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Saproxylic beetles in two types of fine woody debris of Norway spruce

Vítězslav Maňák

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Handledare: Mats Jonsell
Examinator: Göran Nordlander

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SLU, Institutionen för ekologi
Box 7044, 750 07 Uppsala

Abstract

Fine Woody Debris (FWD) has been considered as the promising source of forest fuel in Fennoscandia. Main sources are logging residues which formerly were retained on clearcuts. Recent studies indicate that many saproxylic (wood-living) organisms use this wood, and the harvest may decrease their breeding substrate. However, dead branches of thin diameters constitute a common substrate in closed canopy forest stand. If the fauna of dead branches is similar to that of clearcuts, the negative effects of forest fuel harvesting should be considered rather small. The aim of this study was to compare saproxylic beetle fauna between (1) spruce twigs retained on one-year-old clearcuts and (2) dying bottom branches attached to living trees. I examined the effect of twig type, twig diameter, sun exposure and height on densities of species and individuals as well as on species composition of saproxylic beetles. Twig type was the most explanatory variable and higher densities of species and individuals were found in retained twigs on clearcuts. There were species specifically associated with retained twigs as well as with dying bottom branches. In addition to twig type there was a significant effect of height and sun exposure as those beetles being abundant in dying bottom branches were more common either in open conditions or in branches high above the ground. The results indicate that FWD is not a homogenous substrate for saproxylic beetles. If the pattern is similar for other tree species, the forest fuel harvesting may have negative effect on saproxylic beetles utilizing the dead wood of fine diameters.

Keywords: Boreal forest, saproxylic, Coleoptera, conservation, forest-fuel harvesting, Fine Woody Debris, logging residues, Norway spruce

Introduction

Large numbers of forest dwelling organisms are saproxylic i.e. dependent on dead or dying wood during the part of their lifecycle (Speight 1989). Saproxylic organisms form a very heterogeneous group covering many species of plants, fungi and animals. The estimated number of saproxylic species in Sweden is 5000-6000 (deJong et al. 2004). Of these, saproxylic beetles are one of the largest groups in Fennoscandian forests with about 1300 species. More than 400 of these are red-listed (Berg et al. 1994). This is due to the effect of present day forestry practices, which significantly decreased amounts of Coarse Woody Debris (CWD), i.e. downed logs and snags with a diameter >10cm (Anon. 2004). This has led to the disappearance of about 50% of saproxylic species from managed forests (Siitonen 2001). The quantity of CWD in managed forest ranges between 2-30% of the quantity of unmanaged forest stands. The CWD pool is composed mainly of snags and logs of thin and medium diameters while the wood of coarse diameters is rather rare (Fridman and Walheim 2000). The quantities and dynamics of Fine Woody Debris (<10cm) are much less known but considerable amounts of FWD are present on forest floor and in the canopy of closed forest stands (Fonte and Schowalter 2004).

Fine Woody Debris has recently been considered as the promising source of forest fuel in Fennoscandia. The main sources are logging residues such as treetops and branches that formerly were retained on clearcuts (Anon. 2001). There is on average $15 m^3 ha^{-1}$ of logging residues on clearcuts in Sweden and 65% of its volume may be removed by present day forestry technologies (Rudolphi and Gustafsson 2005). FWD has been considered as a “trivial” substrate for saproxylic organisms and therefore not much studied. Recent studies indicate that logging residues on clearcuts may support a variety of saproxylic insect species as well as many species of cryptogams (Jonsell et al. 2007b; Kruys and Jansson 1999; Nordén et al. 2004). Many beetle species are adapted to utilize the sun-exposed substrates and the CWD retained on clearcuts has been acknowledged to play an essential role in maintaining the biodiversity of forest ecosystems (Jonsell et al. 1998; Ranius and Jansson 2000; Martikainen 2001; Nilsson et al. 2001). Large areas with sun-exposed dead and dying wood are in natural conditions created by disturbances such as forest fires which nowadays have been almost eliminated (Zackrisson 1977; Lindbladh et al. 2002; Lindhe et al. 2004). Clearcuts supply a lot of sun-exposed ground and recently some management practices such as the creation of artificial high stumps and green tree retention have been adopted to supply more sun-exposed wood (Anon. 2000).

Extraction of FWD from clearcuts will decrease the amount of substrate available for many saproxylic organisms. However, dying bottom branches of spruce create the main pool of FWD in coniferous forests in northern Europe (Marklund 1988). The accurate amounts of dying bottom branches are not known but it is assumed that 2% of branches die every year and 70% of freshly dead wood in living trees is composed of branches of the thinnest diameters (0-5 cm) (Jonsell et al. 2007a, Ågren and Hyvönen 2003). There is no information on saproxylic beetles associated with different types of Fine Woody Debris in mature forest stands. If the fauna in dying bottom branches is similar to that of clearcuts, the negative effects of forest fuel harvesting should be considered rather small.

The aim of this study was to determine if dying bottom branches of spruce could host saproxylic beetles to same extent as retained twigs on clearcuts. I compared the density of species and individuals as well as species composition between the two twig types. In addition to twig type, I also examined the influence of sun exposure, twig diameter and height of sampled branches.

Materials and Methods

Wood samples were collected in February and March 2007 at Hågadalen-Nåsten (59º, 49'N, 17º, 34' E) and Lunsen (59°, 45'N, 17°, 40'E) near Uppsala in Sweden, in the southern boreal forest zone. Norway spruce, *Picea abies* and Scotch pine, *Pinus silvestris* are dominant tree species in the study area. At both sites spruce twigs were sampled from a one year old clearcut and from an adjacent forest stand. I sampled only branches of the first decay class (1-2 years) according to the scale of Swedish National Forest Inventory (Anon. 2004). However, the decay stage of dying bottom branches was difficult to asses as the dead twigs of different age may look alike. Therefore I peeled off a piece of bark and selected twigs that looked fresh and had the bark firmly attached.

On clearcuts each sample consisted of 10 m of twigs collected from the ground and from different wood piles over the clearcut. Dying bottom branches were collected either by climbing suitable standing trees (41 samples) or from green living wind-throws (23 samples) on the forest edge or inside the stand. Recently fallen spruces were common because a storm blew down a lot of forest in January 2007. Twigs from one tree were considered as one sample. However it was not always possible to get ten meters of dying bottom branches from one tree and the length of sampled wood was introduced as a covariate in analyses (Table 1).

In total, five variables were recorded for the wood samples (Table 1). I measured the diameter in the middle of the each twig and the "Mean twig diameter" was calculated for each sample. For dying bottom branches "Exposure" of the tree (Open – Semi-shade – Shade) and the Height of sampled twigs were recorded (Table 1). The height range of dying bottom branches varied between the samples but the mean height was used for easier computations.

The beetles were collected directly from the wood by sifting as described by Jonsell and Hansson (2007). First, the bark of the wood was peeled off with a knife on a large cloth either in the site or in the lab. The peeled bark was then poured into a sieve with a mesh size of about 4 mm. Sieved material from field was transported into laboratory in plastic bags to prevent samples from drying out. Finally, beetles were extracted by placing samples in Tullgren funnels for at least 48 hours. Adult beetles were collected and preserved in 70% ethanol. All saproxylic species were identified to species level in accordance with the catalogue of Lundberg and Gustafsson (1995).

Statistical analyses

Differences in numbers of individuals and species per sample between the twig types were tested with Poisson Regression. This method is appropriate for count data containing many zero values (Quinn and Kerough 2002). The scale parameter was specified by "dscale" function to fit the model (Littell et al. 1999). For each effect F- and χ^2 statistics were computed in Type 1 and Type 3 Tables. The interpretation of the data is based on χ^2 values in Type 3 Tables.

Ordination was used to examine how the environmental variables influenced the species composition. In this case, Redundancy analysis (RDA) (Rao 1964) was the appropriate model as the result of "Test of Length of Gradient" performed in DCA turned to be lower then 4

(Leps and Smilauer 2003). The explanatory power of recorded variables was tested with Monte-Carlo permutation test (199 reps.). All variables that contributed significantly ($p<0.05$) to explain the species composition were added to the final model. I found that "Twig Type" was the most significant variable and therefore RDA was also computed for dying bottom branches separately. The ordinations were carried out using CANOCO 4.0 (ter Braak and Smilauer 1998).

Species that occurred in at least five samples were tested for association with selected variables using Poisson regression as described above. Variables were added to the model by forward selection based on highest chi-square values. Regressions were conducted by SAS 6.12 for Macintosh (SAS 1989-96).

Results

Altogether, 64 samples were taken from living trees and 40 from clearcuts. Seventeen samples from dying bottom branches did not cover 10 meters of wood. In total, samples of dying bottom branches consisted of 556.7 m dead wood.

The samples contained in all 2327 specimen of 12 saproxylic beetle species (Table 2). In addition I found 30 specimens of non-saproxylic species from family *Chrysomelidae*, which were excluded from the analyses. Ten beetle species were found in dying bottom branches and nine in retained twigs on clearcuts. Of these, three species occurred exclusively in dying bottom branches and two in retained twigs. Of these unique species, only *D. autographus* was found in retained twigs in more than 5 samples (Table 3). The most common species was *Pityogenes chalcographus* (Scolytidae), with 1848 individuals in retained twigs and only 17 individuals in dying bottom branches (Table 2.)

The number of beetle individuals per sample was significantly higher in retained twigs on clearcuts than in dying bottom branches (Table 4a). This was mainly the effect of *P. chalcographus,* being particularly common in retained twigs. Number of individuals per sample differed also significantly between Sites (Table 4a). However, after the removal of *P. chalcographus*, there was still a significant difference between the two twig types (Table 5a). In both analyses twig diameter had significant effect on number of individuals per sample

(Table 4a; Table 5a). Although the total number of species was higher in dying bottom branches (Table 3) number of species per sample was higher in retained twigs both with and without *P. chalcographus* (Table 4b; Table 5b)

In the analysis of the species composition (RDA), “Site”, “Twig Type” and “Height” contributed significantly ($p<0.05$) to the model where both twig types were included. “Twig Type” had the strongest explanatory power as it was strongly correlated with Axis I, which in turn explained 53.1 % of the total variation (Table 6). “Site” was also significantly correlated to Axis I and additionally, Twig Type was correlated to Axis II and “Site” to Axis III. “Height” was correlated to Axis II but the second and third canonical axes explained only 1% of the variation among the environmental variables (Table 6). In the second RDA for the dying bottom branches separately “Height” was the only variable with significant explanatory power. It was correlated with Axis I, which explained 10% of the variation (Table 7, Fig.2). However, the strongest explanatory effect had the first non-canonical Axis II (explaining 43.6%).

Poisson regression failed for two species, which were absent in one of the categories, but four species could be tested for associations with environmental variables. “Site” had significant effect for almost all species (Table 8). *Pityogenes chalcographus* and *Pityophthorus micrographus* were significantly associated with retained twigs on clearcut and *Phthorophloeus spinulosus* with dying bottom branches (Table 8). “Height” was revealed as significant variable for *P. micrographus* as it was abundant in dying bottom branches high above the ground. Unlike the ordination methods, the Poisson regression revealed “Exposure” as significant for *P. spinulosus* as it was slightly more abundant in open conditions (Table 8). There was also a significant effect of covariate for this species. No clear association was observed for *Cryphalus abietis,* although it tended to be more common in retained twigs on clearcuts (Table 8).

Discussion

In this study, twig type was the most explanatory variable and significantly higher densities of species and individuals of saproxylic beetles were found in the samples of retained twigs on clearcuts than in those from the closed canopy stand. Of the four species tested for association with particular twig type two species showed strong association to the retained twigs and one to dying bottom branches in the forest canopy. This is in accordance with other studies where many beetle species were attracted to sun-exposed substrates retained on clearcuts (Jonsell et al. 1998; Ranius and Jansson 2000; Martikainen 2001; Nilsson et al. 2001). *Pityogenes chalcographus* was the most abundant species in retained twigs and has been shown previously as the most common species in harvest residues on clearcuts (Pfeffer 1955; Jonsell et al. 2007b). The total number of beetles found in retained twigs was rather low and many of the ciid and staphylinid beetles found with the same sampling method by Jonsell and Hansson (2007) were absent. Differences in obtained number of species may be due to early sampling in February and March but as the ciid beetles occur as adults during the whole year, the species numbers obtained in this study were surprisingly low.

Compared to exposed branches on the ground the densities of species and individuals in dying bottom braches were significantly lower and species composition different. It is thought that higher breeding temperature in sun-exposed woody debris may be important for saproxylic species living in rather cold conditions of northern Europe but the differences may be also explained by different patterns of dying of the two twig types. During the loggings vital and rapidly growing twigs are cut at one time and retained on clearcut while bottom branches die rather slowly and remain attached to the tree. The nutrient content is lower in living bottom branches and decreases in the course of the decay succession (Iivonen et al., 2006; Ishii and Kadotani 2006). Despite the high level of sun exposure, most of the twigs retained on clearcut are probably more nutrient rich than dying bottom branches on living trees. A preference for nutrient rich substrates has been shown, for example, for the pine weevil *Hylobius abietis* (Zas et al. 2006).

Of other variables tested in the analysis, “Height” significantly affected the species composition. This was mainly an effect of *Pityophthorus micrographus,* whose larvae bore under the bark of spruce branches high above the ground (Ehnström and Axelsson 2002). In this study the beetles were found in high numbers in dying bottom branches at a height of more than ten meters above the ground. The p-value however, may be overestimated since the high numbers of this species were found only in two samples of dying bottom branches. I obtained only few specimens of this species in lower branches, which is in accordance with Martikainen et al. (1999), who found only low numbers of *P. micrographus* by the use of window traps in old growth forest. This species is probably constrained to higher levels of the forest stand, where the breeding temperature or nutrient levels are higher. This may explain the association of this species both with retained twigs and dying bottom branches high in the canopy. Similar tendency was observed for *Phthorophloeus spinulosus*, another bark beetle boring in thin branches of living spruces (Ehnström and Axelsson 2002). This species was found mainly in dying bottom branches and the results of Poisson regression indicated also association with open conditions.

Recent studies show that many red-listed species are associated with harvest residues left on clearcuts but still very little is known about canopy woody debris of other tree species. The practical conclusion of the present study is that the Fine Woody Debris is not a homogenous substrate for saproxylic species, as different composition of saproxylic beetle species was observed in retained twigs on clearcuts and dying bottom branches attached in the canopy of living spruces. I also found tendencies of beetles abundant in dying bottom branches to be more common in open conditions. In the absence of large disturbances such as fires and large storms, clearcuts have been shown to attract many beetle species adapted to utilize the sun-exposed breeding substrates. Forest-fuel harvesting may remove considerable amount of harvest residues and it should be considered how much wood should be retained on clearcuts to meet the requirements of saproxylic species.

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Table 1. Definition of variables used in the statistical analyses

Name of Variable	Definition (Unit)
SITE	Lunsen
	Hågadalen
TWIG TYPE	Twig type
	Dying bottom branches
	Retained twigs on clearcut
TWIG DIAM	Mean diameter of twigs in one sample (cm)
EXP	Exposure of tree
	open
	semi shade
	shade
HEIGHT	Mean height of sampled branches on the living tree (m)
SAMPSIZE	Length of wood / sample (m) (covariate)

Table 2. Number of individuals (in brackets occurrences) of beetle species found in fine wood samples

	Dying bottom branches	Retained twigs on clearcut
Scolytidae		
Pityogenes chalcographus	17 (6)	1848 (34)
Pityophthorus micrographus	101 (9)	282 (29)
Phthorophloeus spinulosus	15 (8)	2 (2)
Hylurgops palliatus	1 (1)	0 (0)
Dryocoetes autographus	0 (0)	25 (5)
Cryphalus abietis	8 (4)	7 (3)
Crypturgus hispidulus	5 (1)	1 (1)
Cucujidae		
Cryptolestes alternans	5 (1)	1 (1)
Trogositidae		
Nemosoma elongatum	1 (1)	5 (4)
Tenebrionidae		
Corticus linearis	0 (0)	2 (2)
Anobiidae		
Ernobius abietinus	1 (1)	0 (0)
Ciidae		
Orthocis alni	2(2)	0(0)

Table 3. Number of species and individuals found in the two twig types

	Dying bottom branches	Twigs retained on clearcut
Num. of species	10	9
Mean number of spp. per sample	0.53	2.03
Mean number of ind. per sample	2.435	54.325
Number of unique spp.	3	2
Number of occurrences of unique spp.	4	7
Unique species more than 5 ind.	0	1

Table 4. Results on differences in numbers of (a) individuals and (b) species per sample as revealed by Poisson Regression

(a) number of individuals per sample

Source	DF	Chi-Square	Pr>Chi
SITE	1	9.2301	**0.0024**
TWIG TYPE	1	124.4094	**0.0001**
TWIG DIAM	1	5.2229	**0.0223**
SAMPSIZE	1	3.1032	0.0781

(b) number of species per sample

SITE	1	0.1652	0.6845
TWIG TYPE	1	50.0157	**0.0001**
TWIG DIAM	1	1.5337	0.2156
SAMPSIZE	1	3.0582	0.0803

Table 5. Results on differences in numbers of (a) individuals and (b) species per sample after removal of *P. chalcographus* as revealed by Poisson Regression

(a) number of individuals per sample

Source	DF	Chi-Square	Pr>Chi
SITE	1	0.2589	0.6109
TWIG TYPE	1	20.2118	**0.0001**
TWIG DIAM	1	5.2619	**0.0218**
SAMPSIZE	1	4.8714	**0.0273**

(b) number of species per sample

SITE	1	0.4154	0.5192
TWIG TYPE	1	22.6927	**0.0001**
TWIG DIAM	1	1.0992	0.2945
SAMPSIZE	1	2.8399	0.0920

* Note: Numbers in bold highlight the significant results

Table 6. Parameters for canonical axes and environmental variables in RDA for (a) both twig types and (b) dying bottom branches separately

(a) Both Twig types

	Axis I	Axis II	Axis III	Axis IV
Eigenvalue	0.5076	0.0086	0.0014	0.2488
% Variation expl.	53,1	0,9	0,14	28,0
Regr. coefficients				
Site	**0,2848*** **	-0,1043	**-0,9596***	0.0000
Twig Type	**1,2064*** **	**2,2523***	-0,6135	0.0000
Height	0,2599	**2,6568** **	-0,2382	0,0000

Note: Total inertia = 0.518

Statistically significant regression: ***p<0,001, **p<0,01, *p<0,05

(b) Dying bottom branches separately

	Axis I	Axis II	Axis III	Axis IV
Eigenvalue	0,5261	0,1645	0,1277	0,0657
% Variation expl.	10,0	43,6	16,6	12,8
Regr. coefficients				
Height	**1,0217*** **	0,000	0,000	0,000

Note: Total inertia = 0.098

Statistically significant regression: ***p<0,001, **p<0,01, *p<0,05

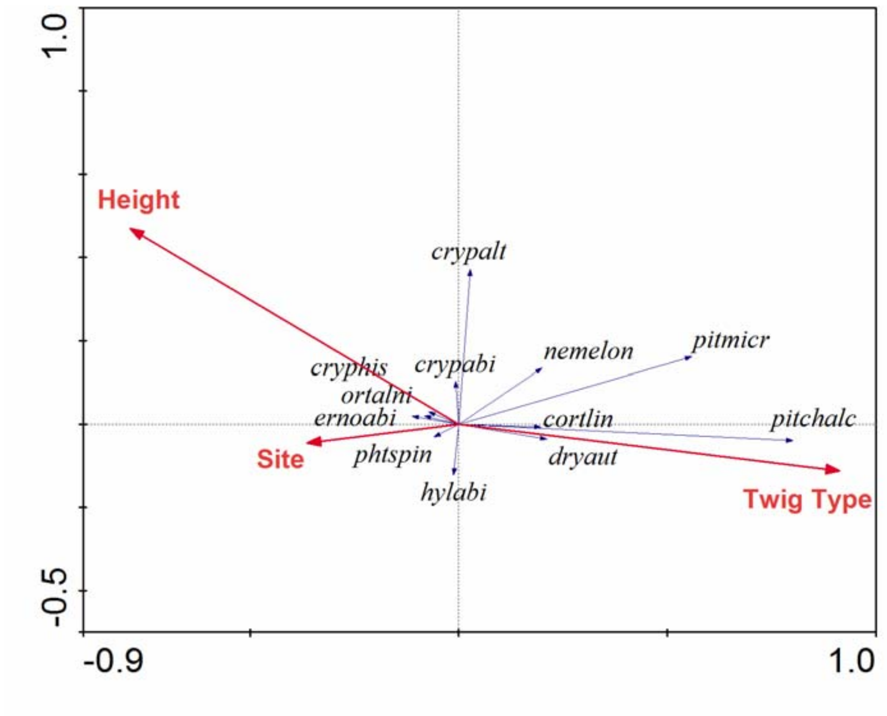
Table 7. Poisson regression models for species tested for associations with environmental variables.

Source	DF	Chi	Pr>Chi
P. chalcographus			
SITE	1	15.9504	**0.0001**
TWIG TYPE	1	5.2281	**0.0222**
EXP	2	1.2647	0.5313
HEIGHT	1	0.0132	0.9085
TWIG DIAM	1	3.1434	0.0762
SAMPSIZE	1	0.0708	0.7902
P. micrographus			
SITE	1	17.7777	**0.0001**
TWIG TYPE	1	33.0108	**0.0001**
EXP	2	3.0587	0.2167
HEIGHT	1	77.5863	**0.0001**
TWIG DIAM	1	0.1849	0.6672
SAMPSIZE	1	0.0109	0.9168
P. spinulosus			
SITE	1	6.0057	**0.0143**
TWIG TYPE	1	9.6704	**0.0019**
EXP	2	9.0287	**0.0110**
HEIGHT	1	1.6433	0.1999
TWIG DIAM	1	1.6060	0.2051
SAMPSIZE	1	8.1987	**0.0042**
C. abietis			
SITE	1	3.6015	0.0577
TWIG TYPE	1	3.7224	0.0537
EXP	2	.*	.*
HEIGHT	1	3.5075	0.0611
TWIG DIAM	1	2.7464	0.0975
SAMPSIZE	1	0.8304	0.3621

* Note: Poisson regression failed for "Exposure" for *C. abietis* as it was absent in one of the categories.

Fig. 1. The RDA diagram plotting environmental and species scores for (a) the two twig types and (b) dying bottom branches separately

(a)



(b)