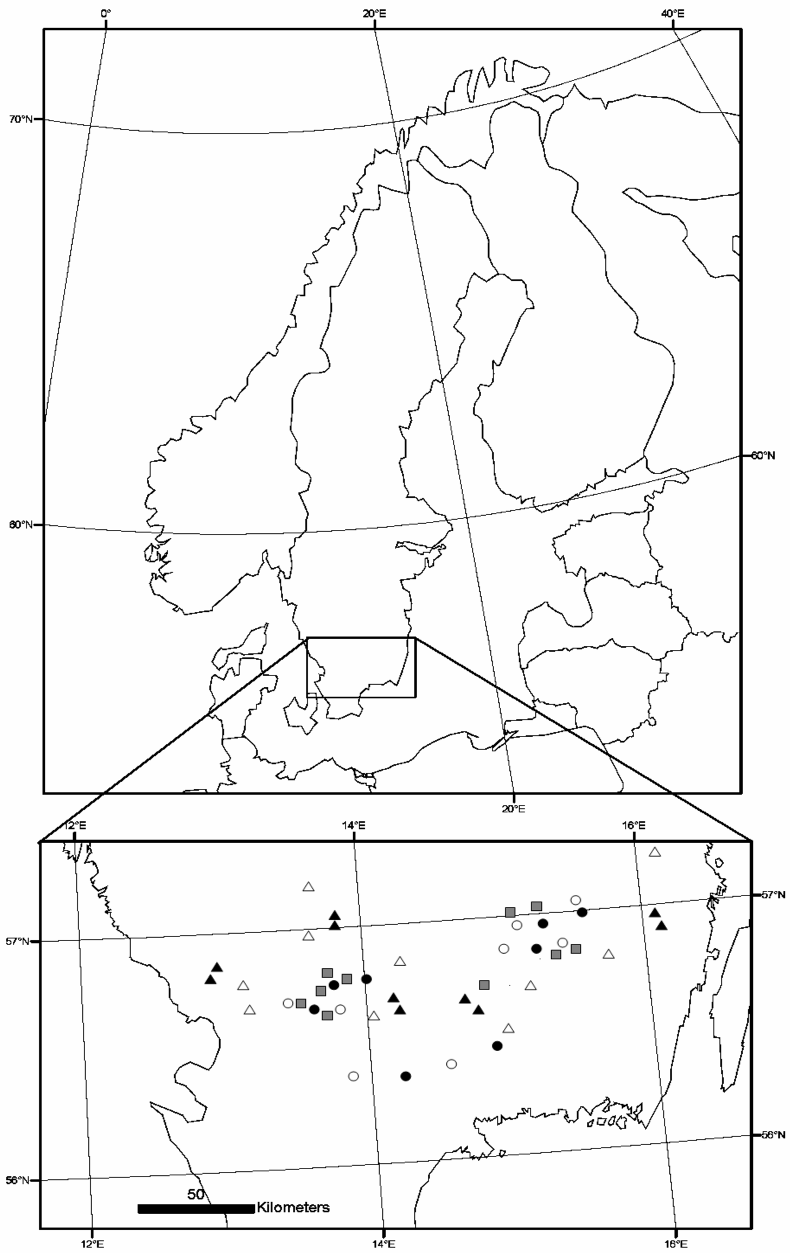

Figure 1. Map over Sweden showing all the sampled sites in the thesis. Circles are showing the clearcut from study I, on the substrate types. Filled circles are one year old clearcuts and open circles are three year old clearcuts. Squares are showing the clearcuts were high-stumps were collected for the butt rot study. Triangles are showing the location of the clearcuts in study III and IV. Filled triangles are showing hotspot clearcuts and open triangles represent matrix clearcuts.

three high-stumps of spruce and three of birch were sieved on each clearcut. In the study in paper IV two high-stumps of each tree species were sampled with window traps. The window trapping preceded the sieving and the same stumps were sampled in both studies. The clearcuts in these five regions were previously dominated by spruce but the more eastern clearcuts had previously had a larger proportion of pine compared to the western clearcuts. The selection of hotspot areas were based on a report by the Swedish Environmental Agency that identifies areas of high species richness (Andersson & Lövgren, 2000) and on a compilation by Nilsson (2001) that identifies areas with high diversity of saproxylic beetles.

Study organisms

Beetles (Coleoptera) are the largest species order in the world with about 350 000 known species and they constitute 40% of all known insects are beetles. In Sweden we have 4,456 beetle species and only the Hymenopterans (wasps, bees, ants and sawflies) with 7,728 species and the Dipterans with about 6,690 species are represented by more species (Gärdenfors *et al.*, 2003). Of the 4,456 beetles 1,300 are saproxylic (de Jong, Dahlberg & Stokland, 2004). Compared to Hymenoptera and Diptera, beetles are a well studied group with good knowledge about the ecology and distribution of most species in Sweden.

Wood living beetles, but also ground living beetles, has often been used in studies focusing on forest management and on its impact on forest biodiversity (Niemelä, Koivula & Kotze, 2007; Nitterus, 2006) Wood living beetles species have been advocated to serve as indicator species on forests of high conservational value (Nilsson *et al.*, 1995).

Sampling methods

Three methods were used to collect beetles. Sieving was the method used in paper I and paper III. It is a method that gives a high proportion of species that are closely associated with the substrate you are investigating (Wikars, Sahlin & Ranius, 2005). The sieve samples were brought back to the laboratory, where the beetles were extracted out of the sample by help of a lamp placed over the sample to let the light and heat drive the beetles down through the sample into a container filled with ethanol. In paper II beetles were reared out from the wood (Figure 5). One meter long of high-stumps were collected and brought in from the clearcuts. The wood was taken from spruce high-stumps that were both infected and non-infected by the wood decaying fungi *Heterobasidion spp.* (see paper II for methods regarding the determination of fungal infection). *Heterobasidion spp.* is a primary wood decayer causing white rot in several tree species. The beetles were reared out from the wood in the laboratory by enclosing the wood with a fine meshed garment and in the bottom of the enclosure the emerging beetles were collected in a container. The sampling was terminated after 10 months. With this method you collect both the beetles living in/under the bark and those living in the wood. However, you might underestimate some species and over estimate others, with this method if the natural micro-climate in the wood is changed too much (Wikars, Sahlin & Ranius, 2005). In paper IV window traps (flight intercept traps) were used and this is a widely used method to collect beetles (Franc, 2007; Jonsell & Eriksson, 2001; Martikainen et al., 2000). The window was 60X40 centimetres and made of a 3 mm thick transparent plastic sheet. The window was placed adjacent to the high-stumps with the centre at breast-height (1.3m) and a funnel with an attached container was placed under the window. The container was filled with a 50% mixture of water and propylene-glycol with a few drops of washing-up liquid to break surface tension. The traps were mounted on the high-stumps in mid April and brought back in the end of September. During the season traps were emptied at least once a month and beetles were caught during 2002 and 2004.

The drawback with window traps is that they to a large degree sample "tourists" i.e. species not interested in a certain substrate. However if the trap is adjacent to the substrate, high-stumps in this case, you will catch a higher proportion of saproxylic species compared to a free standing window trap (Hyvärinen, Kouki & Martikainen, 2006). Furthermore window traps are appropriate if you want a species list as complete as possible for the landscape you are interested in (Wikars, Sahlin & Ranius, 2005).

Results and discussion

Spruce high-stump as substrate

High-stumps and low-stumps (I)

Several studies have documented that high-stumps are used by a large number of saproxylic beetle species (e.g. Jonsell, Nitterus & Stighäll, 2004; Jonsell & Weslien, 2003; Lindhe & Lindelöw, 2004). However the amount of dead wood added to a clearcut by created high-stumps is insignificant compared to the amount of dead wood in the low-stumps (normal cutting stumps). Roughly, there is about 1-1.5 m^3 dead wood in high-stumps per hectare in southern Sweden, compared to about 20-25 m^3 in low-stumps. Of the total volume of coarse woody debris (CWD) in a landscape high-stumps only constituted 0.13% of the total volume (Schroeder *et al.*, 2006). To justify the creating of high-stumps they preferably should contribute with dead wood properties which benefit additional wood-living beetle species. The comparison (paper I) between the three substrate types; low-stumps, high-stumps at ground level and high-stumps at breast height (1.3 m) revealed differences both in the species composition of saproxylic beetles and in the species richness between the three substrates. The species composition was different between the different high-stump substrates and the low-stump. This supports the idea of creating high-stumps as they host a fauna complementary to the one in low-stumps. Depending on the age of the high-stumps/low-stumps, i.e. whether they were one or three years old, the differences in species composition between the substrate types was more or less pronounced. The one year old stumps had a more similar species composition regardless of the substrate type, whereas the species composition between the three year old stumps was more diverged.

The newly created stumps had a rather similar total number of species, whereas the species number on the older stumps differed more between the three substrate types where the high-stumps at breast height had fewer species compared to high-stumps at ground level and low-stumps (Figure 2).

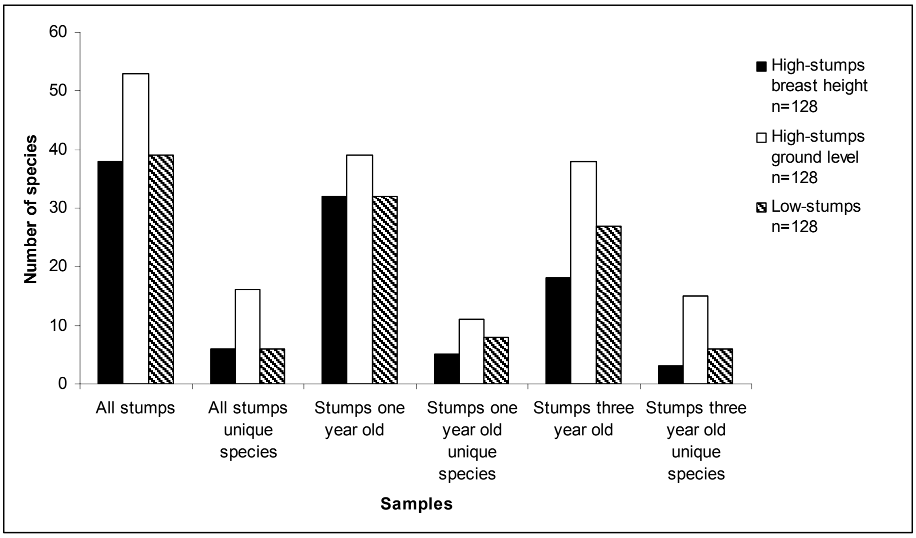

Figure 2. The number of species and unique species (found in one substrate type only) found on each substrate type. For the categories one year old and three year old n=64.

This is probably due to the cambium properties on the recently cut high-stumps and low-stumps. Many of the species that feed on the cambium are generalists, and use the stump regardless where the fresh cambium is available. For both age-classes the substrate with the highest number of species was high-stumps at ground level. This part of the high-stump probably represents an intermediary substrate which has species from both low-stumps and high on high-stumps (Figure 3). The difference in species composition between the substrates increased with age as older substrates showed more pronounced difference in species composition and this is possibly a consequence of the cambium being consumed and other food sources becoming more important.

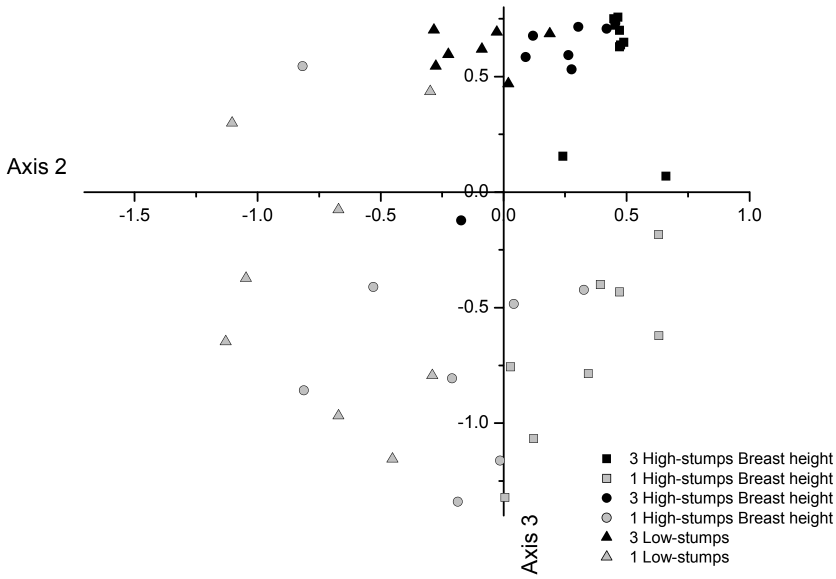

Figure 3. Ordination diagram NMDS, squares represent high-stumps at breast height, circles represent high-stumps at ground level and triangles represent low-stumps. Filled symbols (black) are three year old substrates and open (grey shaded) are one year old substrates.

The importance of the three different substrate types is evident in the species composition but also for individual species. Even though certain species occurred at all substrates they showed strong associations with one or two substrate types.

Several beetle species were only found in spruce high-stumps, either at breast height (1,3m) or at ground level. Also low-stumps had a number of unique beetle species (Figure 2). Some of these unique species were caught as singletons and do therefore not provide much information on their associations. However, there were unique species that occurred more frequently which were associated with the substrate type in question *Hadreule elongatula* for instance, was associated with high-stumps at breast height. Beetle species associated with high-stumps at breast height were mostly bark beetles, whereas rove beetles were associated with high-stumps at ground level. Beetles from the *Nitidulidae* family together with species from the *Rhizophagidae* family were more associated with low-stumps. The differences in species composition (and specific species associations) are probably an effect of the microclimate in respectively substrate type. Sun exposed high-stumps on a clearcut are likely to have a drier and warmer microclimate at breast height compared to the substrates ground level. Forest fire create a number of natural high-stumps and studies have shown that high-stumps on clearcuts benefit saproxylic beetles associated with fire (Kaila, Martikainen & Punttila, 1997; Lindhe, Lindelöw & Åsenblad, 2005; Sverdrup-Thygeson & Ims, 2002). Microclimate in dead wood is probably also important for wood living fungi and their colonisation (Toljander *et al.*, 2006) The fungal flora has an effect on beetle species composition (Jonsell, Schroeder & Weslien, 2005) and possibly affect specific beetle species occurrences in the older substrates in this study. As dead wood gets older the specific tree species properties, important for several saproxylic beetles, have less impact on the species composition as the species-pool includes a higher proportion of fungivorous species that are associated with the fungus rather than the type of wood (Jonsell, Weslien & Ehnström, 1998). Jonsell and co-workers (2005) showed that the beetle species composition in spruce high-stumps, to a large extent, was determined by the fungal flora in the stump. Several other studies have shown strong host-associations for beetles living in fungal fruiting bodies (Fossli & Andersen, 1998; Jonsell, 1999; Jonsell & Nordlander, 2004; Kaila *et al.*, 1994; Orledge & Reynolds, 2005).

To conclude, study I reveals that spruce high-stumps provide new environments for saproxylic beetles compared to low-stumps and add to the species diversity on clearcuts. The study also shows that the high-stumps do not offer a homogenous substrate but that different parts of the stump host a slightly different assemblage of beetles. These beetle assemblages in high-stumps are to some extent complementary to the ones in low-stumps. Furthermore, some beetle species clearly prefer the high-stump habitats over low-stumps. Though there were no red-listed species caught in the high-stumps in this study there are other studies showing that high-stumps also benefit red-listed species (Jonsell & Eriksson, 2001; Jonsell, Nitterus & Stighäll, 2004; Lindhe & Lindelöw, 2004). These results might be of importance if the low-stump harvesting for bio-fuel increases. Today it is only done in small scale but if done on a regular basis the amount of wood on clearcuts will decrease even more. Consequently the high-stumps will be of more importance and especially the lower part that had many species in common with low-stumps.

Saproxylic beetles, wood decay fungi and butt rot (II)

The fungi community in the wood is important for a large number of beetle species and many beetle species are associated with a specific fungus or fungal group (Fossli & Andersen, 1998; Jonsell & Nordlander, 2004; Kaila *et al.*, 1994). The first primary wood decay fungi that colonise the wood will to a large extent determine the following fungal succession (Holmer, Renvall & Stenlid, 1997; Renvall, 1995) and hence, affect the future beetle species composition. *Heterobasidion* spp. are primary wood decay fungi which cause a large economical loss for the forest owner. The frequency of *Heterobasidion* spp. is increasing in production forests and since rotten trees are of low economical value they are often chosen when creating high-stumps.

In total 3,211 individuals divided on 43 species were caught. The number of species did not differ between the two substrates, infected and non-infected stumps. The infected stumps had 30 species whereas the none-infected had 33 species and 20 species were found in both stump types (Table 1). Ten species were unique to the infected stumps whereas thirteen species were found only on non-infected stumps. As most of the unique species only were caught as singletons or doubletons they do not provide so much information except that the high proportion of singletons suggests that additional sampling might be needed (Magurran, 2004).

Figure 4. The author struggling with a part of a high-stump to be studied regarding the effect of butt-rot (paper II).

The thirteen most frequent beetle species were analysed for specific associations with fungi. Three species showed significant negative associations with *Heterobasidion* spp. infection whereas the other ten showed no associations. None of the analysed species showed positive associations with *Heterobasidion* spp (Table 2). Two of the perhaps most common fungi on spruce high-stumps are *Fomitopsis pinicola* and species of the genera *Trichaptum*. These fungi were also recorded on the high-stumps and beetle associations with these fungi were also analysed. Two of the thirteen species showed significant positive association with *F. pinicola* and three species showed associations with *Trichaptum* spp. one of which was negative (Table 2). If *Heterobasidion* spp. have negative effect on another wood decaying fungi and hamper it's ability to colonize dead wood is important to know as such effect could have a great impact on fungivorous beetle species communities (Ehnström, 2001). However, the occurrence of *F. pinicola* and *Trichaptum* spp. did not seem to be affected by presence or absence of *Heterobasidion* spp. *Trichaptum* spp. and *F. pinicola* however never occurred with fruiting bodies on the same stump. This suggests that these two primary wood decay fungi might compete and exclude each other from high-stumps.

Figure 5. The setup to rear the beetles from the wood in the study on butt-rot (paper II)

Table 1. Number of species caught in the root rot study. Species total number for each category, average number of species, unique species and number of individuals are given for absence respectively presence of *Heterobasidion* spp in the stump.

	Heterobasidion present	*Heterobasidion* absent	Total numbers
Number of species	30	33	43
Mean number of species per stump	5.1	6.2	5.6
Number of unique species	10	13	23
Number of individuals	1569	1642	3211

To conclude, the study on saproxylic beetles in *Heterobasidion* spp. infected and non-infected high-stumps revealed that some species are negatively affected by pre-rotten high-stumps. This suggests that if the proportion of pre-rotten high-stumps of spruce increases it could have a negative effect for some saproxylic beetle.

Table 2. Beetle species that showing significant associations with different fungi. The number of signs denotes the degree of significance: one sign $p < 0.05$, two sign $p < 0.01$ and three signs $p < 0.001$. Minus (-) denotes negative association and plus (+) denotes positive association.

Species	*Heterobasidion*	*Fomitopsis*	*Trichaptum*
Hapalarea gracilicornis	---	++	
Cis punctulatus			++
Hadreule elongatula		+++	
Euglenes pygmaeus	--		
Abdera triguttata	---		+++

High-stumps from a landscape perspective

High-stumps in hotspots and matrix areas (III & IV)

An increasing awareness have arisen over the last decades that threats to biodiversity in the forested landscape cannot be solved in the individual stand – a landscape perspective is necessary (Franc *et al.*, 2007; Paltto *et al.*, 2006). The Landscape is however heterogonous, and depending on land-use, management history and underlying bio-geographical landscape factors (e.g. climate), the flora and fauna will be retained to different degrees in different areas. It is suggested that actions aiming at preserving the biodiversity are most effective when concentrated to species-rich areas, so called hotspots (Hanski, 2000). However, the opposite is also advocated (Fahrig, 2001), and it is argued that improving the quality of the production forest (the matrix) is important. By improving matrix quality, isolated species might be able to disperse between patches but also disperse to new suitable patches. For some species, small improvements in the matrix could result in a shift from a sink to a source regarding population survival (Fahrig, 2002). The aim of our studies on landscape ecological issues was to investigate if there were any differences between high-stumps in hotspot areas and matrix areas regarding the saproxylic beetle fauna. Few studies have attempted to study a common conservation action from the landscape scale perspective. The so far published landscape efforts have studied differences between different regions with different management history and most are conducted in boreal forests (Schroeder *et al.*, 2006; Siitonen & Martikainen, 1994; Similä *et al.*, 2002). In these studies (III & IV) we sampled saproxylic beetles and beetle species composition in relation to a number of environmental variables in southern Sweden.

Species richness

In study III & IV a total of 43,682 saproxylic beetles were caught, 39,503 of these species were caught with window traps (paper IV) and 4,179 by bark sieving (paper III). These individuals belonged to 395 different species. 65 species were considered rare or red-listed. Rare saproxylic beetles are those that were listed on the red-list form year 2000 (Gärdenfors, 2000) and red-listed species are those on the present red-list from 2005 (Gärdenfors, 2005). There was no difference in the number of saproxylic beetle species caught between hotspot clearcuts and matrix clearcuts (Table 3) and the number of rare and red-listed beetles did not differ either. The number of beetle species was also compared between hotspot clearcuts and matrix clearcuts separately for spruce and birch high-stumps. We failed to find any significant differences between the landscape types also in this approach (Table 3).

Table 3. Number of species in total, number of rare species and number of red-listed species. Numbers are given for each region (West, Mid-west, Mid, Mid-East and East), tree species of high-stumps (spruce or birch) and landscape type (hotspot or matrix). The species are pooled within each region and landscape type.

Region	Hotspot			Matrix			All
	Spruce	Birch	Total	Spruce	Birch	Total	Total
West	141	135	179	158	125	186	236
Red-listed	5	4	7	4	2	4	10
Rare	5	5	9	6	2	7	13
				4			
Mid-West	162	140	199	148	146	243	243
Red-listed	3	4	5	2	1	3	6
Rare	4	5	7	1	2	3	9
Mid	144	111	176	108	103	141	199
Red-listed	4	3	5	1	1	2	6
Rare	1	0	1	0	1	1	2
Mid-East	108	122	157	114	137	164	221
Red-listed	3	2	4	3	2	3	5
Rare	4	2	5	1	3	3	7
East	154	151	213	168	166	221	265
Red-listed	5	6	11	7	12	13	20
Rare	5	7	11	12	9	15	17

There are several factors that could explain the lack of difference in species composition between hotspot and matrix clearcuts. Too few samples could be one reason. Martikainen and Kouki (2005) concluded that in order to detect differences in species composition a sample of around 400 beetle species from the different sites is necessary to find a pattern if it is there a pattern to find. In our studies nearly 400 saproxylic beetle species were caught and over 40,000 individuals were collected with two different methods. The number of species was from 141 to 243 species per region and landscape type (Table 3). This is not enough according to Martikainen and Kouki (2005). However, they consider all sampled beetle species whereas we only analysed the saproxylic beetles. If also we considered all beetle species, the total number would probably be around 400 per landscape type and region.

Dead wood quality is important for several beetle species. As the high stumps in these studies (III & IV) are man-made they are probably more homogenous than natural high-stumps (Jonsell, Nitterus & Stighäll, 2004). This could possibly explain the similar species numbers between the hotspot clearcuts and matrix clearcuts, especially as the high-stumps only were three years old at the most. The fact that the high-stumps only were four years old at the most discriminates species associated with older dead wood and these species would not show up in the sieved samples (paper III). Furthermore, species associated with older wood types are perhaps not as active dispersers as species associated with more recently dead wood. Late successional species would hence have lower catch rates in the window traps compared to early successional species (paper IV).

The amount and diversity of dead wood is probably the most important factor in explaining the species number and composition. However, this variable was not included in either of the studies (III or IV). This was due to the lack of data on dead wood volumes with high enough spatial resolution and a budget not admitting a dead wood survey. It is too difficult to speculate about possible differences in dead wood volumes around the sampled clearcuts. A higher proportion of broadleaved trees or broadleaved forest might indicate a forest that is not as intensively managed as a coniferous production forest and it could perhaps contain more dead wood.

It is important to keep in mind though, that the hotspot areas are designated based on beetle species diversity and number of red-listed species. As a large part of the saproxylic beetles on the Swedish red-list are associated to broadleaved trees like oak and beech, spruce might be of minor importance for several of the species confined to the designated hotspots. Birch might be more important as it has several species in common with many other broadleaved tree species (Ehnström, 2007; Jonsell, Weslien & Ehnström, 1998)

Species composition and forest composition

Forest composition variables were compared between hotspot and matrix areas (ANOVA) and there were significant differences for some of the variables. Hotspot clearcuts on average had a higher proportion and volume of broadleaved forest in the surroundings compared to matrix clearcuts, whereas it was the opposite for coniferous forest (see Table 2 paper IV). This suggests that the saproxylic beetle fauna could be somewhat different between the two landscape types as beetle species associated with broadleaved trees probably occur in higher numbers if the proportion of broadleaved trees in the surroundings is higher. The tree species composition could perhaps say something about the average landscape quality. A higher proportion of broadleaved forest might indicate a less intently managed forest. Furthermore, the analysis showed that the proportion of WKH (Woodland Key Habitats, forest stands containing high biodiversity values) also differed. The area of WKHs was higher in the surroundings of hotspot clearcuts than in the matrix clearcuts on the larger scale (2500 m radius), and nearly significant also on the smaller scale (500 m radius). This could support that the designated hotspot clearcuts have forest qualities important for biodiversity as WKHs in average contain more dead wood than the surrounding forests (Jönsson & Jonsson, 2007).

The beetle species composition was analysed in relation to environmental variables using CCA. With this ordination technique species are arranged to maximise the explanatory power of the included environmental variables (Quinn & Keough, 2002). The variables connected to the amount and volumes of broadleaved forest in the surrounding of the clearcuts explained a significant amount of the variation in beetle species composition, but the hotspot/matrix variable did not contribute significantly in explaining species composition. However, the hotspot/matrix variable correlated well with variables connected to amount and volume of broadleaved forest (paper IV). The CCA analyses were also done for spruce and birch high-stumps separately with only beetle species associated with respectively tree species included (paper IV). The result from the birch high-stumps showed the same pattern as for the CCA analysis where all samples were included. For spruce it was somewhat different, as variables connected broadleaved forest did not explain much except for volume of beech. The reason that the hotspot variable did not explain species composition could be that the amount and proportion of broadleaved forest surrounding each of the hotspot and matrix clearcuts varied considerably. Some of the clearcuts in hotspot areas are probably surrounded by a large proportion of trivial coniferous production forests, whereas some of the matrix clearcuts probably are situated in potential hotspot areas. The latter is most likely the case for one matrix clearcut, as it had the second highest total number of saproxylic beetle species and the highest number of rare and red-listed species in the study (paper IV). Thus, even if the average hotspot clearcut had a larger proportion of broadleaved forest in the surroundings the variation between the clearcuts was too large for the hotspot/matrix variable to contribute significantly (paper IV).

Additional variables were also important, and longitude was the variable that explained most of the variation in species composition in both paper III and paper IV. It is probably an effect of climate but also of tree species composition. Whether it is the climate or tree species composition that has strongest effect is difficult to say and it is most likely a combination of both. Precipitation was an important climatically related variable (paper III) which was negatively correlated with longitude. Furthermore, there is difference in climate, with a cool and moist west and a warm and dry east. This probably affects the beetle fauna caught in the study and there are several studies supporting a difference in species composition from west to east in southern Sweden (Franc *et al.*, 2007; Økland *et al.*, 1996). Furthermore, inventories on the beetle fauna in south-western Sweden compared to inventories in south-eastern Sweden also show differences in species composition (Andersson, 2001; Nilsson & Huggert, 2001). Also the difference in tree species composition with more spruce and beech to the west, and more pine, oak and aspen to the east (Anon., 2006) is likely to affect the saproxylic beetles species composition (Jonsell, Weslien & Ehnström, 1998; Lindhe & Lindelöw, 2004). For the spruce samples the volume of beech unexpectedly explained much of the species composition. This is most likely an effect of that certain species only were found in the westernmost region.

To conclude, we found that the amount of broadleaved forest in the surroundings is important for explaining species composition on high-stumps. The hotspot clearcuts correlated well with this as they on average had a higher proportion of broadleaved forest in the surroundings. Variables connected to the amount of coniferous forest only explain a small part of species composition, possibly as coniferous forests are dominating the forested landscape of southern Sweden.

Temporal aspects on high-stumps

There are off course temporal aspects to consider regarding the high-stumps in our studies. The clearcuts and the sampled high-stumps were at the most three years old which means that they were all in the early stages of succession. These fresh high-stumps attracted mostly cambium feeders. These beetle species are generally good dispersers compared to species associated with later decay stages. Fresh cambium is probably readily available in similar proportions around both hotspot and matrix clearcuts. This is important to acknowledge since the interpretation of the results here are based on this early phase of dead wood succession. As the practice of creating high stumps is rather new, the knowledge on species composition in the later stages of their succession is not well known. However, there are studies showing that the species composition changes with time (Jonsell & Weslien, 2003). In our study IV there was a dramatic decrease in number of bark beetles between the two sampling occasions which shows the effect of succession even if within a short temporal frame. Most likely the changes in species abundance and composition will continue. How the species composition will develop depends on several factors. The most important factor will probably be what fungi that colonises the high-stumps. The fungal flora is shown to play a key role in determining the beetle species composition in dead wood (Jonsell, Schroeder & Weslien, 2005; Kaila *et al.*, 1994; Økland *et al.*, 1996; Orledge & Reynolds, 2005). Other factors which probably also will affect the species composition of the high-stumps is how long they will be standing and also for how long they will be sun exposed. Regarding paper IV where the landscape is in focus, I think that succession might reveal differences in species composition between the landscape types. If the sampling of the clearcuts in the designated hotspots and clearcuts in the matrix had been done later in the succession, other species would probably have been caught. In paper IV, were we used window-traps, there was a tendency of more of late successional rare and red-listed species caught on the hotspot clearcuts. This implies that there actually could be differences in species assemblages between the two landscape types. However this does not necessarily mean that created high-stumps would be used by these species as high-stumps seem to lack in quality compared to natural high-stumps (Jonsell, Nitterus & Stighäll, 2004).

High-stumps and insect pests

One potential problem when creating dead wood from coniferous trees, especially spruce, is the risk of an increase in primary barkbeetle populations. In all our studies we caught both *Ips typographus* and *Pityogenes chalcographus* which both are primary barkbeetles, i.e. they are capable of killing living trees if attacking a tree in high enough numbers. However, the abundance of these species in the high-stumps was not particularly high. Unless the number of newly created spruce high-stumps increases dramatically relative to todayspruce high-stumps do not pose a risk for the forest health. This is supported by a study by Hedgren and co-workers (2003a) were they showed that *I. typographus* prefers lying, sun exposed and fresh spruce wood. For *P. chalcographus* it is the smaller diameter spruces or the tops of trees were the bark is thinner that are preferred (Hedgren, Weslien & Schroeder, 2003b).

Conclusions and suggestions for the future

This thesis has shown that high-stumps in production forests increase habitat diversity for saproxylic beetles. If the extraction of low-stumps for bio energy becomes a common practice, it will be even more important to leave high-stumps and even increase the numbers as the low part of the high-stumps host several beetles which also were found in low-stumps.

The making of high-stumps is a cost for the forest owner, and to find cost effective conservation actions are of interest for all stakeholders. One such action regarding high-stumps of spruce could be to increase the proportion of rotten high-stumps. Our study shows that pre-rotten high-stumps have a negative effect on some beetle species and increasing this proportion could affect beetle diversity on clearcuts.
No difference in species composition was found between hotspot areas and matrix areas which support the idea of spreading high-stumps in the landscape to improve the matrix quality. Spreading or concentrating conservation efforts depends on what species or species groups that are in focus, but for saproxylic beetles associated to created high-stumps on clearcuts it seems to be most beneficial to spread them in the landscape. However, high-stumps will not preserve all saproxylic beetles and species benefiting from high-stumps are probably rather good dispersers. For several of the more threatened beetle species confined to long lasting, stable substrates, e.g. large hollow oaks, other actions are necessary. Still high-stumps could help in keeping some saproxylic beetles away from the red-list. Especially as they are created on a large scale and they constantly add newly dead sun-exposed wood in the landscape.

Last but not least, it is important to keep in mind that all studies in this thesis were done on at maximum three years old high-stumps. It is probable that some of the conclusions in this thesis would be different if the high-stumps were sampled during the whole succession process.

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