Sveriges lantbruksuniversitet
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Department of Ecology

Qualities and supply of suitable dead wood for *Ceruchus chrysomelinus* and its dispersal pattern in a translocated population

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Abstract

The wood-living beetle *Ceruchus chrysomelinus* is a rare species connected to natural forests. In Sweden, it is red-listed as endangered (EN) and an action plan for its preservation has been done by the Swedish Environmental Protection Agency. In this work I have therefore investigated how a translocation of the species succeeded after 17 years. I aimed to study the species dispersal biology, its substrate preferences and the supply of suitable wood on this site. The study was performed during 2012 in Pansaruddens nature reserve close to Uppsala in Sweden, which is a spruce dominated forest. In 1995 logs with dense populations of *C. chrysomelinus* were translocated into two locations within this reserve. Circular study plots were established with a radius of 75 m around the translocated logs in both sites. All lying dead wood trunks ≥10 cm in breast height within the study plots were investigated. Generalized linear models showed that the presence of *C. chrysomelinus* could be described by degree of decay, rot type (white/brown) and the size of the log. This study also shows that the species had dispersed within the two areas, but only for very short distances. Most findings were done <10 m from the translocated logs. On average the total amount of lying dead wood for the two study plots were 52 respectively 35 m^3/hectare. Only 4 % of the total dead wood supply was suitable for *C. chrysomelinus*, when considering the wood qualities found important for the species in this study.

Keywords: Ceruchus chrysomelinus, saproxylic beetle, translocation, dead wood, dead wood qualities, suitable substrate, species conservation, conservation biology.

Sammanfattning

Många vedlevande arter i Sverige har idag mer eller mindre mörka framtidsutsikter. Anledningen är att skogen har förändrats av människan sedan vi började bedriva ett mer storskaligt skogsbruk. Tidigare var skogarna fyllda med en riklig mängd av död ved. Det är idag väl känt att mängden död ved i våra skogar gynnar den biologiska mångfalden. Samtidigt är det i princip omöjligt att förena bedrivandet av ett rationellt skogsbruk med tillräckliga mängder död ved för de känsligare arterna. Dessutom har olika arter olika krav på vilka egenskaper den döda veden ska ha. Det första som behöver göras innan man kan planera för bevarandet av vedlevande arter är att ta reda på de olika arternas krav på vedkvalité och deras förmåga att sprida sig till ny lämplig ved. Då har man ett underlag för att kunna beräkna vilken mängd av död ved som behövs och hur den bör vara fördelad i landskapet.

Syftet med den här studien var att ta reda på vilka krav den vedlevande skalbaggsarten svartoxe (*Ceruchus chrysomelinus*) har på sin ved, tillgången på lämplig ved samt hur arten har spridit sig i området. Svartoxen är rödlistad och återfinns endast på ett fåtal platser i Sverige. Den hittas främst i liggande grov granved som är kraftigt brunrötad. Arten tycks vara knuten till naturskog där tillgången på död ved är stor. 1995 genomfördes en förflyttning av svartoxe till Pansaruddens naturreservat i Uppsala län, genom att några stockar med svartoxar flyttades till två olika platser i reservatet. Innan förflyttningen genomfördes hade området inventerats för att konstatera att svartoxen inte redan fanns där. Skogen i reservatet är naturskogsliknande och tillgången på död ved i områdena där stockarna placerades var stor och man hoppades på att svartoxen skulle etablera sig.

Studien gjordes genom att alla liggande stockar på de två lokalerna inventerades inom ett område med en radie på 75 m från ursprungsstocken. För varje stock mättes: avstånd till ursprungsstocken, stockens storlek i längd och diameter, nedbrytningsgrad, röttyp, trädart, kvarvarande mängd bark, markkontakt, fuktgrad, svampart om det fanns några synliga fruktkroppar, höjd på markvegetationen, krontäckning samt förekomst av svartoxe.

Svartoxen hade spridit sig i båda områdena och statistiska analyser visade vilka vedegenskaper som kunde förklara förekomsten av svartoxe i en stock.

Resultatet blev att diameter över 30 cm, längd över 10 m, frånvaro av vitröta och den högsta graden av nedbrytning är egenskaper som är viktiga för svartoxen. Avståndet till ursprungsstocken var också av mycket stor betydelse, då svartoxen oftast bara spritt sig ett par meter. Resultaten tyder på att arten har en begränsad spridningsförmåga.

Inom de två provytorna fanns 52 m^3 respektive 35 m^3 liggande död ved per hektar. Det visade sig dock att enbart 4 % av denna vedvolym hade de egenskaper som svartoxen kräver. Avstånden mellan de lämpliga stockarna blir då längre än om en större andel varit lämpliga.

Kombinationen av att svartoxen tycks ha en låg spridningsförmåga och den sparsamma tillgången på lämpliga stockar gör därför att det lär gå trögt för svartoxen att etablera större populationer. Det vore intressant att göra liknande inventeringar av död ved i andra områ-

den med obrukad skog för att se om det generellt enbart är 4 % av den totala volymen död ved i naturskogar är lämplig för svartoxe.

I dagsläget tyder resultatet av den här studien på att mer lämplig ved kan behöva skapas genom aktiva naturvårdsåtgärder i Pansaruddens naturreservat för att säkerställa att populationen kan överleva långsiktigt.

Det är förmodligen inte särskilt troligt att svartoxen flyger några längre sträckor för att kolonisera nya områden. Därför är det viktigt att se till att de lokaler som finns idag sköts på ett sådant sätt att dessa populationer fortsätter att vara livskraftiga eller uppnår livskraftig status.

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1 Introduction

The beetle *Ceruchus chrysomelinus* (Coleoptera, Lucanidae) is nowadays a rare forest species in Sweden. It is living in dead wood and seems to require high quantities of a specificwood substrate, usually found in natural forests.

In Sweden, *C. chrysomelinus* is red-listed in the category EN, endangered (Gärdenfors, 2010). The selection of Red List category is based on that the population is heavily fragmented and have an on-going decline in number of populations, and an on-going decline of suitable habitat or degradation of the habitat quality (Gärdenfors, 2010). To find out how to preserve and favour the species the Swedish Environmental Protection Agency developed an action plan for it (Hedin, 2010).

The distributional range in Sweden is from Skåne/Blekinge to Gästrikland (Hedin, 2010; Ehnström, 1999). Since 1980 it is only known from 20 sites in Sweden (Hedin, 2010), most of them from the areas around Vällen and South Dalälven in the county of Uppsala (Eriksson, 2010).

1.1 The dead wood substrate

Two properties of dead wood, coarse wood and heavily degraded wood, are suggested as particularly important for *C. chrysomelinus* (Ehnström, 1999; Hedin, 2010). These two qualities of dead wood are considered as scarce in Swedish forests (de Jong & Almstedt, 2005).

In 1995 the average volume of dead wood in managed Swedish forests was 6,1 m^3 per hectare (Fridman & Walheim, 2000), to be compared with 60-90 m^3 in unmanaged old-growth forest areas in the boreal zone (Siitonen, 2001). Most of Sweden's natural forest area is located in the mountain areas in the north. Only 1 % of the productive forests in the distributional range of *C. chrysomelinus* could be classified as natural forests (Bernes, 2011). This makes it understandable why species like *C. chrysomelinus* are rare and have a scattered distribution today. Species that requires high quantities of dead wood (about 50 m^3 or more) will not be possible to preserve in areas affected by any rational forestry (de Jong & Almstedt, 2005). For the preservation of *C. chrysomelinus,* actions in the managed forest are not enough and reserves are almost required to ensure proper amounts of suitable wood (Ehnström, 1999).

1.2 Conservation of *C. chrysomelinus*

The long term goal of the species action plan is to stabilize the population size and the distributional range (Hedin, 2010). A short term goal is to analyse future supply of suitable dead wood in occupied sites, to be able to estimate the viability of these populations in the future. However, what characterises suitable wood for the species has not been studied systematically. A number of different qualities of the wood are constantly mentioned in the literature suggested as important for *C. chrysomelinus*: old, coarse logs mainly of *Picea abies* (but also other tree species) and they should be heavily brown rotted (often by *Fomitopsis pinicola*) (Ehnström, 1999; Hedin, 2010; Eriksson, 2010). The wood should have a high moisture content and for this ground contact and shady forests are important (Ehnström, 1999; Hedin, 2010).

When two fallen spruce trees colonised by *C. chrysomelinus* were found in a clear cut, it was decided to translocate them to the closely located nature reserve Pansarudden (in the Vällen area in the county of Uppsala) in 1995. One tree was cut into logs and was moved by helicopter into two different locations within the nature reserve with high concentrations of dead spruce. *C. chrysomelinus* was not known from the reserve before, and a small inventory was performed to ensure its absence before the rescue action started (Ehnström, 1999; Eriksson, 2010).

One of the suggested actions by Hedin (2010) was to make a follow up from this translocation. It is known from 2006 that the species has spread from the origin logs (Eriksson, 2010), but no more advanced or detailed studies have been done on this population. We can probably learn important lessons about *C. chrysomelinus* from studying this population, since it is newly established.

1.3 Current knowledge gaps

More knowledge about species preferences of different types of dead wood is needed and in addition data on the real distribution of these wood qualities (de Jong & Almstedt, 2005). Also knowledge about species dispersal biology is of great importance when formulating environmental objectives, management control measures and performing conservation actions (Almstedt Jansson et al., 2011).

Another problem is the lack of knowledge about actual limiting values for the quantity needed of different substrates, which is connected to the knowledge gaps in species dispersal biology and environmental preferences, etc (Almstedt Jansson et al., 2011). This study is performed with the intention to fill some of these knowledge gaps for *C. chrysomelinus* and three research questions were formulated:

1. **How has *C. chrysomelinus* dispersed and colonised logs around the translocated logs in Pansaruddens nature reserve, 17 years after the translocation in 1995?**
   After answering this question it could be possible also to draw some conclusion about the dispersal pattern of the species. Because the population in Pansarudden is under development, the distribution today will be an evidence of how it is dispersing.

2. **What characterises the dead wood that is colonised by *C.chrysomelinus* in the two translocated populations in Pansaruddens nature reserve?**
   This is important from many aspects. It will indicate which qualities are the most important for *C. chrysomelinus* in this location. It is also necessary information for answering research question 3.

3. **What are the quantities of suitable dead wood for *C. chrysomelinus* in the two translocated populations in Pansaruddens nature reserve?**
   I will also investigate how large proportions of the wood on the sites that are suitable for the species. This proportion will make it possible to estimate how high the general dead wood supply should be in *C. chrysomelinus* sites.

2 Materials and methods

2.1 Research area

Pansaruddens nature reserve (N 59º 59.200' E 018º 21.242') is located about 40 km east of Uppsala in Sweden (Figure 1). This region is located in the hemi-boreal zone and is dominated by coniferous forests and mixed forests. The area of the reserve is 297.4 hectares and mostly consists of the nature type western taiga, which includes older natural-like mixed and coniferous forests free from forestry in recent years (Länsstyrelsen Uppsala län, 2009). Note that the forest in Pansarudden had a history of management but is now developing the qualities of a natural forest. Logs colonised by *C. chrysomelinus* was translocated into two different areas within the reserve (N59º58.810' E018º20.199' and N59º59.203' E018º20.585') in 1995 (Figure 2).

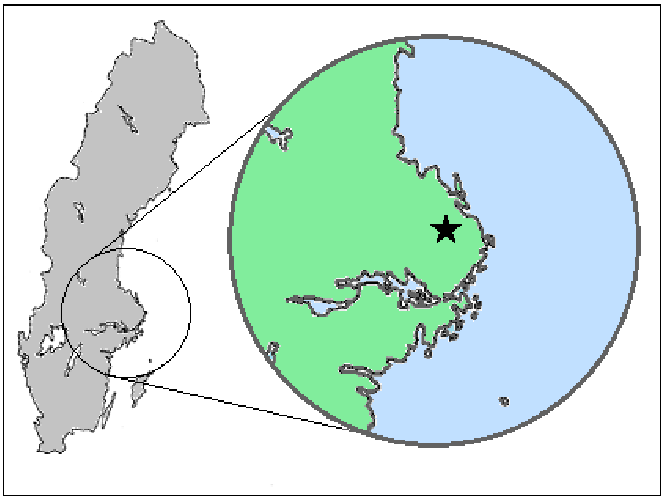

Figure 1. Pansaruddens nature reserve (black star) is located in the middle-east part of Sweden, in the hemi-boreal zone.

2.2 Inventory design

The inventory was performed during June 2012. Around each translocated log (Figure 2) a circular study plot with a radius of 75 m was established. Within these study plots, all logs of dead wood with a diameter ≥10 cm in breast height were surveyed.

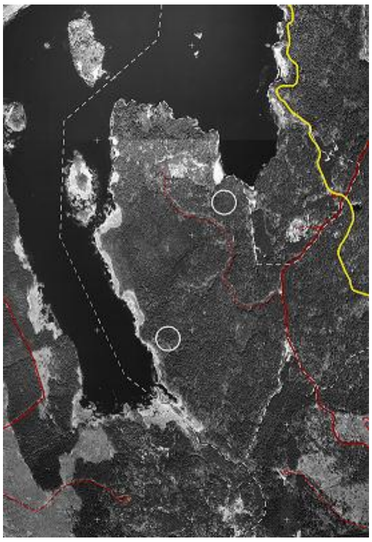

Figure 2. Logs with *C. chrysomelinus* were placed in two separate areas (white rings) about 800 m apart in Pansaruddens nature reserve.

2.3 Measured variables

One highly prioritised part of the action plan is to design proper methods for surveying the *C. chrysomelinus* substrate (Hedin, 2010). This manual was not yet produced when this study was performed and it was necessary to formulate own methods for the survey.

All variables that were measured in the field are summarized in Table 1. For all logs the **distance from the translocated log** and **GPS-coordinates** was measured by a Garmin GPSMAP® 62s. **Length**, **diameter in breast height, tree species** and **decay class** was also noted for all logs. In cases where only a part of a tree trunk was present or the trunk was broken, the diameter was measured 150cm from the thickest end of the trunk piece. The decay class was determined according to the system of Siitonen & Saaristo (2000) where the decay class is determined by how far into the wood it is possible to push a knife. This was done at several places along the trunk and **the highest and lowest value of decay class** was noted. If the highest decay class was determined to 1-4 the log was considered as unsuitable for *C. chrysomelinus* and no more measurements were done on that log. On other logs, further investigations were done where the log had its highest noted decay class.

If the highest decay class was determined to 5-6, the log was further investigated. Five characteristics were measured to describe the qualities of the wood. The **proportion of remaining bark** was determined by eye and was estimated into ten-per cent classes (i. e. 0%, 10%, 20%...100%). The length of the log with **ground contact** was measured in the field and the proportion was calculated afterwards. **Degree of moisture** in the log was measured with a GMR100, which is usually used for measuring moisture content in building materials. It is suggested by Samways et al. (2010) to use such instrument for measuring moisture levels in logs. It calculates the moisture content by measuring the electrical resistance in the material and gives a value in % (moisture content u). The instrument was set to “wood group C” (characteristics curve suitable for *Picea spp., Betula spp., Alnus glutinosa,* and *Populus tremula,* among others). The **rot type**, brown or white, was determined when studying the wood in field. If fruiting bodies of wood decaying fungus were present the **fungal species** was noted.

The conditions of the surroundings were described by two variables. **Canopy cover** was measured according to Siitonen and Saaristo (2000) with four different classes of openness and shade. The **height of ground vegetation** (scrubs, sprigs, herbs and grasses but not trees >5 cm diameter) was classified by a self-made method. Six classes where used: 1) no ground vegetation or moss, 2) blueberry sprigs, 3) low herbs, 4) high herbs, 5) bush <5m and 6) bush >5m.

The **presence of *C. chrysomelinus*** was investigated by opening a 50 cm long part of the log with a knife. This spot was chosen by the eye, always in the part of the log of highest decay class. Moisture content and rot type was also measured in this part of the trunk. Only presence or absence of insects was investigated, mostly because searching for *C. chrysomelinus* means destruction of its habitat. To be present, at least one adult insect or larvae needed to be encountered. The **diameter at the ”sampling-spot”** was also noted.

2.4 Statistical analysis

To analyse how well the measured qualities of the wood describes the presence or absence of *C. chrysomelinus* Generalized Linear Models were used in the statistical software JMP 9.0. Binomial distribution, logit link function and α-level 0.05 were used. The data from plot 1 and plot 2 where pooled together in the analysis. First all measured variables was tested one by one. After that, different multivariate models were tested to find out if any new variables could turn out significant in combination with other variables. The method of choosing variables for these models was backward selection, where insignificant variables were taken away one by one from the model. The variable taken away was always the one with the highest p-value in the model. Also models with two variables were tested. Then one of the significant variables from the single test was tested together with the other variables.

When calculating the proportion of suitable wood within the total wood mass, the volumes (m3) of the entire logs with suitable qualities were used. All wood qualities found significant for describing the presence of *C. chrysomelinus* in a log were used when counting on suitable wood.

Table 1. List of measured variables during the inventory

Variable	Description
<u>All logs</u>	
Distance from the translocated log	Measured with a Garmin Astro 220, (m)
GPS-coordinates	Measured with a Garmin Astro 220
Tree species	
Length of log	(m)
Diameter in breast height	(cm)
Decay class	Classes 1-6, according to Siitonen and Saaristo (2000)
<u>Logs of decay class 5-6</u>	
Diameter at the ”sampling-spot”	(cm), a 50cm part of the trunk where moisture content, rot-type and findings of C. chrysomelinus were measured.
Proportion of remaining bark	Classes of 10 % (10 %, 20 %, 30 %...100 %)
Proportion of log with ground contact	(%), length of log with ground contact / length of log
Degree of moisture	(%, moisture content u), measured with a GMR100
Type of rot	Brown rot or white rot
Species of wood decaying fungi with fruiting body	
Height of vegetation	Classes 1-6, according to methods above
Canopy cover	Classes 1-4, according to Siitonen and Saaristo (2000)
Presence of *Ceruchus chrysomelinus*	Presence or not of adults or larvae

3 Results

In total 416 logs of dead wood where recorded, with a total volume of 154 m^3. The average density of dead wood was 52 m^3/hectare in area 1 and 35 m^3/hectare in area 2. Present species of the dead wood were *Picea abies, Betula pendula, Populus tremula, Alnus glutinosa, Fraxinus excelsior, Salix caprea* and *Quercus robur.* Most common was *P. abies* with 86 % of the total volume of dead wood. *B. pendula* consisted of 6 % of the total volume and other deciduous tree species consisted of 8 %. The two areas differed some in their distribution between coniferous wood and deciduous wood, (area 1: coniferous=89 %, deciduous=11 %, area 2: coniferous=82 %, deciduous=18 %).

Findings of *C. chrysomelinus* were done in both areas, two logs with *C. chrysomelinus* were found in area 1 and three in area 2.

3.1 Dead wood qualities

In the statistical test 21 variables were tested how well they describe the occurrence of *C. chrysomelinus* in a log of dead wood (Table 2). Significant results were found for five variables:

The variable with the strongest effect on *C. chrysomelinus* was distance to the translocated log, which was indicated by the lowest p-value (p=0.0002) and had a negative parameter estimate. This means that the probability for *C. chrysomelinus* to occur in a log will be much higher close to the origin log. Distance was tested in several multiple models together with other variables, always resulting in significant p-values (Table 3).

Brown rot did not give any significant result, but white had a significant negative influence (p=0.0077). A high number of logs with dominating brown rot were found without *C. chrysomelinus*, even if all beetle findings were done in logs with brown rot. But *C. chrysomelinus* was never found in logs with dominating white rot and only one finding was done in a log with both rot types (Figure 3). When putting the variables white rot and brown rot together in a multivariate model, still only white rot received a significant p-value (Table 3).

C. chrysomelinus was exclusively found in logs of decay class 6 (Figure 4).Decay class was tested with three different variables, the highest and lowest noted values in the log and the average value. Only the highest decay class showed significant result (p=0.0083). The parameter estimate was positive and very high (+18.75).

Table 2. Results from regression analyses where all variables were tested for how well they describe the presence of C. chrysomelinus one by one.

Variables	p-value	Estimate
Distance	0.0002*	-0.133526
Picea abies	0.0856	16.341494
Betula pendula	0.1918	-16.21423
Other deciduous species	0.3067	-15.14734
Decay class (average)	0.4885	0.5110451
Decay class (highest)	0.0083*	18.750518
Decay class (lowest)	0.7692	-0.144459
Length	0.0177*	0.1516243
Diameter in breast height	0.0444*	0.0735536
Diameter at sample-taking spot	0.0735	0.0764073
Remaining bark	0.2125	-0.03475
Ground contact (m)	0.0610	0.1404828
Ground contact (%)	0.8953	0.0017181
Moisture content	0.3430	0.03736
Brown rot	0.1621	14.37986
White rot	0.0077*	-1.883634
Fomitopsis pinicola	0.8260	0.02559334
Fomes fomentarius	0.3013	-15.15064
Antrodia serialis	0.4161	-15.10934
Canopy cover	0.1092	-0.896566
Height of vegetation	0.1499	0.504876

Two variables describing the size of the log were significant, length and diameter in breast height (Table 2). However, diameter at the sample-taking spot was not significant. In a multivariate regression model with length and diameter in breast height, the model was significant ($p=0.0454$) but not the variables themselves (Table 3). When testing a model with diameter in breast height and white rot, the p-value of diameter in breast height became lower than in the single test (Table 3). *C. chrysomelinus* was only found in logs with length ≥10 m and with a diameter ≥ 30cm (Figure 5 and 6). Even if the shape of Figure 5 and 6 may look like normal-distribution curves with low probabilities also on coarse logs, it is most correct to only draw a lower limit for the species, because the models were testing for linear relationships. In addition, it was also much fewer logs within the longest (4 logs ≥30 m) and thickest (28 logs ≥45 cm) classes, which also affect the probabilities.

None of the variables remaining bark, ground contact, moisture content, presence of *F. pinicola*, height of vegetation and canopy cover did show any significant result related to the presence or absence of *C. chrysomelinus*. And neither of these variables became significant in any multivariate model. Tree species did not either give any significant result, although all *C. chrysomelinus* findings were done in logs of *P. abies*.

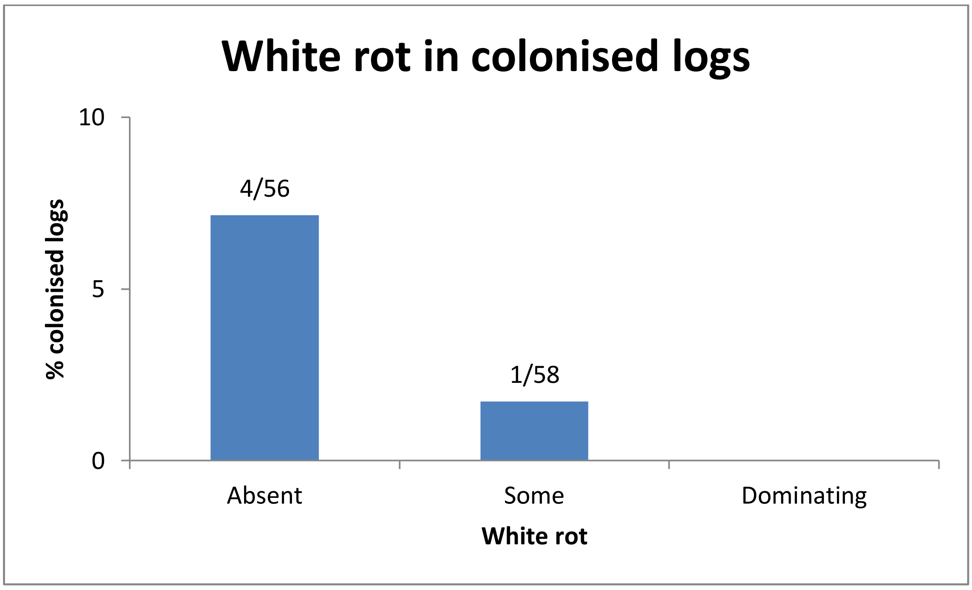

Figure 3. *C. chrysomelinus* was never found in logs mainly rotted by white rot. Only one finding was done in a brown rotted log rotted with a very small content of white rot. The labels give the number of colonised logs and the number of logs in the class.

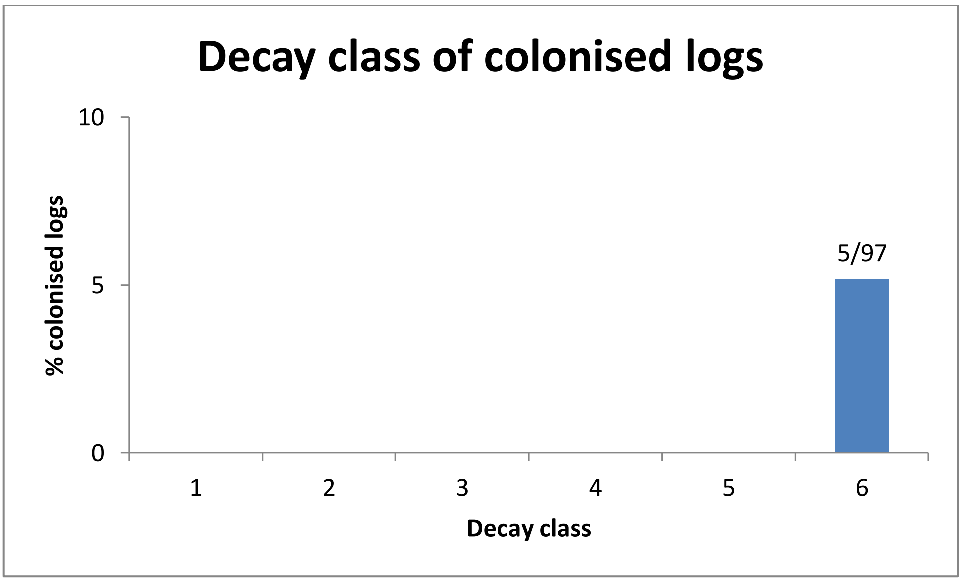

Figure 4. All *C. chrysomelinus* findings were done in logs of decay class 6. The label gives the number of colonised logs and the number of logs in the class.

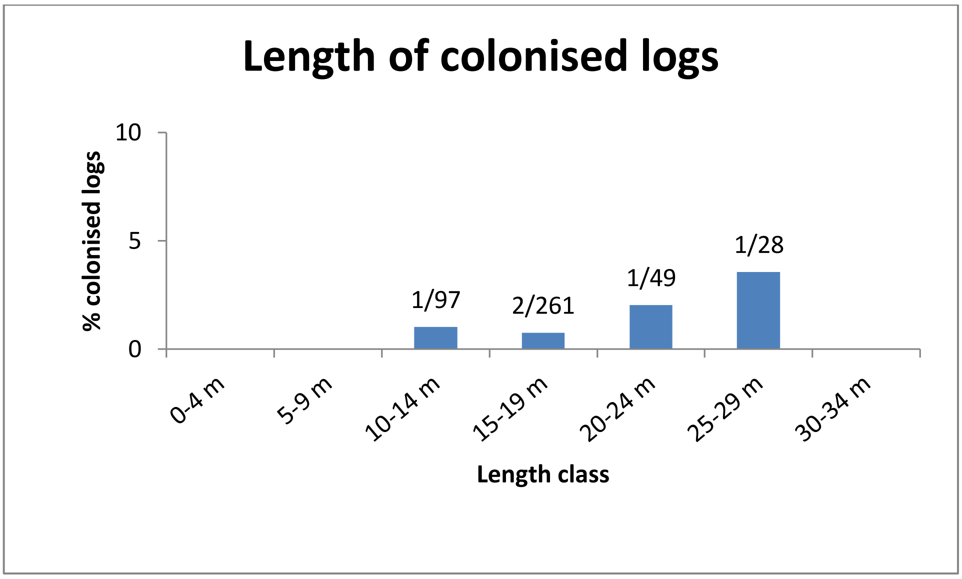

Figure 5. There were no findings of *C. chrysomelinus* in logs shorter than 10 m. The labels give the number of colonised logs and the number of logs in the class.

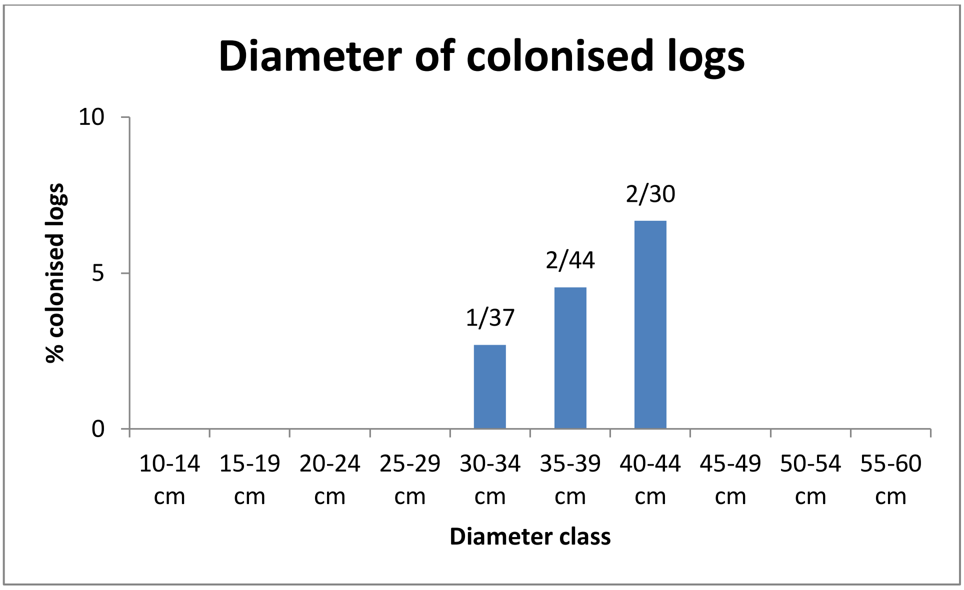

Figure 6. *C. chrysomelinus* was found in logs of medium diameter in breast height. The lower limit was 30 cm. The labels give the number of colonised logs and the number of logs in the class

Table 3. Results from regression analyses in multivariate models testing for how well different variables together describe the presence of C. chrysomelinus.

Variables	p-value	Estimate
Model	<.0001*	
Distance	0.0021*	-0.151132
White rot	0.0003*	-4.756982
Length	0.0241*	0.3324738
Diameter in breast height	0.8961	-0.014005
Degree of moisture	0.7524	0.020787
Model	0.0224*	
Brown rot	0.4752	12.3134
White rot	0.0175*	-1.782262
Model	0.0454*	
Length	0.1434	0.1164288
Diameter in breast height	0.4559	0.0332853
Model	0.0015*	
White rot	0.0028*	-2.187021
Diameter in breast height	0.0155*	0.1032209
Model	>0.0001*	
Distance	0.0004*	-0.125939
Decay class	0.0205*	20.638513
Model	0.0003*	
Distance	0.0013*	-0.118226
Length	0.1904	0.0690473
Model	0.0007*	
Distance	0.0001*	-0.135922
Ground contact (%)	0.5126	0.0089502

3.2 Amount of suitable wood

The volume of all lying dead wood in the study plots was highest close to the centre point, and decreased down to 10.5 and 4 m^3/hectare in distance class 70-75 m from the translocated log in the two study plots (Figure 7).

I also calculated how large proportion of the total dead wood volume suitable for *C. chrysomelinus* was. About 22 % of the total dead wood volume was from logs in decay class 6. When adding the aspect of no white rot, the amount of suitable wood was 7 %. In addition, diameter in breast height ≥30cm gave 5.5 % suitable wood. And, when including the last variable, length ≥10 m, only 4 % consisted of suitable wood.

By using the limiting values for suitable wood from above, the volume of suitable wood is highest close to the translocated log, and the densities are decreasing further away (Figure 8).

The colonised logs consists of 2 % of the total volume of dead wood, i. e. half of the suitable wood volume.

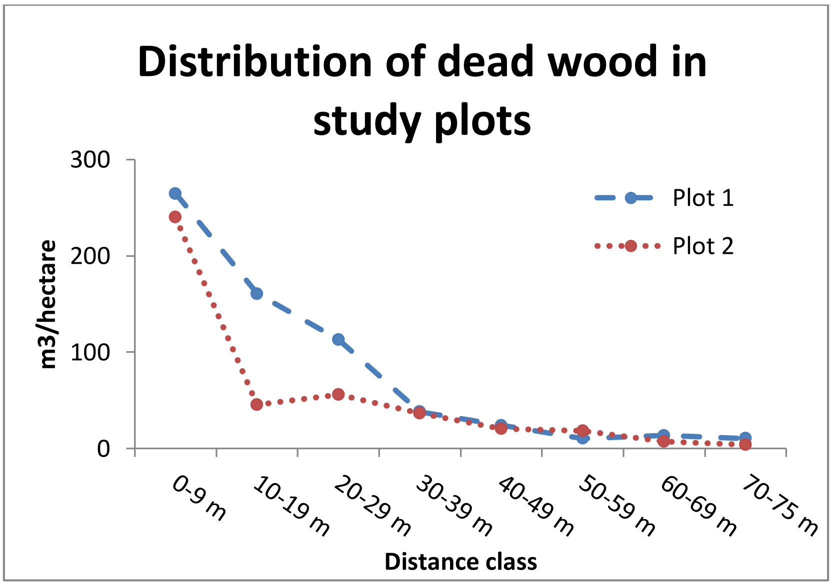

Figure 7. The distribution of all lying dead wood (with diameter in breast height ≥10 cm) within the two study plots. The average volume of dead wood was 52 m^3/hectare in area 1 and 35 m^3/hectare in area 2.

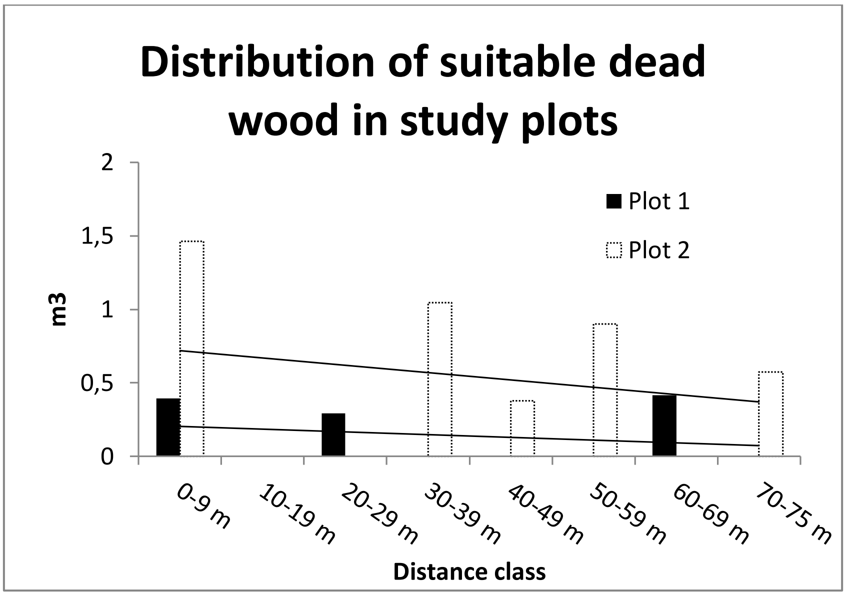

Figure 8. The volume of dead wood suitable for *C. chrysomelinus* in the two study plots was highest close to the translocated logs. The trend lines show a decrease further away from the centre.

3.3 Dispersal pattern

All findings, except one, were done less than 10 m from the translocated log (Figure 9). Both areas had six logs less than 10 m from the translocated logs, where three of 12 logs had the qualities suitable for *C. chrysomelinus* detailed above. All of these logs were colonised. Here, also one log with a small content of white rot-was colonised, which means that is was considered as unsuitable according to the statistical test.

None of the 34 logs in next distance class (10-19 m) had the qualities suitable for *C. chrysomelinus*. In the distance classes 20-29 m and 30-39 m only one log in each class were suitable. One finding of *C. chrysomelinus* was done in the distance class 40-49 m. Also here, only one suitable log was present.

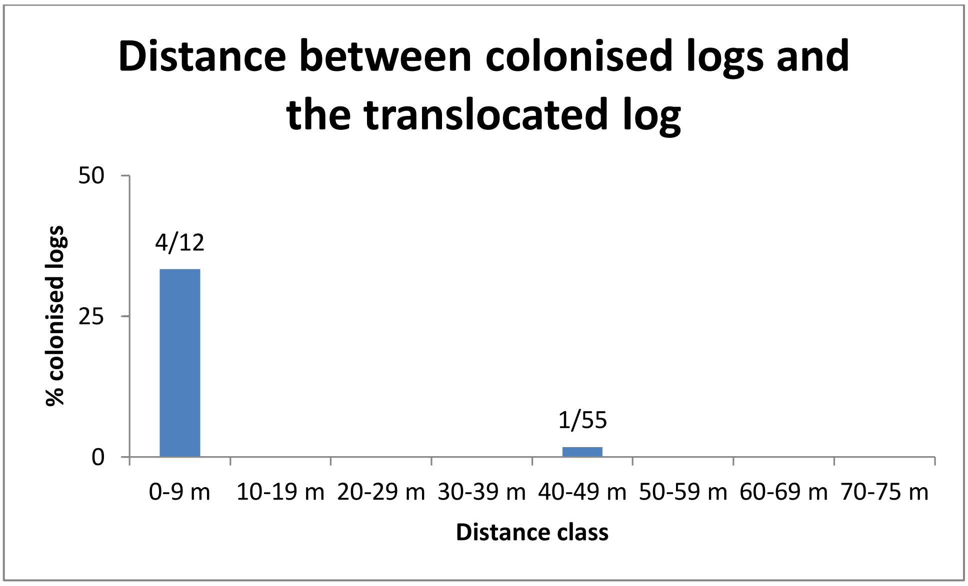

Figure 9. Frequency of colonised logs over different classes of distance from the log that was translocated to the area in 1995. Both areas are included in the figure. The labels give the number of colonised logs and the number of logs in the class.

4 Discussion

This far the translocation of *C. chrysomelinus* to Pansaruddens nature reserve seems to have been successful. In 2006 a small inventory was performed where three logs were found to have alive individuals (Eriksson, 2010), and during this study in 2012 five logs were found. But, if *C. chrysomelinus* will succeed in the long term is dependent on the supply of suitable substrate within these locations.

4.1 Qualities of suitable wood

Four qualities of the dead wood turned out to be important for the presence of *C. chrysomelinus* from the statistical tests in this study: a high degree of decay (class 6), absence of white rot, logs with a length of at least 10 m and a breast height diameter of at least 30 cm. This confirms the literature, where heavily brown rotted thick logs repeatedly are mentioned as characteristics of *C. chrysomelinus* substrate (Ehnström, 1999; Eriksson, 2010; Hedin, 2010).

Large logs are often mentioned as important in terms of diameter (coarse logs) (Ehnström, 1999; Hedin 2010). Also length was important according to the statistical tests in this study. It is not surprisingly that size is of importance, larger logs decay more slowly and the moist and temperature conditions are more stable in coarse logs (Stokland et al., 2012). This would be favourable for *C. chrysomelinus* who has a generation time of at least two years and often stays in the same log for several generations (Palm, 1959).

In this study, it was found that a breast height diameter of at least 30 cm is important for *C. chrysomelinus*. Hedin (2010) mentions 20 cm as a lower limit for suitable logs. Several logs of 20-29 cm which were suitable in decay stage and type were found in this study, but none of these logs were colonised. They would distinctly have increased the density of suitable wood. Samways et al. (2010) suggests to measure suitable environmental conditions in a source habitat. A source habitat is a spot where a surplus of individuals are produced, because of the favourable conditions in the spot (Pulliam, 1988). On the other hand, individuals from an overproducing population may be forced to colonise logs with unfavourable qualities – sink habitats. This could have been the case where *C. chrysomelinus* were found in logs as thin as 10 cm in diameter (Nilsson et al., 2000).

Most of the tested variables, several of them earlier suggested as possibly important (Ehnström, 1999; Hedin, 2010), like tree species, remaining bark, ground contact, moisture content, presence of *F. pinicola*, height of vegetation and canopy cover did not show any significant effects in this study. However, the lack of significance does not confirm that they are totally unimportant. But they may not be of critical importance. Fore example, *C. chrysomelinus* was found in logs with *F. pinicola*, but there were a much higher number of unoccupied logs hosting this fungus, which affects the statistical test. However, it is more effective to focus on just some of the wood qualities (a high degree of decay, absence of white rot, logs with a length of at least 10 m and a breast height diameter of at least 30 cm) when searching for high potential occupied logs.

4.2 The method

It is probable that the population size found in this study is underestimated and it could be discussed if it was enough to only search for the beetle in a 50 cm long part of each log to be able to detect a proper sample for the statistical tests. The reason for this small sample size was that searching for *C. chrysomelinus* means that its habitat is being destroyed. Often only a small part of a trunk is colonised, for example one meter in a 20 m trunk (Ehnström, 1999). This may depend on that only a part of the trunk is suitable at the moment. Seldom, the entire log has the same decay class. It is obviously not important to search for *C. chrysomelinus* in the whole log, consequently not in the parts of the log that is not degraded enough. An alternative to the used method may be to search in a certain proportion of the highest degraded part of the log.

4.3 Supply of suitable wood

The supply of lying dead wood in the two study areas was generally high (52 respectively 35 m^3/hectare) and almost comparable with the levels in natural forests where the total volume of dead wood (including standing dead wood) is about 60-90 m^3/hectare (Siitonen, 2001). Still, only 4 % of the dead wood in this study was suitable for *C. chrysomelinus* when taking the significant variables in account. Probably even more factors, which are hard to measure, are also involved.

Some of the already lying wood would get suitable eventually, because it has proper qualities but is not yet degraded enough. Unfortunately, far most of the wood is too small or white rotted and will never turn suitable for *C. chrysomeli-*

nus. The time scale for the degrading process and conversion between different decay classes is varying and hard to estimate. It has been tested with simulation models predicting future coarse dead wood supply in old-growth *P. abies* forests. It was concluded that the models were efficient on landscape level but had a high deviation in individual plots (Ranius et al., 2004).

Hedin (2010) suggested the target level of available suitable wood for known sites of *C. chrysomelinus* to be at least ten logs >20 cm and five >40 cm in breast height per hectare. This gives about the same volume as was considered suitable in both study areas together. In future studies it would be interesting to find out if the distribution of suitable wood is the same for natural spruce forests in general as in Pansaruddens nature reserve. If so, the target level in Hedin (2010) would only be reached in spots with much higher total supply of lying dead wood than in Pansaruddens nature reserve.

4.4 Dispersal pattern

A very interesting result was that distance to the translocated log was highly significant for the occurrence of *C. chrysomelinus*. The colonised logs were concentrated just a few meters from the origin log on both sites, and all suitable logs less than 10 m from the origin log were colonised. Only one finding was done more far from the origin log, but still in less than 50 m. Outside the first ten meters, none or only one log per each next ten meter from the centre was suitable. Consequently, suitable logs were present all over the study plots, but in low densities. The results from the multiple models showed that distance was always significant, independent of which variable it was combined with. From this, it seems like *C. chrysomelinus* preferably disperse only a few meters, even if there is suitable substrate available further away.

Species with a short lived patchily distributed habitat will theoretically evolve to have higher dispersal ability and species with good access of predictable habitat will not (Southwood, 1962). New (2010) pointed out saproxylic beetles as a typical group of long distance dispersal organisms since they often have patchily distributed substrate or a substrate that occurs in an unpredictable pattern. This is also discussed by Hedin (2010) who means that *C. chrysomelinus* previously had good access to suitable wood in our forests and therefore it would not have had any reasons to evolve high dispersal ability.

Another approach when considering natural selection is the trade-off between r- and K-selection, where r-selection is concentrating on reproduction and K-selection on competition. K-selected organisms are more long lived and develop slowly, have larger body size, have more stable population sizes, lives in fairly constant environment and are density-dependent (Pianka, 1970). This fits well on

C. chrysomelinus compared to other wood living species, since it colonise logs in a late successional stage. Species colonizing the wood in early stages have a shorter time period for utilizing the resources and needs to be there quickly. Later on more competitive species will colonise and take over. The first successional invertebrate phases in *P. abies* last a much shorter time than the last phase (Esseen et. al., 1992), where we find *C. chrysomelinus*.

Eriksson (2010) experienced even when there only was a few hundred meters between a site of *C. chrysomelinus* (south of lake Tämnaren) with poor supply of suitable substrate and a spot of better conditions, the species had not dispersed to it. This indicates that the species rarely does longer flights or that the colonization ability is lower than the dispersal ability.

However, a problem is the fact that the population is very small, since small populations are more sensitive and more exposed to go extinct by catastrophes, different types of stochastic events and genetic factors (Shaffer, 1981; Frankham, 2005). Siitonen & Saaristo (2000) considered populations of *Pytho kolwensis* with 20 colonised logs as too small and at a high extinction risk, which is a higher population size than I found in this study.

4.5 Implications for conservation

Such small populations as found in this study are threatened by a high risk of extinction, and it is critical for the species to disperse and colonise more logs. Preferably within as short time as possible. The limiting factor for the dispersal of *C. chrysomelinus* in Pansaruddens nature reserve seems to be a combination of its poor dispersal ability and the restricted supply of suitable substrate.

Comparable results were found by Brunet & Isacsson (2009) when studying red-listed saproxylic beetles in a *Fagus sylvatica* forest in southern Sweden. They found that two factors, current substrate supply and substrate continuity, were important for the distribution of red-listed species, mostly because of the poor dispersal ability. Substrate densities within the forest stand affect the occurrence of these species. It is more efficient to concentrate the suitable habitats and resources than to distribute it more evenly in the whole landscape when preserving specialised species dependent on natural forests (Hanski, 2000).

The volume of dead wood per hectare was high in the two studied sites. But the distribution within the study areas with a radius of 75 m was very uneven. The dead wood densities were much lower in the edges and far from the 52 and 35 m^3/hectare that was the average for these areas. Since the results from this study indicates poor dispersal ability in *C. chrysomelinus*, a “high” density of suitable substrate is critical. Therefore, the abundance of dead wood has to be high and more evenly distributed in the area. Therefore I suggest that more coarse dead wood should be created in these areas. Otherwise, too little suitable wood will be present to ensure stable population growth.

For further studies, it would be interesting to perform similar analyzes in other forest areas to see if it is true in general that only 4 % of the present wood volume is suitable. It is of critical importance to be aware of this level when planning for conservation actions. From this it will be possible to calculate how high densities of dead wood and how large areas that are needed to maintain viable populations of *C. chrysomelinus*.

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