Swedish University of Agricultural Sciences
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Bevarande av stubbar vid stubbrytning på våt mark och dess inverkan på vedlevande insekter

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Master Thesis, 30 ECTS credits *Advanced D-level in Forest Management (EX0487)*

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Sammanfattning

Avverkningsstubbar svarar för upp till 80 % av den döda ved som lämnas kvar vid slutavverkning. De förser många vedlevande insekter (insekter som är beroende av död ved för att överleva) med lämpliga habitat att försöka sig i. Stubbrytning, som i ökande takt görs efter slutavverkningar för att utvinna bioenergi, minskar därför deras livsutrymme. De vedlevande insekterna har sedan tidigare identifierats som en grupp som hotas av intensivt skogsbruk och stubbrytning riskerar att ökar denna negativa påverkan.

På grund av tekniska svårigheter och miljöhänsyn, till näringsurlakning och erosion, är skogsstyrelsens riktlinjer för stubbrytning att man bör lämna stubbar i blötare partier på hyggena. Det finns dock anledning att tro att stubbar i dessa partier inte är lämpliga substrat för vedlevande insekter. Målet med detta projekt var därför att testa om de blött stående stubbarna är fattigare på vedlevande skalbaggsarter än stubbar på torrare mark. Jag testade även om mönstret var detsamma för gran- och björkstubbar.

Skalbaggsfaunan provtogs genom att kläcka fram dem ur vedprover. Prover från 100 stubbar sågades ut och samlades in (50 gran och 50 björk) från fyra slutavverkningsbestånd, 5 till 7 år gamla, utanför Uppsala i Mellansverige. Stubbarna provtogs i par, med en blött och en torrt placerad stubbe. Inom paren var trädslag, diameter och solexponering desamma. Varje prov placerades i två månader i en låda för att skalbaggarna skulle kläcka fram. Vedlevande skalbaggar och fjärilar artbestämdes, andra grupper bestämdes till ordning eller familj.

Totalt hittades 17065 insekter från 114 arter, varav 97 ansågs vara vedlevande. Totalt samlades 76 respektive 55 vedlevande arter in från björk- respektive granstubbar. Artrikedomen per stubbe var också högre i björk (genomsnitt 11 arter) än i gran (4 arter).

För granstubbarna var det signifikant fler arter i de torra stubbarna än i de blöta, medan det för björk inte fanns någon skillnad. En analys av artsammansättningen (ordination) kunde dock inte detektera någon skillnad mellan torra och blöta stubbar.

Slutsatsen av studien är att de granstubbar som lämnas i blöta lägen på hyggena är ett sämre habitat för vedlevande skalbaggar än stubbar i torra lägen. Att enbart lämna stubbar i blöta lägen är sålunda ingen fullvärdig miljöhänsyn för den vedlevande mångfalden.

Nyckelord: *stubbrytning, fuktig mark, saprofyter, insekter, biologisk mångfald*

Abstract

Low stumps represent on their own up to 80% of the dead wood remaining on clear cuts and therefore supply suitable habitat for saproxylic insects i.e. insects depending on dead wood for their survival. Recent stump harvesting activities threaten this substrate of ecological importance and increase the anthropogenic negative impacts on these species. Because of technical and environmental reasons (nutrient leakage, erosion) guidelines for stump harvesting recommend to retain stumps standing in wet parts of clear cuts. However, stumps in wet positions might not be a satisfactory substrate for saproxylic insects and therefore might not be as much used as stumps in dry positions. To test this hypothesis, a total of 100 stumps (50 spruces and 50 birches) were collected on four clear cuts between 5 and 7 years old near Uppsala, Sweden. Stump samples were paired to get a balanced dataset, each pair containing two stumps of the same tree species, diameter and sun-exposure, one dry and one wet. Each sample was placed in a rearing box for 2 months. All emerging insects were sorted out down to order, family, genus or species level according to their importance in the project. Species richness, abundance and composition in each type of stumps were analyzed. Proportion of stumps inhabited, density and Shannon's diversity and evenness were calculated for each insect order. A canonical correspondence analysis was performed to investigate the possible connections existing between insect species and the tree species and dryness of the stumps. In total, 17065 insects were collected representing 114 species out of which 96 were considered as saproxylic. An overall of 76 and 55 saproxylic species were collected on birch and spruce stumps respectively. Species richness was higher in birch stumps with 11 species in average per sample and only 4 in spruce ones .The results show that the tree species was the only factor significantly affecting both the species richness and the species abundance of a stump. The variable "Dryness" had significant effect on the samples' species diversity with dry samples harboring a higher number of species. The proportion of stump types used by different orders clearly shows that the tree species was again the main factor influencing the species abundance of a stump. More insects were found in birch stumps, regardless of their dryness, than spruce. Wet spruce and dry birch stumps were respectively the least (7.9%) and the most used (34.1%) substrates. Coleoptera beetles were more numerous in birch stumps but did not show any preference concerning the moisture level of the stumps. The other orders showed a similar pattern with Hymenoptera, Lepidoptera insects however favoring dry birch stumps and Dipterans wet ones. *Arhopalus rusticus* and *Curtimorda maculosa* were the only species to show a significant correspondence to a substrate and were associated to spruce stumps.

The results show that both birch and spruce support the life cycle of many different insect species and not only saproxylic. As wet spruce stumps presented the lowest biodiversity, it could be thus advised, in a context of biodiversity conservation, to set aside in priority birch and more generally broadleaves stumps.

Key words: *stump harvesting, wet ground, saproxylic insects, biodiversity*

Résumé

Les souches représentent à elles seules 80 % du bois mort présent sur une parcelle forestière après coupe rase. Elles constituent une source de substrat importante pour les insectes saproxyliques qui dépendent de la présence de bois en décomposition pour leur survie. La demande croissante en bois énergie a influencé l'apparition de nouvelles méthodes de production se focalisant sur la récoltes de ces souches. Pour des raisons techniques et environnementales (érosion, lessivage de nutriments), les guides de récolte conseillent de ne pas arracher les souches présentes dans les parties humides des coupes rases. Cependant, si ce type de souche venait à être le seule à rester sur place, les souches en position humide ne sont peut être pas un substrat satisfaisant pour les insectes saproxyliques et ne sont peut être pas autant utilisées que les souches en position sèche. Afin de tester cette hypothèse, un total de 100 souches (50 d'épicéa et 50 de bouleau) ont été récoltées sur 4 coupes rases entre 5 à 7 ans d'âge dans la région d'Uppsala, dans le sud de la Suède. Les échantillons de souches ont été récoltés par paire. Chaque paire contenait deux souches de même essence, de même diamètre et d'exposition lumineuses similaires, l'une sèche et l'autre humide. Chaque échantillon a ensuite été placé dans une boîte d'émergence pendant 2 mois. Tous les insectes émergents ont été triés et identifiés jusqu'à l'ordre, la famille ou l'espèce en fonction de leur importance dans le projet. L'abondance, la richesse et la composition en espèces ont été analysées pour chaque souche. Les indices de Shannon ont été calculés pour chacun des ordres d'insectes représentés ainsi que le nombre d'individus de chaque taxon utilisant les différents types de souches. Une analyse en composantes principales (ACP) a été réalisée pour enquêter sur une possible relation entre espèces d'insectes, essence et humidité des souches. Au total 17065 insectes ont émergés, représentant 114 taxons parmi lesquels 96 ont été considérés comme saproxyliques. 76 et 55 taxons ont respectivement émergés des souches de bouleau et d'épicéa. La richesse en espèces était plus importante dans les échantillons de bouleau avec en moyenne 11 taxons contre 4 pour ceux d'épicéa. Les résultats montrent que l'essence d'arbre a eu un impact significatif sur la diversité et l'abondance en espèces des différents échantillons. La variable 'humidité' a significativement influencé la diversité entomologique des souches, les souches sèches présentant un nombre plus important d'espèces. L'analyse de la proportion de la population de chaque ordre présente dans chaque type de souche a clairement indiqué que, encore une fois, l'essence de la souche était le principal responsable du nombre et de la diversité des espèces présentes. Les souches de bouleau, quelque soit leur humidité, ont été préférées aux souches d'épicéa: les souches humides d'épicéa et les souches sèches de bouleau étant respectivement les moins (7.9%) et les plus (34,1%) utilisées. Les coléoptères ont été plus souvent trouvés dans les échantillons de bouleau mais n'ont pas montré de quelconque préférence concernant leur humidité. Le même constat a été fait pour les autres ordres avec néanmoins quelques nuances : les hymenoptères et les lepidoptères plus souvent trouvés dans les échantillons de bouleau sec et les diptères de bouleau humide. *Arhopalus rusticus* et *Curtimorda maculosa* ont été les seuls espèces à être significativement associées à un type de souche: les souches d'épicéa.

D'une manière générale, les résultats montrent que quelque que soit l'essence des échantillons, les souches réprésentent un type de substrat utilisé par de nombreuses espèces d'insectes et pas seulement saproxyliques. Comme les souches d'épicéa humides ont présenté la plus faible valeur écologique, il serait donc conseillé, dans une optique de conservation et de préservation de la biodiversité saproxylique, de maintenir en premier lieu les souches de bouleau, et plus généralement de feuillus, présentes sur les coupes rases.

Mots clés: *souches, sol humide, insectes saproxyliques, biodiversité*

Contents

1 Introduction

The production of forest fuels has tremendously increased in Sweden over the last decades (Björheden 2006). The main sources of logging residues are crowns, branches and other small woody debris. But more recently, forest companies started to focus on tree stumps left after clear cuts. Even if stump harvesting present a lot of advantages such as production of wood fuel or additional revenue for forest owners, this process can strongly affect and disturb the environmental conditions of an area (Walmsley and Godbold 2010). One major consequence of such activities is a reduction in the amount of coarse woody debris (CWD) (Rabinowitsch-Jokinen and Vanha-Majamaa 2010) which many different insects, (especially early succession communities) depend on and use as a feeding, breeding and hibernating substrate (Grove 2002).

1.1 Forests and forestry in Sweden

Sweden has the 20th highest percentage of forest cover in the world and the second in Europe, after Finland. Forests in Sweden represent 66% of the total land area with a cover of 27,5 million hectares (FAO 2011). Trees are thus found all over the country and are part of the natural resources that have long formed the base of the country's economic development. Their abundance and distribution have not only enabled the development of a strong and stable forest industry but also those of many other important industries of economical importance such as mining. Therefore, Swedish forests have always been and will remain a keystone in the national economy. Currently 75% of the forest land is managed and dedicated to the production of flagship items such as timber, wood pulp or wood biomass. The Swedish forest sector occupies an important position in the national economy and contributes to 3% of the GDP and to 12% of the total commercial exports (Skogsindustrierna 2011).

1.2 Swedish environmental policies and their consequences on forestry practices

During the last decades, an increased general environmental awareness, combined with a future shortage of fossil fuels and a climate change context, pushed Swedish authorities to review their environmental policies (Hillring 1998). Priorities are, since then, focused on the use of renewable energies from sun, wind, water and biomass. Consequently, the demand for and the production of forest fuels have tremendously increased and five years ago wood fuels represented a fifth of the utilized energy in Sweden (Björheden 2006). The forest industry, accounting for 60% of the industrial energy's demand in the country (Ericsson et al. 2004), immediately took the opportunity to enter this new promising market which was not only supplying the sector's demand but also developing and extending its activities. Forest companies rapidly found the solution to supply the bioenergy market by using logging residues usually left in situ after forest activities. Residues first consisted in crowns, branches and other small woody debris, but now also include low stumps.

1.3 Tree stumps for bioenergy: harvesting methods and its environmental impacts

Stump harvesting processes are simple: a harvester comes to a clear cut and collects the stumps by means of special head which split the stump in two halves and lift them out of the ground. The stumps are then clustered in situ to dry. Once the stumps are dry enough, they are crushed and delivered to domestic heating centrals where they will be burnt to produce energy. However, even if this source of energy seems promising, if not properly settled, the previously described harvesting methods can lead to negative environmental impacts.

In addition to unknown impacts, stump harvesting have already been shown to affect soil, water, forest pests and biodiversity (Walmsley & Godbold 2010, Staaf & Olsson 1994). For instance, the machinery used is heavy and disturbs the upper soil layer leading to compaction or erosion. The removal of stumps also reduces the amount of organic matter in the soil and thus interferes with and disturbs the ground nutrient stocks and cycles (Palviainen et al. 2010, Zabowski et al. 2008, Lauren et al. 2008). As any other vegetal material, stumps store carbon. By extracting stumps after final harvest, forest activities can transform previous carbon storages into carbon sources (Melin et al. 2010). Moreover, stumps constitute an important substrate for many different species and their removal can have a strong impact on the biodiversity of a given area.

1.4 Stump harvesting and saproxylic insects

An obvious consequence of stump harvesting is the reduction of the amount of coarse dead wood (coarse woody debris or CWD) (Rabinowitsch-Jokinen & Vanha-Majamaa 2010). Low stumps represent up to 80% of the dead wood remaining on clear cuts (Hjältén et al. 2010). Many different saproxylic insects, including numerous red listed species, depend on dead wood (Jonsell et al. 1998; Grove 2002) and use low stumps as a feeding, breeding and hibernating substrate (Hjältén et al. 2010; Jonsell and Hansson submitted ms). Thus the removal of stumps potentially has a great importance for saproxylic insects.

The presence of insects in a stump depends on its location, diameter, tree species and sun exposure. A large part of the total saproxylic fauna favor dry and sun exposed substrates for their survival and reproduction (Jonsell et al. 1998; Martikainen 2001). Therefore stumps in dry positions are probably of first interest coming to setting aside stumps at stump harvest in order to minimize potential negative impacts on saproxylic insects (Kaila et al. 1997; Kouki et al. 2001, Lindhe & Lindelöw 2004). However, because of technical and environmental reasons such as nutrient leakage or erosion, stumps will largely be retained in wet parts of clear cuts (Skogsstyrelsen 2009).

Stumps retained on wet ground, even though positioned on a clear cut, might still be too cold and/or moist for saproxylic insects and during periods of heavy precipitations may even be waterlogged. Most of the studies about saproxylic insects have focused on dead wood, its tree species, size or sun-exposure and how those factors affect the quality of a stump as breeding, feeding or hibernating substrate (Jonsell et al. 2004, Lindbladh et al. 2007, Lindhe et al. 2005). Very few studies have actually analyzed the relation between the moisture level of a substrate and its insect diversity.

1.5 Aims of the study

1.5.1 Background and key questions

Stump harvesting guidelines recommend avoiding harvesting stumps situated in wet areas where the erosion risks are higher. Those guidelines might then directly affect saproxylic insects if those latter depend on the wetness of the ground surrounding the stumps. There is currently a lack of knowledge considering the impacts on insects' diversity of such forest activities. Therefore, this study aimed at describing if there was a relationship between the moisture conditions of a stump within a clear cut and the community of saproxylic insects colonizing it. The following questions were investigated:

- Are saproxylic insects more common in stumps situated in dry parts of the clear cut?
- Are there significant differences in saproxylic insects' composition and diversity between stumps in wet and dry areas?

- Is the tree species influencing the saproxylic diversity between stumps situated on wet and dry ground?

I chose to study Norway spruce because it is the most common used tree species in stump harvesting. Birch was added to analyze because deciduous trees are already known to host very different species assemblages than conifers (Jonsell and Hansson submitted ms).

1.5.2 Hypothesis

My hypothesis was that stumps situated in wet sites will not be so much used and will thus present a lower diversity of saproxylic insects because they are too wet to be suitable. The tree species was forecasted to play an important role in the stumps' insect assemblage as this factor has already been described as a major driver of species composition (Lindbladh et al. 2007, Lindhe & Lindelöw 2004).

2 Materials and methods

2.1 Description of the study

The study was in the Neoboreal-conifer-dominated zone, in the province of Uppland, southern Sweden (Figure 1). A total of 4 clear cuts were selected. All were situated within a 25 km radius area in the Länna-Almunge region, east of Uppsala (Figure 3). The GPS coordinates of each of them are presented in Appendix A. The selection of the clear cuts was based on 4 factors: their age, tree species mixture, topography and location.

Figure 1. Location of Uppsala in Sweden (source: wikipedia.org).

- Clear cuts had to be around 5 years old, so that the stumps would be decayed enough to harbor a more diverse assemblage of saproxylic insects than fresh stumps.
- They had to present a marked topography so that dry and wet stumps were possible to find: dry stumps preferably allocated uphill and wet ones downhill in moist hollows.
- The study focused on two tree species: Norway spruce (*Picea abies* (L.)H. Karst.) and Birch (represented by two species: *Betula pubescens* Ehrh. and *Betula pendula* Roth.). Therefore clear cuts had to present those two tree species.
- Finally the study sites had to be located within Uppsala's region for logistic reasons.

Saproxylic beetle and lepidopterans species were chosen as study organisms because their identification, biology and distribution were well known enough to draw conservational conclusions based on the species lists.

2.2 Sampling design

A total of 100 stump samples were collected. According to the protocol, 20 samples were supposed to be collected in 5 different clear cuts, each sample set representing a balanced distribution between tree species and treatments (Table 1 and Figure 2).

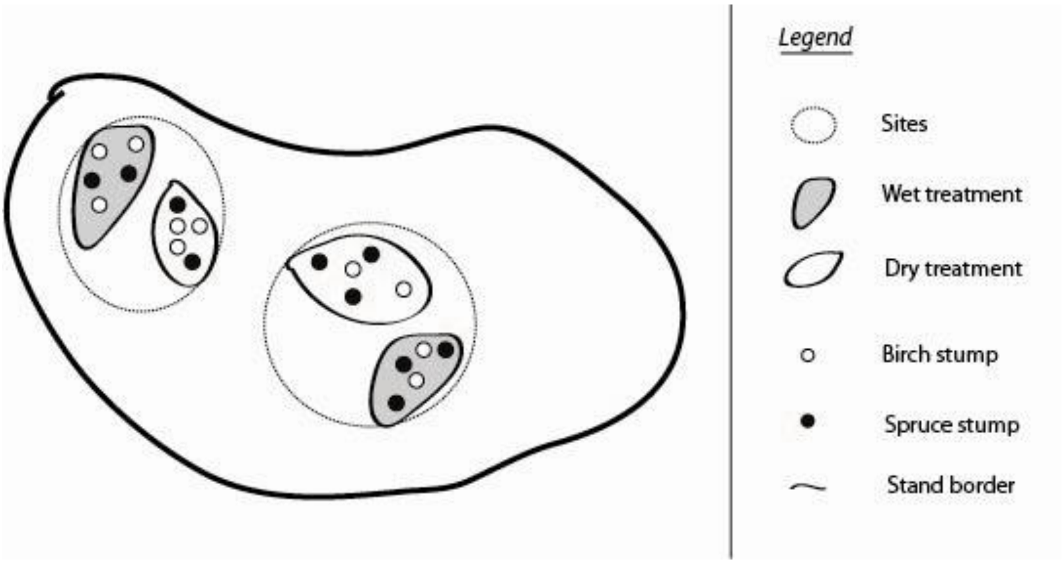

Figure 2. General design of the study.

Table 1. Stump collection protocol within a clear cut

	Tree species		
Treatment	**Spruce**	**Birch**	**Total**
Wet	5	5	10
Dry	5	5	10
Total	10	10	20

However, due to a lack of suitable clear cuts and an unpredictable low number of birch stumps in the preselected stands, only 4 clear cuts, were finally selected within which only 2 presented a suitable amount of birch stumps to follow the protocol (Table 2).

Table 2. Location and distribution of the collected stumps

		Number of stumps		
Clear cut	**Location**	**Spruce**	**Birch**	**Total**
1	Almunge.S	10	0	10
2	Länna.Selknä	10	0	10
3	Nord.Länna	10	20	30
4	Osby.Nyvalla	20	30	50
Total		50	50	100

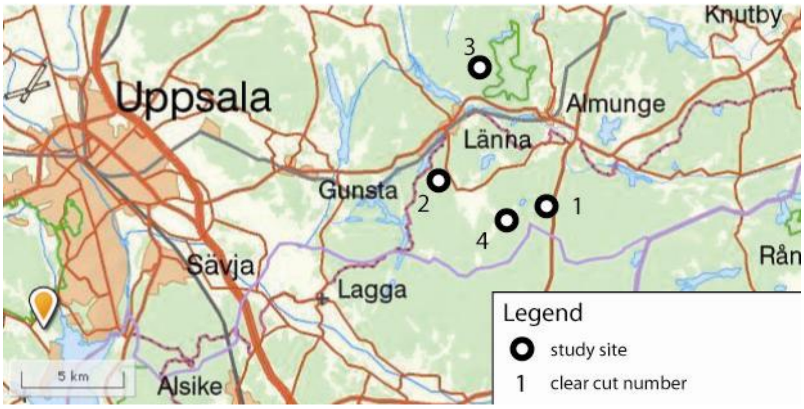

Figure 3. Location of the study sites (source: lantmateriet.se).

The stumps were sampled in pairs, consisting of a dry stump and a wet stump with similar characteristics: the same tree species and of diameters not differing more than 5cm. Wet sites were delimited using high water table level-indicator plant species such as *Sphagnum* sp., *Caltha palustris* or *Carex rostrata* following Wierda et al. (1997). If those species were not present in situ, wet treatments were restricted to areas with visible water tables. Dry sites were, on the opposite, restricted to uphill dry zones. Stumps within a pair were sampled as close as possible to each other. However, due to a lack of wet sites, the distance within a pair was sometimes longer than 50m.

Stumps with visible damages from logging activities or lacking bark were avoided. Presence of fungi on a stump was specified on the data sheet. All samples were cut using chainsaws and cut as close as possible to the ground according to a fix 0,10 m^2 bark area, favoring high samples rather than wide ones. The sampled stumps were situated at least 50m from the clear cut's border to avoid undesirable edge effects.

After samples were collected from marked stumps, a cable tie was placed around the sample to tighten the bark and prevent it from falling (Figure 4). Each wood sample was then numbered and its height and length were recorded (Figure 4). Sampling was done from the 11^{th} to the 19^{th} of April 2011. On each marked stump, I measured the diameter, maximum and minimum heights, surrounding vegetation, sun exposure and presence of fungal fruit bodies.

Figure 4. Wet stump sample and stump sample measuring (photos by C.Ols).

2.3 Rearing process and identification

Each stump sample was put in a rearing box (Figure 5) and placed in a green house for 8 weeks from the 15th of April 2011 until the 15th of June 2011, when the emergence decreased noticeably. This rearing method has been described as one of the best methods to target larvae and emerging adults (Saint Germain et al 2006, Siitonen 1994, Wikars et al. 2005). Thus, all individuals collected were for sure coming from the stump samples we collected, allowing us to draw conclusions on single host selection and colonization.

Figure 5. Rearing boxes (photo by C.Ols).

Emerging insects were first collected on a daily base and then, as the flow of individuals decreased, twice a week. All individuals coming out from a rearing box were placed in a single jar. The insects were then sorted out down to order, family, genus or species level according to their importance in the project. All Coleoptera were identified down to species level according to Silfverberg (2004) except for some broken individuals. The identification of dipterans was restricted to family level following Oosterboerk (2007). Saproxylic species were defined according to Palm (1959), Hansen (1694) and Koch (1989).

2.4 Statistical analysis

All data analyses were restricted to saproxylic species. I performed ANOVA analyses using R to test the effects of locality, dryness and tree species on the species richness and abundance of saproxylic insects. The data met the assumptions of normality and homogeneity of variances so no transformation was used.

Species rarefaction curves were obtained for each type of substrate using EstimateS 8.2.
Shannon's diversity and evenness indexes were calculated for each order and each type of stump in Excel 2007.

A canonical correspondence analysis (CCA-ordination analysis) was performed in Canoco 4 to investigate the possible connections between species composition and environmental variables of the stumps. The influence of tree species, dryness, diameter, mean height and location on the overall species composition was tested using a Monte Carlo test with 499 permutations. Species present in less than 5 samples or with less than 20 individuals in total were excluded from the ordination.

3 Results

In total, 17065 insects were reared out, 15466 in birch stumps and 1599 in spruce stumps (Table 3). The high number of individuals was principally due to the abundance of Dipterans. Indeed, the most abundantly emerged order was Diptera followed by Coleoptera and Hymenoptera with respectively 12819, 2196 and 1943 individuals reared. Dipterans represented 75% of all emerged insects and 91.5% of flies pertained to the Cecidomyiidae and Sciaridae families and were found in great quantity as soon as they were present in a sample. The Orthoptera, Thysanoptera and Raphidioptera orders were also represented in the samples but only by low number of individuals.

Table 3. Number of individuals and taxa in different substrate types

	Number of individuals				Number of taxa			
	All	Saproxylic	Saproxylic Coleoptera	Saproxylic Lepidoptera	All	Saproxylic	Saproxylic Coleoptera	Saproxylic Lepidoptera
Birch								
Dry	9970	9767	1344	18	65	58	33	4
Wet	5496	5328	594	17	64	58	33	4
Subtotal	15466	15095	1938	35	85	76	46	4
Spruce								
Dry	757	661	134	1	49	41	22	1
Wet	842	804	112	0	36	30	15	0
Subtotal	1599	1465	246	1	65	55	29	1
Total	17065	16560	2184	36	114	96	59	6

3.1 Taxa diversity

An overall of 73 and 69 taxa respectively emerged from dry and wet samples. The moisture level of the stumps did not seem to influence the saproxylic insects' species number of the samples. Indeed, birch samples had the highest species density regardless of their moisture level. Moreover, the species densities in wet and dry birch stumps (WB, DB) were very similar with a total of 58 species identified in both types of substrate. However, dry spruce samples (DS) had a higher species density than wet ones (WS) with 41 species compared to 30 only. This discrepancy was shown to be significant as none of the 95% confidence limits of dry or wet spruce overlapped the line of the other curve (Figure 6).

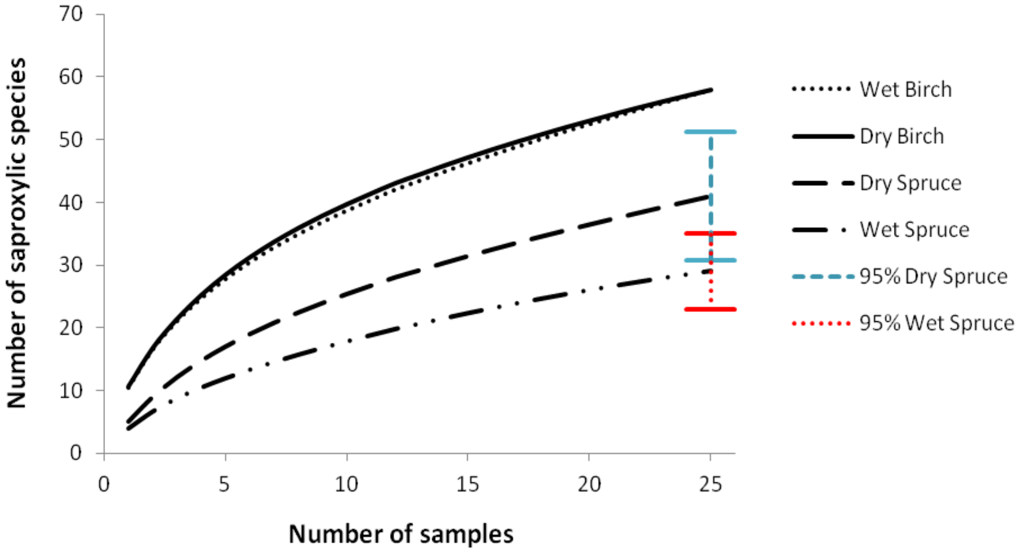

Figure 6. Rarefaction curves of saproxylic beetles in the four types of stumps-Error bars indicate 95 % confidence limits.

Focusing on tree species, a total of 76 and 55 saproxylic taxa were respectively collected on birch and spruce stumps with 11 and 4 species in average per sample. Birch samples had the highest taxa diversity and the difference between wet and dry stumps was minor (Figure 7).

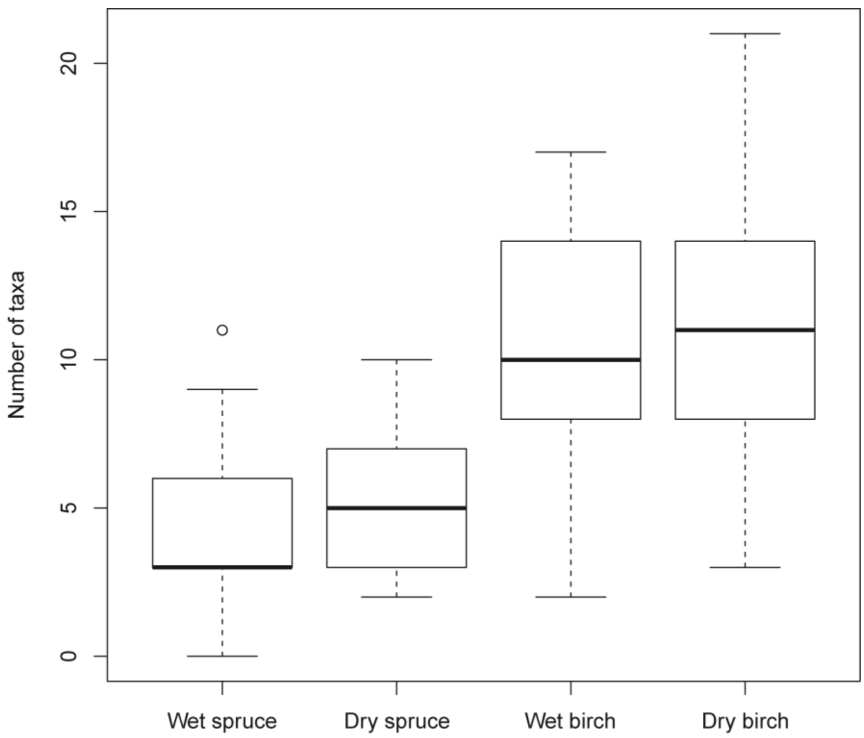

Figure 7. Box and whisker plot: Number of taxa per type of stump, including minimum, quartiles, median and maximum.

When restricting the analysis to the taxa determined to species level (Coleoptera and Lepidoptera), dry birch samples still had the highest species number but the discrepancies between wet and dry spruce were more visible with an average of respectively 3 and 0.5 species per sample (Figure 8). In addition, the variable "Dryness" significantly affected the number of species per sample ($p<0.05$), dry samples presenting a higher diversity than wet ones. No interactions were detected between environmental factors.

Birch presented the highest species richness and the abundance, underlining a significant effect of the tree species on both environmental response variables (Table 4).

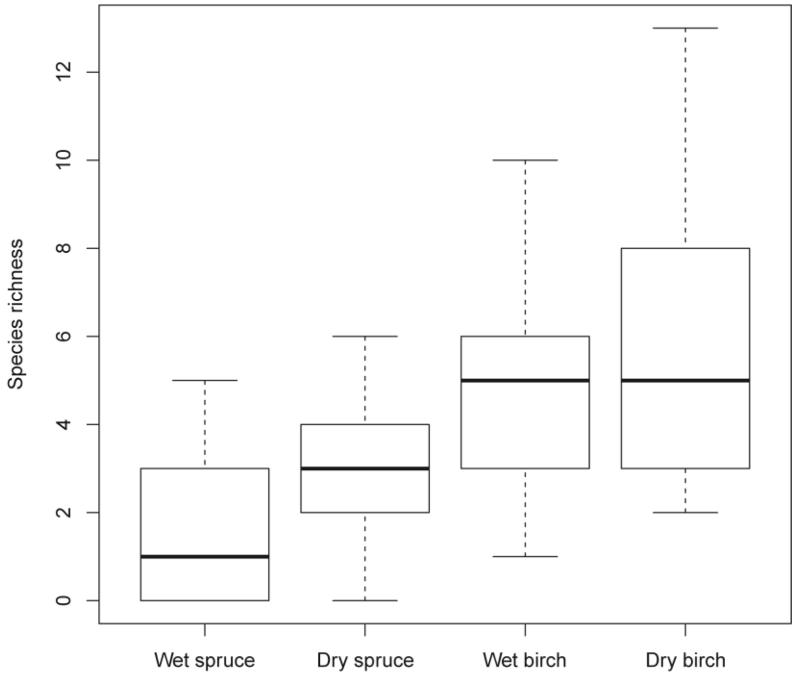

Figure 8. Box and whisker plot: Number of species per type of stump restricted to Coleoptera and Lepidoptera orders- minimum, quartiles, median and maximum represented.

Table 4. ANOVA with insects number and species richness as response variable, and site (n=4), tree species (n=2; spruce and birch) and dryness (n=2; wet and dry) as explanatory factors- interaction between explanatory factors included, data restricted to Coleoptera and Lepidoptera orders and SS type III

	Df	**SS**	**MS**	**F**	**p**
Species richness					
Tree species	1	259.21	259.2100	47.0187	9.307E-10
Dryness	1	22.09	22.0900	4.0070	0.04839
Location	3	23.49	7.8310	1.4206	0.24215
Tree species : Dryness	1	2.75	2.7500	0.4988	0.48191
Tree species : Location	1	0.85	0.8470	0.1536	0.69609
Dryness : Location	3	5.75	1.9180	0.3478	0.79080
Tree species : Dryness : Location	1	6.11	6.1110	1.1085	0.29529
Residuals	88	485.14	5.5130		
Number of individuals					
Tree species	1	29860	29859.8	14.6346	0.0002434
Dryness	1	5960	5959.8	2.9210	0.0909592
Location	3	4396	1465.3	0.7181	0.5437644
Tree species : Dryness	1	5554	5554.4	2.7223	0.1025228
Tree species : Location	1	1944	1944.4	0.9530	0.3316395
Dryness : Location	3	202	67.2	0.0329	0.9919192
Tree species : Dryness : Location	1	882	881.6	0.4321	0.5126811
Residuals	88	179551	2040.4		

3.2 Presence of insect orders in the different types of stump

In both tree species, insects were more numerous in dry samples i.e. the highest population of insects was found in dry stumps (Table 5). Wet spruce and dry birch stumps were respectively the least (7.9%) and the most (34.1%) used substrate (Table 5).

Beetles were more numerous in birch stumps regardless of their moisture level. The other orders showed a similar pattern with Hymenoptera, Lepidoptera insects however favoring dry birch stumps and Dipterans wet ones. Hemipterans were, on the other hand, mainly present in dry spruce stumps. However, the low number of individuals collected in the Hemiptera and Lepidoptera orders makes the percentages to be analyzed carefully. In addition, Lepidoptera or Hemiptera orders were totally absent in wet spruce samples.

Table 5. Percentage of the total number of insects for each order present in the different types of stumps

	Stump type			
	Dry birch	**Wet birch**	**Dry spruce**	**Wet spruce**
Coleoptera	32.2	34.9	23.0	9.9
Diptera	27.9	31.5	18.5	22.2
Hymenoptera	42.2	35.1	15.2	7.4
Hemiptera	23.6	22.2	54.2	0.0
Lepidoptera	44.8	38.6	16.7	0.0
All	34.1	32.5	25.5	7.9

3.3 Shannon's diversity and evenness indexes

Shannon's indexes were calculated for Coleoptera and Lepidoptera as they were the only orders with individuals identified down to species. For more details on how Shannon's indexes were calculated see Appendix C.

Table 6. Shannon's diversity and evenness indexes for Coleoptera and Lepidoptera orders and stump type

	Stump type			
	Dry spruce	**Wet spruce**	**Dry birch**	**Wet birch**
Shannon's diversity index (H)				
Coleoptera	2.47269	1.56376	1.25183	2.05388
Lepidoptera	0.00000	NIL	1.35489	1.11507
Shannon's evenness index (E_H)				
Coleoptera	0.79995	0.57745	0.35802	0.58741
Lepidoptera	0.00000	NIL	0.97734	0.80435

Lepidoptera Shannon's indexes couldn't be calculated in wet spruce stumps because no moths emerged from that type of substrate. The diversity of moths reached its highest value in dry birch stumps but this diversity was only slightly lower in wet ones (Table 6). However, this index was equal to 0 in dry spruce samples for only one moth species, *Montescardia tessulatella*, emerged from this type of samples. On the contrary, beetles were most diverse in dry spruce samples with a diversity index of 2.47, then came wet birch and wet spruce samples with a respective index of 2.05 and 1.56.

Concerning the evenness of the species assemblage, the two orders were again reacting quite differently to the treatments. Even if Coleoptera insects presented their highest evenness in dry spruce stumps, Lepidoptera moths were more even in dry birch samples (Table 6). In addition, the evenness within Lepidoptera communities was, regardless of the substrate, always higher than within the Coleoptera order.

3.4 Species composition

In this section we tried to determine if certain species were contributing more than others to the differences in assemblage between substrate types and if so, which they were. Only insects determined to species level were included in the analysis (Coleoptera and Lepidoptera).
Species present in less than 5 samples or with less than 20 individuals in total were excluded of this analysis. Out of 65 saproxylic species, only 20 were abundant enough to satisfy the pre requirements. All selected species were individually analyzed in a canonical correspondence analysis (CCA) to investigate the possible existing connections between the insect species, the tree species, dryness and location of the stumps.

The influence of tree species, dryness, diameter, mean height and location on the overall species composition was tested using a Monte Carlo test with 499 permutations. Among all factors, only the tree species and the Osby study site factors were significantly explaining the species assemblage variation within stumps and thus added to the Canoco model. The other factors were omitted (Table 7). The total inertia of 4.274 indicated a low global variation within the data set. The 2 first axes of the model explained all variance of species-environmental relation and 7.5 % of the variance of the species data (Table 8).

Table 7. Marginal and conditional effects of the different environmental factors- LambdA and Lambda A indicate the variance that each factor singly explains

Marginal Effects

Variable	**LambdA**
Spruce	0.25
Osby	0.08
Diameter	0.07
NordLänna	0.06
Almunge	0.06
Height	0.05
Wet	0.05

Conditional Effects

Variable	**LambdaA**	**P**	**F**
Spruce	0.25	0.002	5.17
Osby	0.07	0.094	1.43

Table 8. Overall variation in the set of data and variation explained by each axe

	Axes				
	1	**2**	**3**	**4**	
Eigenvalues	0.254	0.065	0.983	0.355	
Species-environment correlations	0.737	0.514	0	0	
Cumulative percentage variance					
of species data	5.9	7.5	30.5	38.8	
of species-environment relation	79.6	100	0	0	
					Total inertia
Sum of all eigenvalues					4.274
Sum of all canonical eigenvalues					0.319

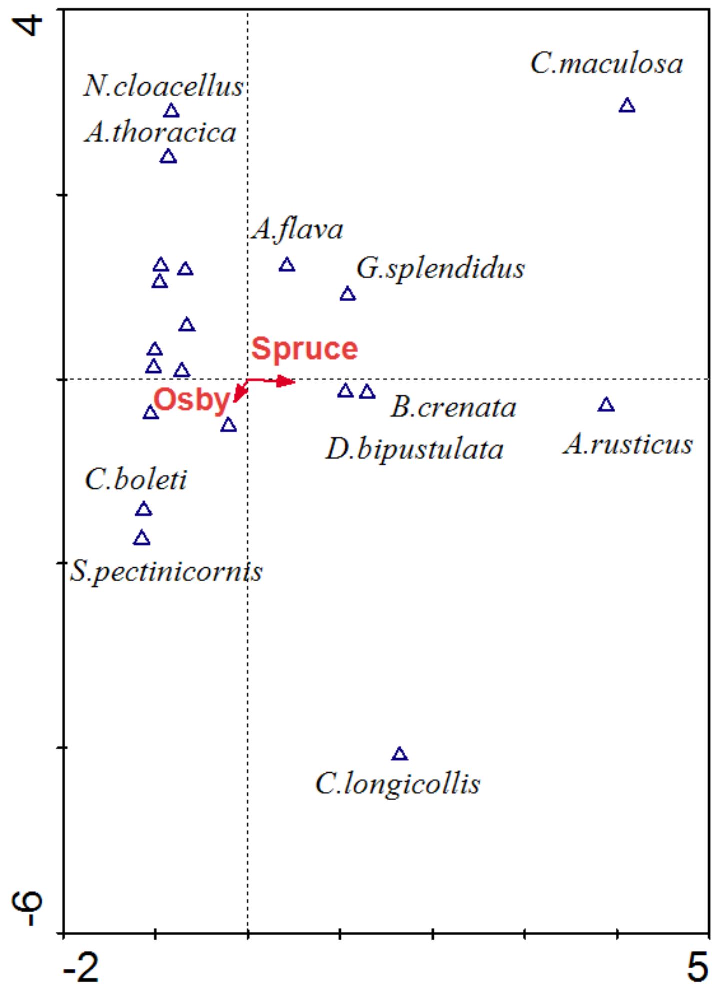

Figure 9. Canonical Correspondence Analysis (CCA) biplots of the species restricted to Coleoptera and Lepidoptera orders.

Two beetle species were strongly associated to spruce stumps: *Arhopalus rusticus*, and *Curtimorda maculosa*. However, another group of four beetle species could be underlined on the ordination plots: *Bitoma crenata*, *Corticaria longicollis*, *Dacne bipustulata* and *Gabrius splendidus*. On the opposite, none of the species present on the left part of the graphic showed the same level of linkage and thus did not differ sufficiently from the others to be classified as birch indicator (Figure 9).

4 Discussion

The results clearly showed that spruce and birch stumps provide an appropriate habitat and support the life cycle of a high number of insect species and not only saproxylic. This was confirmed by previous studies reporting stumps and other logging residues as a largely used substrate by saproxylic insects (Hjältèn 2010, Hedgren 2007, Jonsell et al. 2007).

The orders that most numerously emerged were Diptera, Coleoptera and Hymenoptera, following the same pattern as in Nittérus et al. (2004) experiment. Coleoptera and Lepidoptera orders reached their highest Shannon's diversity and evenness value in respectively dry spruce and wet birch stumps. Those discrepancies could be explained by the fact that even if dry spruce stumps were harboring less beetle species, all species were represented by a low number of individuals which naturally increased the level of diversity of the sample. This is underlined by the high Shannon's evenness level for beetles in dry spruce stumps. Only 6 moths' species were identified as saproxylic and when emerging from a sample the number of individuals was always low. Lepidoptera, regardless of the stump type, consequently showed a higher evenness level than Coleoptera.

Contrarily to our hypotheses, insects were not more common in dry stumps and the moisture level only significantly affected the species composition of the samples when the analyses were restricted to Coleoptera and Lepidoptera orders. However, wet spruce stumps presented the lowest species diversity and abundance and birch stumps, regardless of their dryness, the highest one. The fact that birch showed a higher saproxylic biodiversity is not surprising as broadleaves trees are known to harbor a higher diversity of species.

In addition, even if the tree species factor was playing the most important role in the global assemblage, the humidity level of the samples seemed to influence the colonization of a specific sample. Differences in occurrence showed a statistically significant pattern with wet spruce stumps being the least used substrate and dry birch samples the most preferred substrate. In addition the dryness of stumps of the same tree species was not significantly influencing their species assemblage. Nevertheless, regardless of the tree species, dry stumps were more used than wet ones and this was especially seen in spruce samples.

However, the absence of interaction between the dryness and the species assemblage of the samples might indirectly underline the difficulties of selecting stumps of the same moisture level. It is clear that a certain humidity variation existed between wet stumps and that some were moister than others. The surrounding vegetation and the water table level might not be factors that one can objectively use. The water table level, for example, depends a lot on the local climatic conditions of an area (precipitations and soil structure for instance), can vary a lot even within short periods and is thus not easy to analyze within a day of field work. It should then be advised to visit the clear cuts at different periods of the year to locate more accurately wet areas.

On the other hand, the ‘Locality’ of the clear cuts did not affect significantly the species assemblage of a specific stump. This result was expected as the selection of the clear cuts was done in order to minimize a potential location effect. However the age of the 4 clear cuts varied from 5 to 7 years old. So stumps from 5 to 7 years old could then be said to host similar entomological characteristics and attract the same saproxylic communities.

In the CCA, one of the localities was significantly affecting the species assemblage of the samples and included in the model. This sudden significant effect of the location can be explained by the reduced data set as the smaller it is, the more the factor can express itself.

In the same CCA, only two beetle species, *Arhopalus rusticus* and *Curtimorda maculosa*, were strongly associated to spruce stumps and categorized as contributing the most to assemblage differences between tree species. More indicators species could have been expected as the range of stumps type was quite broad thus increasing the probability that a specific substrate would present a typical species composition. And this could be due, once more, to a too small data set. The pre requirements to include a species in this analysis might have been too high, and thus only selecting generalist species which make rather small difference between wet and dry stumps.

Managed forests are lacking the most important substrate for the survival of saproxylic insects: dead wood. Nowadays stumps represent 80% of the dead wood available after final harvest (Hjältèn 2010). Stump harvesting processes decrease dead wood volume and connectivity and thus directly threaten the future survival of many different species (Schiegg 2000, Okland et al. 1996). By advising to set aside stumps on wet ground, technical guidelines reduce slightly the ecological loss that would be not to leave anything after stump extracting activities. And as far as such forest activities as concerned, the main substrate targeted by guides is spruce stumps. Setting aside wet spruce stumps is thus not the best solution to protect the future ecological potential of a clear cut, especially if in our case they are not harboring specific species. Birch stumps, on the other hand, regardless of their moisture level should be the priority for they present the highest species diversity and ecological values. Coming to stump harvesting processes, it is thus important to know that regardless of their dryness, broadleaves stumps have to be set aside and protected from any harvest in reasonable quantity.

4.1 Future experimentation

A recent review from the UNECE 2011 reported that in a context of rising coal and oil prices, and nuclear disasters, public policies and financial incentives have pushed the expansion of modern technology for producing heat and electricity. The wood energy market has thus enjoyed a constant growth during those last few years and the production of pellets keeps on increasing. Consequently stump harvesting are going to be more largely applied and especially in Europe as this continent is the largest consumer of such renewable source of energy. The environmental impacts of such forest activities have to be more investigated to minimize or counteract any possible negative consequences on the biodiversity of our future forests (UNECE 2011).

In this study we have been mainly focusing on the impact of the moisture level of stumps on their insect assemblage. But other studies suggest that coming to saproxylic insect conservation, the variables related to the abundance and quality of dead wood supply should not be the only criteria to be taken into account (Fayt et al. 2006). The surrounding vegetation, the presence of fungi, bacteria and other forms of live can also directly affect the insect assemblage of a specific stump. For example, a higher moisture level can possibly favor the growth of fungi and thereby the colonization of the stump by fungivore insect species such as Cisidae species (Jonsell et al 2005) or even Dipterans.

This experiment was only one step in understanding how stump harvesting activites are affecting the saproxylic diversity present on clear cuts. Its scope should be widened and developed to non saproxylic species for the relationships between saproxylic and non saproxylic species can be of major importance in explaining the specific assemblage of a substrate. Future experiments can for example focus on Diptera insects as this order was the most abundant and flies were abundant in all types of substrate. Such high amounts of individuals allow more accurate and reliable statistical analyses and thus unable to draw objective conclusions on the possible effects the moisture of a stump can have on its Diptera community.

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Appendices

Appendix A. Stand location and RT90 GPS coordinates

Stand	Location	GPS -RT90	
		X	**Y**
1	S-Almunge- R273	6637734	1625811
2	Länna-Selknä	6638518	1619459
3	Nord Länna	6644851	1621904
4	Osby-Nyvalla	6636999	1624229

Appendix B. Species list (including non saproxylic species) and number of individuals per type of stump

		Stump category			
	Saproxylic species	Dry birch	Dry spruce	Wet birch	Wet spruce
Coleoptera					
Acalypta sp.					1
Ampedus balteatus	x			1	
Ampedus nigrinus	x			1	
Ampedus sanguineus	x	3			1
Ampedus sp.	x	2		2	
Anaspis flava	x	18	10	18	3
Anaspis rufilabris	x	1			1
Anaspis sp.	x		1		
Anaspis thoracica	x	11		4	
Antherophagus pallens					1
Anthribus nebulosus		1			
Arhopalus rusticus	x		21		3
Asemum striatum	x		3		
Atheta sp.				1	
Bembidion sp.		1			
Biblioporus sp.	x	1			
Bibloporus bicolor	x		1		
Bitoma crenata	x	25	19	27	21
Cerylon ferrugineum	x	21	1	15	
Cerylon histeroides	x	24		27	
Cerylon sp.	x				4
Cis boleti	x	5		8	
Cis comptus	x	16		6	
Cis hispidus	x	50	1	91	2
Corticaria longicollis	x	1	3	1	
Cryptocephalus parvulus		1		2	
Crypturgus sp.	x		2		
Crypturgus pusillus	x		1		
Crypturgus subcribrosus	x		1		
Curtimorda maculosa	x		8		
Dacne bipustulata	x	21	18	8	4
Dasytes niger	x			1	2
Dasytes plumbeus	x	1			
Denticollis linearis	x			2	
Euplectus nanus	x			1	
Euplectus piceus	x			1	
Gabrius splendidus	x	7	11	15	2
Hylis cariniceps	x	2	4		
Judolia sexmaculata	x	1			
Leptura quadrifasciata	x	1		4	
Leptusa fumida	x			1	
Lygistopterus sanguineus	x	1			

	Saproxylic species	Dry birch	Dry spruce	Wet birch	Wet spruce
Coleoptera					
Mordella huetheri	x			2	
Nepachys cardiacae		1			
Orthocis alni	x			5	
Ostoma ferruginea	x		1		
Phyllotreta sp.				1	
Pyrochroa coccinea	x			1	
Rhagium inquisitor	x		1		
Rhagium mordax	x	1		1	
Rhyncolus ater	x	1	1		
Schizotus pectiniformis	x	20		43	
Scolytidae	x		2		
Sepedophilus testaceus	x	1			2
Staphylinidae			1	1	1
Stenus sp.					1
Stictoleptura rubra	x		1		
Sulcacis affinis	x	1003	23	279	64
Tomoxia bucephala	x	70		6	
Trichius fasciatus	x	18		3	
Tyrus mucronatus	x	2			
Ptilidae	x	6		5	
Diptera					
Anthomiidae	x				1
Asilidae	x	1	1		
Cecidomyiidae	x	6208	247	2382	305
Ceratopogonidae	x	8	3		
Chaoboridae	x		2		
Chloropidae	x	9		16	1
Ctenophora astrata	x	1		3	
Diptera sp	x		2		
Dolichopodidae	x	3	4	17	3
Fanniidae	x	21	2	10	
Hybotidae	x	303	45	281	5
Keroplatidae	x	7	4	4	4
Lauxanidae	x				1
Lonchaidae	x	11	1	3	1
Megachilidae	x		1	6	
Milichidae	x	119	26	100	2
Muscidae	x			2	
Mycetophagidae	x	2		1	
Phoridae	x	14	4	11	
Pipunculidae	x				1
Sciaridae	x	1473	84	952	89
Syrphidae	x			2	1
Tachinidae	x	1		2	
Tipulidae	x	2		3	

	Saproxylic species	Dry birch	Dry spruce	Wet birch	Wet spruce
Hymenoptera					
Braconidae	x	3			
Formicidae	x	213	88	912	277
Hymenoptera sp		188	80	154	24
Ichneumonidae	x	1		1	
Chrysididae	x		1	1	
Hemiptera					
Aphidae			4		
Aradus sp.	x	1	6		
Hemiptera sp		3			
Xylocoris cursitans	x	4	5	8	
Rhynocoris annulatus	x		1		
Lepidoptera					
Lepidoptera sp		3		2	
Oecophora bractella	x	5		1	
Acronicta psi		1			
Crambus lathoniellus					1
Morophaga choragella	x	4		5	
Montescardia tessulatella	x		1		
Nemapogon cloacellus	x	6		9	
Nemapogon granellus	x	3			
Nemaxera betulinella	x			2	
Scopula immulata				3	
Orthoptera					
			5		
Thysanoptera					
		2	2		1
Raphidioptera					
		4	1	6	7

Appendix C. Shannon's diversity and evenness indexes calculation

Shannon's diversity index is used to measure the species diversity in a certain community and is calculated as follow:

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

n_i: number of individuals in species i; the abundance of species i
S: number of species (also called species richness)
N: total number of all individuals
p_i: relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community (n_i/N)

Shannon's evenness index is calculated according to Shannon's diversity index and assumes values between 0 and 1:

$E_{H'} = H'/H'max$ with $Hmax = \ln S$ here

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