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ORIGINAL PAPER

Sampling saproxylic beetle assemblages in dead wood logs: comparing window and eclector traps to traditional bark sieving and a refinement

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Abstract The use of saproxylic beetle community as a metric to evaluate nature conservation measures in forests requires efficient methods. We first compare traditional bark sieving to a potential improvement (extracting beetles from whole bark with Tullgren funnels) to determine the most efficient. Secondly we compare this most efficient bark sampling to eclector and window traps. At the species, family, and functional group levels, we consider species richness, abundance and practical aspects. Traditional bark sieving missed >50% of the individual beetles compared to whole bark sampling so we recommend the latter. Window traps caught large numbers of mobile saproxylic beetles, but a high proportion of non-saproxylics results in high sorting cost; bark sampling and eclector traps had a high proportion of saproxylics and obligate saproxylics. Compared to bark sampling, eclector traps are non-destructive, and monitor the whole saproxylic assemblage (i.e. also beetles inside the wood). Overall, window traps are useful because they capture saproxylic beetles attracted to dead wood and sample the local species pool, whereas eclector traps capture the saproxylics that actually emerge from a particular piece of dead wood, and thus are suited to detailed studies. Overall, we suggest that a combination of these two best methods is highly complementary.

Keywords Saproxylic beetles · Bark sieving · Window trap · Eclector trap · Bark sampling

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Introduction

In response to public opinion and demands from customers, Scandinavian forestry has changed dramatically during the last 20 years with respect to nature conservation. Currently, many nature conservation measures are taken, especially at final felling, in order to ensure the survival of fauna and flora (Larsson and Danell 2001). However, we still need much more explicit knowledge about the value of various management practices to preserve biodiversity (Larsson and Danell 2001). Dead wood is a resource that diminishes with intensive forestry (Siitonen 2001) and today much effort is devoted to preserving dead wood and all the associated fungi and fauna involved in the wood decay process. Saproxylic beetles have been proposed as indicator species (Speight 1989; Nilsson et al. 2001) because they are highly dependent on dead wood, and are therefore particularly sensitive to forestry (e.g. Siitonen 2001 and references therein). They also constitute a large group of species, and they represent many functional groups. In order to be used as a tool to evaluate forestry measurement, we must have efficient methods for studying these saproxylic beetles.

Many methods have been used to study saproxylic beetles, but surprisingly few studies have explicitly compared different sampling techniques in the ideal design where there was a one-to-one correspondence among different sampling methods on the same piece of dead wood at the same time (but see Økland 1996; Ranius and Jansson 2002; Wikars et al. 2005). In order to improve our knowledge of how these sampling techniques sample beetles in general and saproxylic beetles in particular, we first compare traditional sieving with whole bark sampling (i.e. omitting the

sieving step and instead process all bark in Tullgren funnels) and then, we compare (1) the most efficient bark sampling technique that emerges from this comparison, (2) eclector traps (in situ, i.e. enclosing part of the dead wood as opposed to ex situ where wood is cut off and enclosed) and (3) window traps on the same logs. Building on studies by Økland (1996) who compared window to in situ eclector traps, and Wikars et al. (2005) who compared window traps, traditional sieving and ex situ eclector traps (i.e. cutting of and enclosing a part of the dead wood) our study also uses this ideal one-to-one sampling design. Thus, our study is an important addition to a limited number which specifically aim at improving the methodological tools needed to efficiently assess the effects of forestry on biodiversity by using saproxylic beetles.

Sieving, and other types of extraction from woody substrates, have a long tradition (e.g. Saalas 1917; Palm 1951, 1959) and are commonly used. In the traditional sieving method, bark is placed in a sieve, broken into small pieces, and invertebrates plus the small bark fragments which fall through the openings in the mesh are collected, brought to the lab and processed in a Tullgren funnel while the material left above the mesh is discarded. Traditional sieving provides good information about the microhabitat choices and biology of the beetles. However, much substrate is destroyed so the use of sieving in long-term monitoring studies is very problematic, species truly living inside the wood are under-represented, the method has been difficult to standardise among observers, and many species of interest are too infrequently collected to allow statistical comparisons even with a large sampling effort (e.g. Kaila 1993; Siitonen 1994). Window traps are also frequently used because they catch large numbers of beetles (much more than extraction methods), but do not give exact information about microhabitat selection (e.g. Kaila 1993; Siitonen 1994; Økland 1996). The eclector trap is a relatively new method which catches beetles leaving decaying wood by means of an enclosure (Albrecht 1990; Schmitt 1992). The method has several advantages over sieving, such as catching wood-boring species which have developed inside the wood (as opposed to bark or cambium), and because it does not destroy the dead wood habitat (Økland 1996) it is particularly well-suited to long-term studies in which repeated sampling of the same dead wood objects are needed. Eclector trap samples integrate over the catching period (often a whole season) as opposed to sieving which collects the species present at the specific time of sampling (Økland 1996).

Here, we first quantified beetles missed by the traditional sieving approach, by comparing the material passing the mesh (the traditional sieving sample) with the material left above the mesh (disregarded in traditional sieving), to evaluate if the efficiency of bark sampling can be improved by omitting the sieving step and instead taking whole bark samples back to the lab for processing with Tullgren funnels. In a second step we compare the most efficient bark sampling technique determined in step one (i.e. either traditional sieving or whole bark samples) to eclector and window trapping with respect to beetle species richness, abundance and different aspects of trapping efficiency.

Specifically we addressed the following questions: (a) for bark sieving, does the sieved material (which has passed the sieve) and un-sieved material (which was retained above the mesh) differ? (b) do the three methods differ in their ability to catch beetles and especially saproxylic beetles? (c) what are the differences among the methods with respect to material costs, handling time in the field, processing time in the laboratory, etc.?

Study area

The study was done in Långrumpskogen nature reserve ca 50 km SE of Umeå, Sweden, 63°42′ N, 19°36′ E. The forest is dominated by Norway spruce, *Picea abies* L., the field layer is dominated by shrubs such as bilberry *Vaccinium myrtillus* L. and lingonberry *Vaccinium vitis-idea* L., and the ground layer is dominated by mosses (see Gibb et al. 2005 for more detail).

Material and methods

Selection of logs and sampling

Within an area of about 2 ha, 15 spruce logs were selected. Logs were selected based on decomposition stage. We used a modification (Atlegrim and Sjöberg 2004) of the classification scheme proposed by Söderström (1988). Decomposition stages were: (1) log with hard wood and the bark remaining intact (>95% remaining), (2) log with hard wood, bark broken up in patches but >50% remaining and (3) wood has started to soften, <50% bark remaining (but still present). Logs in later decay stages could not be used in the study because sieving requires bark. The softness of the wood was tested using a knife on several places along the log and five logs in each decomposition stage were randomly selected. The position of the traps (eclector and window traps) and the location for the sieving

sample were randomly assigned to a 0.5 m section of the log. Traps were left in the same position during the entire July–October season whereas the positions for the sieving samples were randomly assigned at each sampling period. The sampling period included mid-July to mid-October with traps emptied once a month and at the same time sieving samples were taken.

Eclector traps

The eclector traps (Fig. 1a) enclosed a 0.3 m wide strip around the log (to sample the same area as the bark sieving samples: see below), positioned in the centre of the randomly assigned 0.5 m log section. A black plastic fabric polypropylene weed barrier was used to enclose the area. Along the borders of the trap, staples and steel wire secured the fabric to a 3 cm wide strip where the bark was removed to achieve a close fit of the cloth. An internal support of steel wire held the cloth away from the wood. A hole was made in the cloth to which a lid for translucent plastic bottles was fastened, and this was the only place where light came into the trap. Beetles emerging from the trap were caught in the bottle screwed into this lid (see Johansson et al. 2006 for additional details).

Window traps

A transparent rigid plastic sheet, 10 by 15 cm, was used in the window traps and placed perpendicular to each log as a flight intercept (Fig. 1b). An aluminium tray, 11 by 15 cm and 5 cm deep, half filled with ethylene glycol and a trace of detergent to reduce surface tension, was attached under the plastic to collect insects.

Sieving

The sieve was constructed of cotton fabric and wire mesh. The opening had a diameter of 35 cm. A metal sieve, mesh size 9 by 9 mm, was attached to the cloth 35 cm below the opening. Before sampling, a piece of cotton fabric was placed under the log to collect bark and beetles falling to the ground during bark removal from the log. All bark was removed along a 0.3 m section (to sample the same area as the eclector trap). Bark was broken to a maximum size of approximately 15 by 15 mm inside the sieve and was shaken for 5 min together with the material collected on the fabric under the log. The material which had passed through the mesh (‘‘lower sieving’’ hereafter), was put in a cotton bag—this corresponds to traditional sieving samples. The material not passing the mesh, i.e. traditionally discarded (‘‘upper sieving’’ hereafter), was put in a separate bag. The two bags were brought to the laboratory, placed in separate Tullgren funnels, for three days and beetles were collected in jars filled with ethylene glycol and detergent.

Analysis

Determination and classification

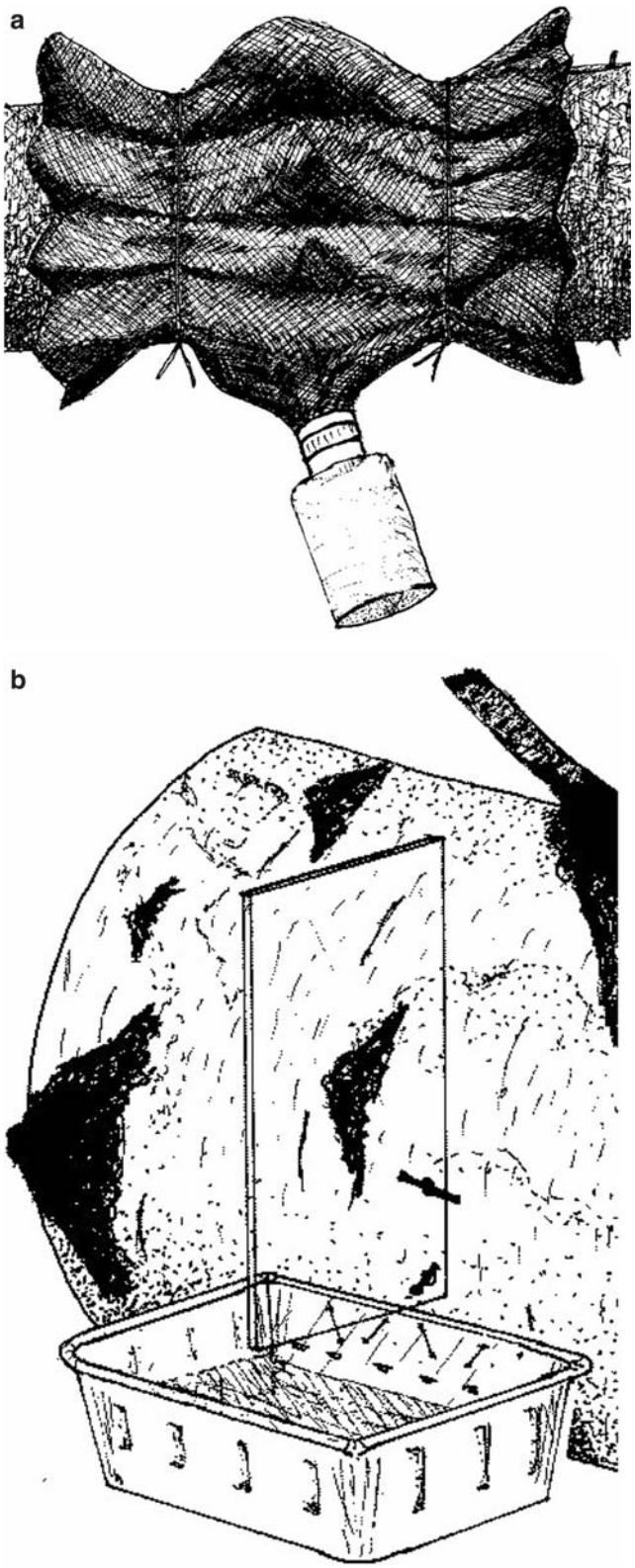
We analyzed only individuals which were determined to species, so a few larvae were excluded if they could only be determined to family or genera. Based on the definition by Speight (1989) beetles were classified as non-saproxylic, obligate saproxylic and facultative saproxylic using the Nordic saproxylic database (Dahlberg and Stokland 2004) modified for northern Sweden (Hilsczcanski, Pettersson, and Lundberg, pers. comm.).

Compilation of data

Because our interest is in the overall performance of the 3 sampling methods and not in temporal aspects, the data for the three catching periods were pooled (i.e. resulting in 15 independent samples for each method). Based on these 15 values we calculated mean values and standard errors for the variables: number of (a) species (total), (b) saproxylic species, (c) obligate saproxylic species, (d) facultative saproxylic species, (e) species in different families, (f) individuals (total), (g) saproxylic individuals, (h) obligate saproxylic individuals, (i) facultative saproxylic individuals, (j) individuals in different families, and (k) individuals of different species. Furthermore, in order to ensure the generality of our findings and to ensure a sharper focus in our considerations, we present only families and species for which we caught at least 15 individuals. Thus, the overall analysis uses the entire data set, but in the interests of brevity and robust analysis, the detailed consideration of families/species is restricted to just those with at least 15 individuals.

Comparison of methods

We also compared the methods qualitatively with respect to species caught. We compiled the number of species uniquely caught by each method for total, saproxylic, obligate saproxylic and facultative saproxylic species. Furthermore, the qualitative Sorenson β-diversity index (Magurran 1988, p. 95) was used to compare similarity among the methods.



◄**Fig. 1** (**a**) Eclector trap. A black plastic fabric polypropylene weed barrier secured by staples and steel wire enclosed a 0.3 m wide strip around each log. An internal support of steel wire held the cloth away from the wood to allow insect movement. (**b**) Window trap. A transparent rigid plastic sheet, 10 by 15 cm, with an aluminium tray half-filled with ethylene glycol and a trace of detergent to reduce surface tension, was placed perpendicular to each log as a flight intercept

In a first step we used one way ANOVA ($N = 30$) to compare the upper and lower parts of the sieving samples. If this analysis reveals that traditional sieving (i.e. only using the beetles that pass the mesh into the lower sample) can be improved by omitting the sieving step and instead taking whole bark samples (i.e. all bark is taken to the lab and processed in Tullgren funnels), we will compare window traps and eclector traps to this improved way of sampling bark.

To compare the eclector, window and the most efficient bark sampling method we also used one way ANOVA ($N = 45$) with post hoc Tukey tests (pairwise test, $N = 15$). The assumption of normality was tested by the Kolmogrov–Smirnoff one sample test, and homogeneity of variances was tested with Bartlett's test and residual plots (Tabachnick and Fidell 2001). Although small departures occurred in a few cases, ANOVA is robust to departures from the assumptions of normality and homogeneity of variances when sample sizes are large and when experiments are balanced as was ours (Underwood 1997). In comparing the eclector, window and the most efficient bark sampling methods, we extended the qualitative comparison further. Dominance patterns of families, genera and species for each method were compiled by calculating how large a proportion each family, genera and species constituted of the total number of individuals and total number of species for families.

Furthermore, to assist researchers in choosing the best method for their particular situation, we also ranked the methods with respect to (i) costs for material, (ii) construction time (i.e. preparation prior to field work), (iii) set up in the field, (iv) sampling time in the field (i.e. time to empty traps or collect samples), (v) sensitivity to weather, (vi) material costs in the lab, (vii) sorting time in the lab and (viii) determination time. We did not calculate efficiency as ''beetles per Euro'' because it would vary greatly with study conditions. For example, in a study area with abundant mires, window traps would likely have more flies, wasps, etc., which have to be removed before even getting to the Coleoptera, let alone identifying saproxylic Coleoptera. Here, window traps would have a

much higher cost per saproxylic beetle identified. Thus, we chose the more conservative ranking approach because it is more likely to be stable and to generalize to other situations.

Results

Overview of the data

We caught a total of 1587 individuals which could be identified to one of 148 species with representatives from 79 genera and 22 families. Around 67% percent (1069) of the individuals and 65% (97) of the species were saproxylic. Of these saproxylics, 79% (843) of the individuals and 56% (54) of the species are classified as obligate saproxylics. The 226 individuals and 43 species of facultative saproxylic beetles found thus constituted 21% of the saproxylic individuals and 44% of the species.

Comparison of lower and upper sieving samples

Surprisingly, the total number of individuals was similar for lower and upper sieving samples ($F = 0.05$, $p = 0.819$, $R^2 = 0.002$; Fig. 2), indicating that the traditional sieving approach captures only about half the beetles present. The pattern was the same for saproxylic and obligate saproxylic individuals ($F = 0.07$, $p = 0.790$, $R^2 = 0.003$ and $F = 0.15$, $p = 0.703$, $R^2 = 0.005$, respectively; Fig 2) while the number of facultative saproxylic individuals was significantly higher in the lower sample compared to the upper ($F = 4.31$, $p = 0.047$, $R^2 = 0.133$; Fig. 2)

The mean number of species, saproxylic species, facultative saproxylic species and Staphylinidae species per trap, were significantly greater in the lower samples than in the upper samples ($F = 6.29$, $p = 0.018$, $R^2 = 0.183$; $F = 5.46$, $p = 0.027$, $R^2 = 0.163$; $F = 5.97$, $p = 0.021$, $R^2 = 0.176$; $F = 5.15$, $p = 0.031$, $R^2 = 0.155$, respectively; Fig. 2).

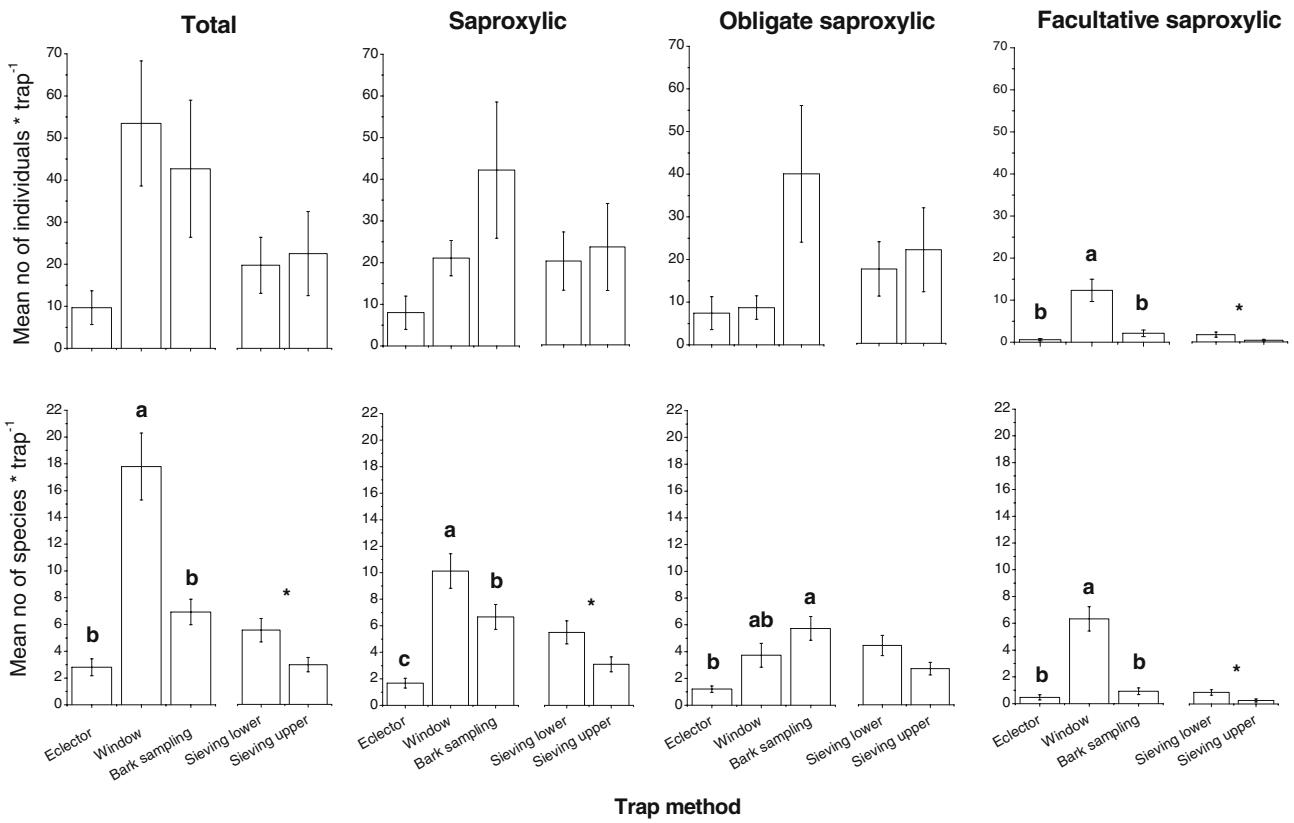


Fig. 2 Mean abundance and number of species for all, saproxylic, obligate saproxylic and facultative saproxylic beetles caught with eclector traps, window traps, bark samples, lower sieving samples, and upper sieving samples on spruce logs in Långrumpskogen, Västerbotten, Sweden. Columns represent mean values per trap ± SE, means calculated on the pooled values of three catching periods (July to October) for each log ($N = 15$) and method, respectively. Unequal letters above the bars for eclector, window and bark sampling show significant differences between the methods (Tukey test, $N = 15$) and star above the bars for lower and upper sieving samples show significant difference (ANOVA, $N = 15$)

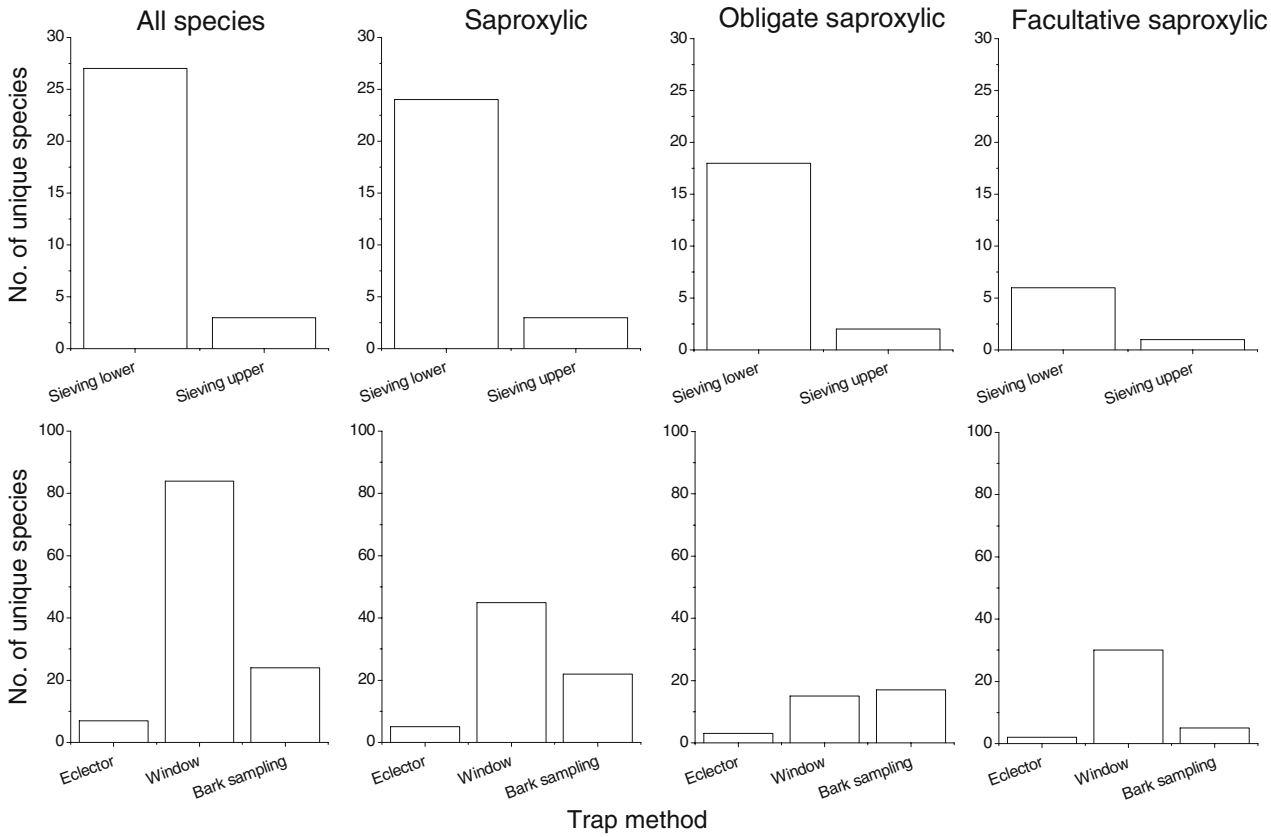


Fig. 3 The number of unique species, species caught with only one method, for different sampling methods. The upper row shows comparison between lower and upper sieving samples. The lower row shows comparison between eclector traps, window traps and bark samples

Twenty-seven of the 44 species (61%) caught by sieving were unique to the lower samples (Fig. 3). Also more unique saproxylics, obligate saproxylics and facultative saproxylics species were found in lower than upper samples (Fig. 3). Only 3 unique species (*Phloeonomus pusillus* (Grav.) 0.27 ± 0.18 (mean ± 1 SE), *Atheta myrmecobia* (Kraatz) 0.02 ± 0.02 and *Cryptur-gus cinereus* (Herbst) 0.02 ± 0.02) were found in the upper samples, i.e. these species did not pass the sieving net even after shaking for 5 minutes. Although a high proportion of the species were only found in the lower samples, the similarity between the lower and upper samples with respect to species was rather high ranging from 0.364 to 0.591 (Fig. 4; Sørenson index). Obligate saproxylic species were most similar, closely followed by saproxylics and all species while facultative saproxylics were less similar (Fig. 4).

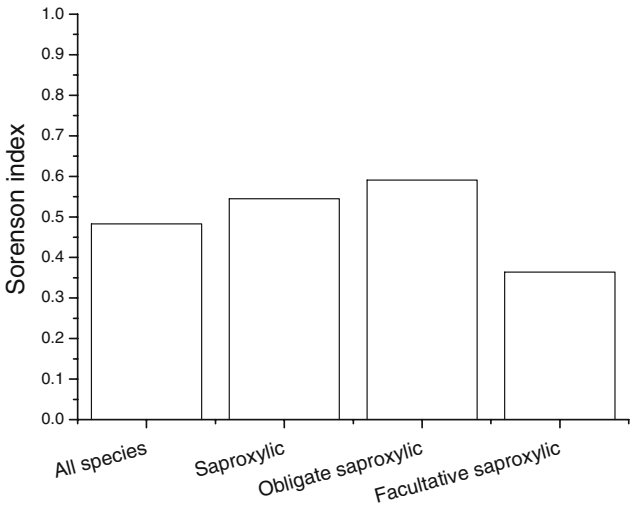


Fig. 4 Species similarity between lower and upper sieving samples as measured with Sørenson index for all species and species in different functional groups

Because almost half of the individuals did not pass through the mesh and would have been missed with traditional sieving, and also because unique species were found in the upper sieving samples which are normally discarded, we chose not to treat the sieving method in the conventional way, i.e. only using the lower part of the samples. Instead we pooled the upper and lower parts into a joint sample. This joint sample (hereafter ''bark sampling'') corresponds to a whole

bark sample (i.e. omitting the sieving step in traditional sieving) and was subsequently compared to the eclector and window methods.

Comparison of eclector, window and bark sampling

Mean number of species and individuals per trap

The number of species, saproxylic species, obligate saproxylic species and facultative saproxylic species per sample differed among methods (Table 1). The window trap method caught significantly more species per sample than eclector traps or bark sampling (Fig. 2, Table 1). The number of saproxylic species differed significantly among all three methods, window traps having the highest number followed by bark sampling and eclector traps (Fig. 2, Table 1). Bark sampling had significantly more obligate saproxylic species than eclector traps (Fig. 2, Table 1). Window traps had significantly higher number of facultative saproxylic species per sample than both eclector and bark sampling (Fig. 2, Table 1).

In the window traps a large proportion of the beetles (41%; 47 species) were non-saproxylic compared to eclector traps 35% (10 species) and bark sampling 5% (2 species). Most importantly, a high proportion of the saproxylic beetles in the eclector and bark sampling, 74 and 79%, respectively, were obligate saproxylics whereas for window traps this group constituted only 47% with the remaining 53% being facultative saproxylics.

The number of species per sample within the families Carabidae, Curculionidae, Leiodidae, Monotomidae, Nitidulidae and Staphylinidae were significantly affected by method (Table 1). Window trapping had significantly more species of Carabidae, Leiodidae and Staphylinidae than both eclector and bark sampling (Table 1). The window method also caught more

Table 1 Comparision of trapping methods tested at Långrumpskogen nature reserve, Västerbotten, Sweden

Variable	No. of individuals						No. of species					
	Anova			Tukey test			Anova			Tukey test		
	F-value	*p*	R^2	W	E	B	*F*-value	*p*	R^2	W	E	B
All	3.11	0.055	0.129				**24.06**	**<0.001**	**0.534**	**a**	b	*b*
Saproxylics	2.97	0.062	0.124				**20.15**	**<0.001**	**0.490**	**a**	c	*b*
Obligate saproxylic	**3.67**	**0.034**	**0.149**	a	*a*	**a**	**9.45**	**<0.001**	**0.310**	*ab*	b	**a**
Facultative saproxylic	**15.54**	**<0.001**	**0.425**	**a**	b	*b*	**35.53**	**<0.001**	**0.622**	**a**	b	*b*
Families												
Carabidae	**5.91**	**0.005**	**0.220**	**a**	*b*	b	**12.52**	**<0.001**	**0.373**	**a**	*b*	b
Curculionidae	2.86	0.069	0.120				**3.40**	**0.043**	**0.139**	*ab*	b	**a**
Leiodidae	**7.45**	**0.002**	**0.261**	**a**	*b*	b	**15.18**	**<0.001**	**0.419**	**a**	*b*	b
Monotomidae	2.06	0.141	0.089				**4.00**	**0.024**	**0.160**	**a**	b	*ab*
Nitidulidae	2.85	0.069	0.119				**4.20**	**0.022**	**0.167**	**a**	b	*ab*
Staphylinidae	**6.18**	**0.004**	**0.227**	**a**	b	*b*	**20.94**	**<0.001**	**0.499**	**a**	b	*b*
Species												
Calathus micropterus	**4.92**	**0.012**	**0.190**	**a**	*b*	*b*						
Crypturgus pusillus	2.62	0.085	0.111									
Dryocoetes hectographus	**5.62**	**0.007**	**0.211**	*b*	*b*	**a**						
Hylurgops glabratus	0.34	0.712	0.016									
H. palliatus	0.21	0.808	0.010									
Polygraphus poligraphus	0.44	0.648	0.020									
Anisotoma humeralis	2.94	0.064	0.123									
Rhizophagus dispar	2.06	0.141	0.089									
Atheta aeneipennis	**5.79**	**0.006**	**0.216**	**a**	*b*	*b*						
Autulia impressa	**5.53**	**0.007**	**0.208**	**a**	*b*	*b*						
Leptusa pulchella	**15.81**	**<0.001**	**0.429**	*b*	b	**a**						
Phloeonomus sjoebergi	1.81	0.177	0.079									
Proteinus brachypterus	**5.18**	**0.010**	**0.198**	**a**	*b*	*b*						
Quedius tenellus	3.00	0.060	0.125									
Tachinus laticollis	2.93	0.064	0.122									
T. pallipes	**3.81**	**0.030**	**0.154**	**a**	*ab*	b						

One-way Anova ($N = 45$) to test for differences among Window traps (W), Eclector traps (E) and Bark sampling (B) and post-hoc Tukey-test (to determine which trap method differed from other method(s); Pair-wise comparison $N = 15$) for the number of all individual coleoptera and species, and divided into different functional groups, families and species. Only families and species which were found in 15 individuals or more are presented. Trap types with unequal letters are significantly different by the Tukey test; a **bold** letter shows the trap type with the highest no of individuals/no of species, italic the second highest

species per sample of Monotomidae and Nitidulidae than eclector traps. Bark sampling had significantly more Curculionidae species than Eclector traps (Table 1).

The ANOVA revealed that method significantly affected only the number of obligate and facultative saproxylic individuals per trap, but a subsequent (conservative) Tukey test indicated only a significant pair-wise difference between the numbers of facultative saproxylic individuals being higher in window traps vs. eclector traps and bark sampling (Fig. 2, Table 1).

The trapping methods also differed with respect to their composition of individual coleoptera. Only 39% of the individuals in window traps were saproxylic while (as expected) saproxylic individuals dominated the eclector traps and bark sampling (83% and 99% of the individuals, respectively). In both eclector traps and bark sampling obligate saproxylics constituted 93% and 95%, respectively, of the saproxylic individuals. In contrast, obligate saproxylics only constituted 41% of the saproxylic individuals in the window traps and facultative saproxylic individuals dominated the total catch.

Method significantly affected the abundance of the families Carabidae, Leiodidae and Staphylinidae and the window traps had a significantly higher abundance of these families compared to both eclector and bark sampling (Table 1, Appendix 1).

Of the 148 species captured in total, sixteen were found in abundance equal to or higher than 15 individuals and ANOVA revealed a significant effect of trapping method for seven of these (Table 1, Appendix 1). Compared to both the eclector and window methods, bark sampling detected significantly more *Dryocoetes hectographus* and *Leptusa pulchella*. Window traps caught more individuals of *Calathus micropterus*, *Atheta aenipennis*, *Autulia impressa*, and *Proteinus brachypterus* compared to both the eclector and bark sampling (Table 1, Appendix 1). The window method also caught significantly more *Tachinus pallipes* than bark sampling (Table 1, Appendix 1).

Number of unique species

Window traps caught the most unique species (i.e. species not caught by any other method) followed by bark sampling and then eclector traps (Fig. 3). A similar pattern was found for unique saproxylic species (Fig. 3). The number of unique obligate saproxylic species was almost equal for window traps and bark sampling while eclector traps had very few unique obligate saproxylic species (Fig. 3). Interestingly, window traps had more unique facultative saproxylic species than both bark sampling and eclector traps (Fig. 3).

Similarity

Of the 148 beetle species caught in total, only 22% (33 species) were caught by two or three methods, suggesting that the methods were indeed sampling the beetle community rather differently. The similarities between the methods with respect to all species were all below 0.300 (Sørenson index) and was highest between eclector and window traps (Fig. 5). With respect to the target group of saproxylic species, 26% were caught by two or three of the methods. The greatest similarity was found between window traps and bark sampling while eclector traps and bark sampling had the lowest similarity. Even though the number of common obligate saproxylic species, 19 species, was lower compared to all species and saproxylics, they constituted 35% of the joint obligate saproxylic species caught by all three methods. The similarity values for the obligate saproxylics are also notably higher than

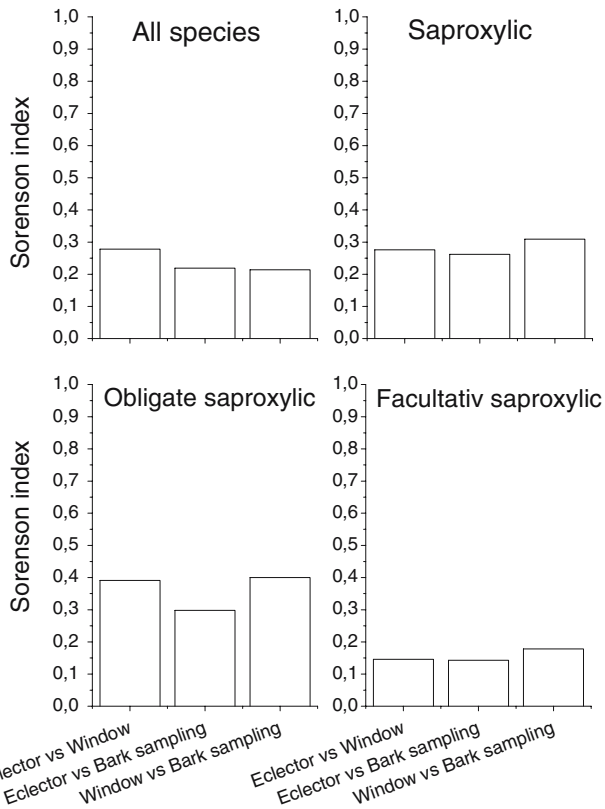


Fig. 5 Species similarity between eclector traps, window traps and bark samples as measured with Sørenson index for all species and species in different functional groups

Table 2 Dominant families, genera and species in eclector and window traps, and sieving samples applied on 15 logs in Långrumpskogen, Västerbotten, Sweden

		Method		
		Eclector	Window	Bark sampling
No. of species				
Family	Carabidae		6%(7)	
	Curculionidae	31%(9)	11%(13)	23%(10)
	Leiodidae		11%(13)	
	Staphylinidae	28%(8)	52%(60)	43%(19)
Abundance				
Family	Carabidae		8%(65)	
	Cuculionidae	69%(100)	6%(51)	74%(474)
	Leiodidae		12%(97)	
	Staphylinidae	18%(26)	67%(536)	18%(112)
Genera	Calathus		7%(54)	
	Crypturgus			56%(356)
	Dryocoetes			7%(42)
	Hylurgops	54%(78)		8%(50)
	Polygraphus	8%(12)		
	Anisotoma		6%(50)	
	Catops		5%(36)	
	Atheta		10%(79)	
	Leptusa			7%(44)
	Phleonemus			6%(36)
	Proteinus		6%(46)	
	Tachinus	10%(14)	34%(272)	
Species	*Calathus micropterus*		7%(34)	
	Crypturgus pusillus			55%(355)
	Dryocoetes hectographus			5%(35)
	Hylurgops glabratus	30%(43)		
	H. palliatus	24%(35)		5%(30)
	Polygraphus poligraphus	8%(12)		
	Anisotoma humeralis		5%(41)	
	Leptusa pulchella			7%(43)
	Proteinus brachypterus		6%(46)	
	Tachinus pallipes	8%(12)	30%(245)	

Values are given as proportion of total number of species or individuals caught with each method, respectively, and in parenthesis the actual number of species or individuals

for the other categories (Fig. 5). Window traps were more similar to both eclector and bark sampling than eclector to bark sampling. Only 6 (14%) of the 43 facultative saproxylic species were caught by two or three of the methods. Correspondingly, the similarity between the methods was lowest for this functional group and the highest similarity was found between window and bark sampling (Fig. 5).

Dominant families

With respect to number of ***species***, four families dominated. Staphylinidae were dominant in all three methods while Curculionidae were also rather dominant in eclector traps (Table 2). With respect to ***abundance***, Staphylinidae dominated in the window traps and Curculionidae dominated eclector and bark sampling (Table 2).

At the genus level, *Hylurgops* dominated in eclector traps, *Tachinus* in window traps and *Crypturgus* in bark sampling. At the species level, *Hylurgops glabratus* and *H. palliatus* dominated the eclector traps. In the window traps *Tachinus pallipes* dominated. *Crypturgus pusillus* was the single dominant species in the bark sampling (Table 2).

Other aspects of efficiency

There are several other aspects that may influence the choice of collecting method (Table 3). Eclector traps were the most efficient overall if all criteria in Table 3 are weighted equally—researchers must of course themselves determine which factors are most important to them (cost, limited time during the field season, etc.). Clearly, for eclector traps, setup is time consuming but other subsequent parts of the sampling process are very efficient compared to the other methods (Table 3). For example, once the eclector traps are set up, samples are rapidly collected, the traps are not sensitive to weather, and material costs and time demands in the laboratory are low. We found that the material costs and time for constructing window traps as well as application time in the field was lower than for eclector traps, but sampling in the field was

Table 3 Efficiency measures of the methods used in the study other than catches of beetles

The methods are ranked in relation to each other and the ranking is based on experience from the study. Low rank corresponds to high efficiency, i.e. low cost, least time, low sensibility, etc

Variable	Method		
	Eclector	Window	Bark sampling
Material costs	3	2	1
Construction time prior to field	3	2	1
Application and construction in field	3	2	1
Sampling in field	1	2	3
Sensibility to weather conditions	1	2	3
Material costs in laboratory	1	2	3
Sorting time	1	3	2
Determination time	1	3	2
Sum	14	18	16

slower, and much more time to process sampling in the lab meant that window traps were ranked as the least efficient of the three methods (Table 3). Bark sampling was ranked intermediate because it required considerably longer sampling time in the field, was sensitive to weather, and required considerable material costs and time in the laboratory (Table 3).

Discussion

The efficiency of a trapping method should of course always be evaluated in relation to the hypothesis to be tested. Often the method catching the most individuals and/or species richness is considered the most efficient but other aspects like specimens per trap and costs for handling, sorting, determination, etc., should also be considered.

Sieving

Sieving is a traditional and common method in studies of saproxylic beetles. Our value of 2.5 saproxylic species per m^2 bark sampled is higher than corresponding values of earlier studies (Wikars et al. 2005 1.1 species per m^2; Siitonen 1994 0.7 and 1.2 species per m^2). Even with our higher-than-average result for sieving, we still found that it missed so many beetles that our conclusions regarding the relatively poor performance of sieving are very likely to be a general pattern.

There could be several reasons for this. The drying out process in the Tullgren funnel will also force out beetles both from the softer inner bark as well as the hard inner bark, while traditional sieving only captures beetles from soft bark. Compared to other studies, our high capture rate is consistent with the idea that our implementation of the traditional bark sieving technique was quite good (recall that this method is difficult to standardize among observers). Thus, the fact that we doubled the capture of beetles by combining the upper and lower samples (i.e. using whole bark samples) over our already high capture rate using traditional sieving (i.e. just using the lower sample), suggests that other studies might experience even greater improvements. We thus recommend that instead of sieving the bark samples in the field (i.e. traditional sieving), researchers take whole bark samples back to the lab and treat them in a Tullgren funnel because about twice as many individuals will be detected. Leaving out the sieving step in the field would also reduce field time and make the method less weather dependent. Furthermore, even though both whole bark samples and traditional sieving are forms of destructive sampling, taking whole bark samples and extracting them in a Tullgren funnel seems more ethical because it provides maximum information from this destroyed dead wood habitat. For these reasons, we used the improved bark sampling technique, i.e. taking whole bark samples, in the preceding comparison with eclector and window traps.

Comparison between eclector traps, window traps and bark sampling

In accordance with earlier studies we found that window trapping yielded more individuals and species, although many are not saproxylic and thus often not the focus of interest (Økland 1996; Bakke 1999; Schiegg et al. 1999; Schiegg 2000; Ranius and Jansson 2002; Wikars et al. 2005).

Bark sampling caught more saproxylic and obligate saproxylic individuals than window traps, and in our study bark sampling and window traps caught an equal number of obligate saproxylic species. Compared to window traps, Wikars et al. (2005) also found that sieving yielded many more individuals of saproxylic and obligate saproxylic beetles but fewer species of these groups. Also in agreement with earlier studies (Økland 1996; Schiegg et al. 1999; Schiegg 2000; Wikars et al. 2005) we found that eclector traps yielded low numbers of individuals and beetle species.

There are, however, more than one kind of eclector trap, and they may give different results. Wikars et al. (2005) used ex situ traps (i.e. a piece of the log was cut off and enclosed) while Økland (1996) and our study used in situ traps (i.e. a piece of the log was enclosed). We are unaware of any study which compares the two types of eclector traps on the same dead wood substrates. Finally, in choosing between eclector trap alternatives, it is important to note that the ex situ method is a form of destructive sampling, whereas the in situ method that we employed is non-destructive and thus suitable for long-term studies in which the same dead wood object must be sampled over time, or in situations where the researcher must avoid any destruction of dead wood.

Our window traps contained many species that were not found in either eclector traps or bark sampling. Although a large proportion of these species unique to window traps were not saproxylic (a clear disadvantage because these non-targets increase sorting time in the lab), window traps still contained over 40 saproxylic species not caught by the other methods (indicating an important and useful role for window traps in estimating the species pool in an area; see also Økland 1996). Bark sampling also contained many saproxylic species not caught by other methods (mainly obligate saproxylics) while eclector traps contained very few unique species. The similarity (as measured with the Sørenson index) between the trapping methods was generally low, indicating that methods sampled the beetle community differently. The greatest similarity was found for saproxylic species, but in contrast to Wikars et al. (2005), we found the lowest similarity for saproxylic species between eclector traps and bark sampling. One reason for this low similarity in our study may be that 47% of the saproxylic beetles caught with eclector traps lived inside the wood compared to 30% of the saproxylics caught in the sieving sampling.

Surprisingly consistent patterns regarding the proportion of beetle groups (e.g. obligate or facultative saproxylics) emerged when we compared our data with reanalyzed data from previous studies (Økland 1996; Svedrup-Thygesen 2002; Wikars et al. 2005). In window traps the proportion of saproxylic species varied only between 59% and 64% (Økland 1996; Svedrup-Thygesen 2002; Wikars et al. 2005, our study). In sieving or bark sampling the proportion of saproxylic species was much higher but still within a surprisingly narrow range (81–95%; Wikars et al. 2005, our study). For in situ eclector traps the proportion ranged only between 62.5% and 65% (Økland 1996, our study). Obligate saproxylics represented 58–75% of the species caught in bark sampling, 48–70% in eclector traps and only 28–49% in window traps (Økland 1996; Wikars et al. 2005, our analysis). Thus, considering all coleoptera, bark sampling and eclector traps were more efficient in catching saproxylics and obligate saproxylics than window traps.

Even though that two families Curculionidae and Staphylinidae were either dominant or subdominant with respect to the number of species and individuals in the three methods there were some clear differences among the methods. Window traps were superior for catching Staphylinids compared to both eclector traps and bark sampling. This result is consistent with results from Økland (1996) and Wikars et al. (2005). Like Wikars et al. (2005), we found that curculionids were caught in greater numbers by eclector traps and bark sampling than window traps. In contrast, window traps and bark sampling yield more curculionid *species* than eclector traps (Økland 1996; Wikars et al. 2005, our results). Consistent with earlier studies (Kaila et al. 1994; Økland 1996; Wikars et al. 2005) we found that window traps detected more species and individuals of Leiodidae than both eclector traps and bark sampling. Species within the families Staphylinidae and Leiodidae are highly mobile, a characteristic which may contribute to their high numbers in window traps (Hammond 1997; Martikainen et al. 1999; Scheigg et al. 1999).

In our study the abundance of curculionids in bark sampling was caused by the genus *Crypturgus*, especially *C. pusillus*, and *Dryocoetes hectographus*. In our eclector traps, the high abundance of curculionids was caused by *Hylurgops* (*H. glabratus* and *H. palliatus*) and *Polygraphus* (*P. poligraphus*). Like previous studies (Kaila et al. 1994; Økland 1996; Wikars et al. 2005), our analysis reveals that the genus *Anisotoma*, especially *A. humeralis*, and *Catops* had high species richness and abundance in window traps.

Even though the Staphylinidae was a dominant family in all three sampling methods, we found significant differences in composition among the methods. Both species richness and abundance of *Atheta* and *Tachinus*, and abundance of *T. pallipes*, were significantly higher in window traps compared to both eclector traps and bark sampling, in agreement with Wikars et al. (2005). Bark sampling had significantly more species, more individuals of *Leptusa*, and more *L. pulchella* than eclector and window traps.

Our study reveals clear differences among eclector traps, window traps and bark sampling. Window traps had more individuals and species, but a large proportion were non-saproxylic. In contrast, a large proportion of the beetles caught by eclector traps and bark sampling were saproxylic. A further difference was that obligate saproxylics dominated in eclector traps and

bark sampling while obligate and facultative saproxylic had an almost equal proportion in window traps. Highly mobile beetles represented by species within the families Staphylinidae and Leiodidae dominated in window traps while species within the family Curculionidae dominated in eclector traps and bark sampling. Also, the beetle community sampled by eclector traps and bark sampling is somewhat different as indicated by the low similarity of saproxylic species that our analysis revealed—recall that 47% of the saproxylic beetles caught by eclector traps lived inside the wood, compared to 30% in sieving sampling.

Conclusions

Our analysis of beetles from the upper and lower sieving samples revealed that traditional sieving seriously underestimates the abundance of beetles (half of the individuals are missed if bark is sieved in the field) and to some extent also the number of species (three species were unique to the upper sieving sample). We therefore recommend whole bark samples be taken back to the lab for treatment in Tullgren funnels. By eliminating the sieving of samples, this will make the field sampling faster, less weather and operator sensitive, and more ethically defendable because it maximizes information from each bark sample which is inevitably destroyed.

The choice of sampling method must always be determined by the aim of the study. The high number of species and individuals caught by window traps makes them suitable for monitoring and comparing forest habitats by catching both predominantly mobile saproxylic and nonsaproxylic beetle species (e.g. Kaila 1993; Økland 1996; Hammond 1997; Backe 1999; Martikainen et al. 1999; Scheigg et al. 1999; Wikars et al. 2005 and our study). We suggest that eclector traps and bark sampling are more favourable for dead wood oriented studies per se because they catch higher proportions of saproxylic beetles, and they can be applied to specific dead wood objects with a high certainty that the beetles originate from this particular substrate (e.g. Wikars et al. 2005 and our study). However, we wish to point out the advantage of complementing window traps (which shows the fauna attracted to, or at least present around, the dead wood), with eclector traps (which shows which beetles can actually complete their development within these specific substrates and then successfully emerge). In the choice between eclector and bark sampling, we suggest that eclector traps may be preferable because our analysis reveal that they better sample the whole assemblage of saproxylic beetles including those living inside the wood per se (see also Wikars et al. 2005). Furthermore, eclector traps show that a given species can complete its life cycle inside the dead wood and successfully emerge, whereas bark sampling provides only a momentary snapshot during this process. Other aspects of sampling should not be ignored. For example, both bark/sieving sampling and ex situ eclector traps (see Wikars et al. 2005) are destructive and less suitable in long term studies than window traps or in situ eclector traps. A large sampling effort with window traps or bark sampling will result in much tedious sorting and determination work in the laboratory compared to eclector traps which, on the other hand, take longer to apply in the field. All these aspects have to be weighed and judged against the central aim of a study when deciding on a sampling method. Overall though, we suggest that for many studies a combination of the two best methods would be highly complementary: window traps reveal the species pool in a geographic area (and thus potential colonizers), while eclector traps reveal which species can complete their life cycle and successfully emerge from the dead wood.

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Appendix

Table 4 Mean number of family and species abundance ± 1 SE, only families and species for which we captured at least 15 individuals are presented

Family/Species	Family	Eclector		Window		Bark sampling		Sieving lower		Sieving upper	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Carabidae		0.27	0.21	4.33	1.72						
Curculionidae		6.67	3.93	3.40	1.34	31.60	15.25	12.33	5.85	19.27	9.83
Leiodidae		0.40	0.21	6.47	2.28	0.07	0.07				

Table 4 continued

Family/Species	Family	Eclector		Window		Bark sampling		Sieving lower		Sieving upper	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Monotomidae				0.60	0.23	1.40	0.81	1.33	0.64	0.27	0.18
Nitidulidae				0.80	0.35	0.33	0.21	0.33	0.21		
Staphylinidae		1.73	0.71	35.73	12.52	7.47	1.89	4.53	1.05	2.93	1.03
Calathus micropterus	Carabidae			3.60	1.62						
Crypturgus pusillus	Curculionidae	0.07	0.07	0.27	0.21	23.67	14.53	7.27	5.35	16.40	9.59
Dryocoetes hectographus	Curculionidae	0.13	0.09	0.13	0.09	2.33	0.92	1.27	0.64	1.07	0.37
Hylurgops glabratus	Curculionidae	2.87	2.80	0.87	0.68	1.33	1.14	0.93	0.75	0.40	0.40
Hylurgops palliatus	Curculionidae	2.33	2.19	0.80	0.54	2.00	2.00	1.40	1.40	0.60	0.60
Polygraphus poligraphus	Curculionidae	0.80	0.80	0.27	0.18	1.33	1.13	0.87	0.67	0.47	0.47
Anisotoma humeralis	Leiodidae	0.20	0.20	2.73	1.53						
Rhizophagus dispar	Monotomidae			0.60	0.23	1.40	0.81	1.13	0.64	0.27	0.18
Atheta *aeneipennis*	Staphylinidae			2.07	0.86						
Autalia impressa	Staphylinidae			1.00	0.42						
Leptusa pulchella	Staphylinidae			0.07	0.07	2.87	0.71	1.80	0.51	1.07	0.28
Phloeonomus sjoebergi	Staphylinidae			0.13	0.13	1.53	1.09	0.87	0.73	0.67	0.41
Proteinus brachypterus	Staphylinidae			3.06	1.35						
Quedius tenellus	Staphylinidae	0.33	0.19	1.47	0.72	0.07	0.07	0.07	0.07		
Tachinus laticollis	Staphylinidae	0.13	0.13	1.07	0.57						
Tachinus pallipes	Staphylinidae	0.80	0.33	16.33	8.16						

References

Albrecht L (1990) Grundlagen, Ziele und Methodik der Wald-ökologischen Forschung in Naturwaldreservaten. Naturwaldreservate in Bayern, Schreitenreihe 1:1–220 [In German]

Atlegrim O, Sjöberg K (2004) Selective felling as a potential tool for maintaining biodiversity in managed forests. Biodivers Conserv 13:1123–33

Bakke A (1999) High diversity of saproxylic beetles in a hemiboreal mixed forest reserve in the south of Norway. Scand J For Res 14:199–208

Dahlberg A, Stokland JN (2004) Vedlevande arters krav på substrat – sammanställning och analys av 3600 arter. Skogsstyrelsen, Jönlöping [In Swedish]

Gibb H, Ball JP, Johansson T, Atlegrim O, Hjältén J, Danell K (2005) Effects of management on coarse woody debris volume and composition in boreal forests in northern Sweden. Scand J For Res 20:213–222

Hammond HEJ (1997) Arthropod biodiversity from Populus coarse woody material in north-central Alberta – a review of taxa and collection methods. Can Entomol 129:1009–33

Johansson T, Gibb H, Hilszczanski J, Pettersson RB, Hjältén J, Atlegrim O, Ball JP, Danell K (2006) Conservation-oriented manipulations of coarse woody debris affect their value as habitat for spruce-infesting bark and ambrosia beetles (Coleoptera: Scolytinae) in Northern Sweden. Can J For Res 36: 174–185

Kaila L (1993) A new method for collecting quantitative samples of insects associated with decaying wood or wood fungi. Ent Fenn 4:21–23

Kaila L, Martikainen P, Punttila P, Yakovlev E (1994) Saproxylic beetles (Coleoptera) on dead birch trunks decayed by different polypore species. Ann Zool Fenn 31:97–107

Larsson S, Danell K (2001) Science and the management of boreal forest diversity. Scand J For Res Suppl 3:5–9

Magurran AE (1988) Ecological diversity and its measurement. Chapman and Hall, London

Martikainen P, Siitonen J, Kaila L, Punttila P, Rauh J (1999) Bark beetles (Coleoptera, Scolytidae) and associated beetle species in mature managed and old-growth boreal forests in southern Finland. For Ecol Manage 116:233–245

Nilsson SG, Hedin J, Nicklasson M (2001) Biodiversity and its assessment in boreal and nemoral forests. Scand J For Res Suppl 3:10–26

Økland B (1996) A comparison of three methods of trapping saproxylic beetles. Eur J Entomol 93:195–209

Palm T (1951) Die Holz- und Rinden-käfer der nordschwedischen Laubbäume. Medd St Skogsforsk Inst 40:1–242

Palm T. (1959) Die Holz- und Rinden-käfer der sud und mittelschwedischen Laubbäume. Opusc Entomol Suppl 16:1–420

Ranius T, Jansson N (2002) A comparison of three methods to survey saproxylic beetles in hollow oaks. Biodivers Conserv 11:1759–1771

Saalas U (1917) Die Fichtenkäfer Finlands I. Ann Acad Sci Fenn (A) 8:1–566

Scheigg K (2000) Effects of dead wood colume and connectivity on saproxylic insect species diversity. Ecoscience 7:290–298

Scheigg K, Obrist M, Duelli P, Merz B, Ewald KC (1999) Diptera and coleoptera collected in the forest reserve Sihlwald ZH. Mitt Schweizer Entomol Gesellschaft 72:289–302

Schmitt M (1992) Buchen-Totholz als lebensraum für xylobionte Käfer. Waldhygiene 19:97–191

Siitonen J (1994) Decaying wood and saproxylic Coleoptera in two old spruce forests: a comparison based on two sampling methods. Ann Zool Fenn 31:89–95

Siitonen J (2001) Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecol Bull 49:11–41

Söderström L (1988) Sequence of bryophytes and lichens in relation to substrate variables of decaying coniferous wood in northern Sweden. Nord J Bot 8:89–97

Speight MCD (1989) Saproxylic invertebrates and their conservation. Saproxylic invertebrates and their conservation 42:1, Nature and Environmental Series, Strasbourg, 81 pp

Svedrup-Thygeson A (2002) Key habitats in the Norwegian production forest: a case study. Scand J For Res 17:166–178

Tabachnik BG, Fidell LS (2001) Using multivariate statistics, 4th edn. Allyn and Bacon, Needham Heights, MA

Underwood AJ (1997) Experiments in ecology: Their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge

Wikars LO, Sahlin E, Ranius T (2005) A comparison of three methods to estimate species richness of saproxylic beetles in logs and high stumps of Norway spruce. Can Ent 137:304–324