Risk of Bark Beetle (Coleoptera, Scolytidae) Damage in a Spruce Forest Restoration Area in Central Finland

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A beetle inventory using window traps was performed to examine the effect of forest restoration by artificial addition of dead wood on the abundance of beetles and to evaluate the risk of bark beetle damage in a forest restoration area. The number of beetle families was slightly increased, but no consistent differences were found in the abundance of families containing saproxylic Coleoptera between the restoration and control plots. The abundance and species number of bark beetles and longhorn beetles were significantly higher on the restoration plots. *Ips typographus* and *Pityogenes chalcographus* increased only slightly in abundance. In the regression models produced, the abundance of bark beetles was best explained by the volume of recently dead wood. However, the bark beetle species whose abundance increased most were secondary and the material also suggests an increase in the abundance of bark beetles' natural enemies. The risk of bark beetle damage in the area is thus considered insignificant.

Keywords biodiversity, dead wood, forest pests, forest restoration, damage
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1 Introduction

In a managed forest, the amount of dead wood is significantly lower than in a natural forest both at the stand and landscape level. According to e.g. Siitonen et al. (2000), the volume of dead wood in an old natural spruce forest can be almost tenfold compared with an old managed forest. The amount of dead wood has decreased especially during the 20th century: in the late 1800s the volume of dead wood in managed forests in central Sweden is estimated to have been 12–13 m^3/ha, but in the 1970s only 0–1 m^3/ha (Linder and Östlund 1992).

As a tree starts to senesce, various decomposing organisms, including insects and fungi, start to decompose it. Bark beetles (Coleoptera, Scolytidae) are among the first insect groups to attack a dead or weakened tree. Most of the species that have benefited from modern forestry are capable of reproducing in logging slash or timber storage sites and benefit of the warm climate of the clearings (Nuorteva 1968). Most bark beetle species are harmless to healthy living trees, but some, notably the spruce bark beetle *Ips typographus* (L.), can attack and kill healthy trees. *Pityogenes chalcographus* (L.) can also attack and kill trees, but it does not seem to threaten healthy trees (Hedgren 2004). Usually the abundance of *I. typographus* is low and the beetles only attack dead or weakened trees under stress from e.g. drought or fungi (Anderbrant et al. 1988). If this kind of material is abundant (e.g. following storm damage), the population may increase sufficiently to start an epidemic. In an epidemic situation, spruce bark beetles can overcome the resistance of healthy trees.

Extensive storm fellings in spruce forests almost inevitably result in outbreaks of *I. typographus*. In Finland, no major outbreaks have been recorded in the past 100 years. In Central Europe and Scandinavia, however, such outbreaks have occurred. Southern Sweden was hit by a severe storm in November 1995. The 1990's saw two major storm incidents in Central Europe: Vivian/Wiebke in February–March 1990 and Lothar in December 1999. An outbreak of *I. typographus* followed both storms, resulting in extensive bark beetle damage (Engesser et al. 2002, Schröter et al 2002). The global climate change is likely to affect bark beetle dynamics among other things (Wermelinger 2004).

The survival of saproxylic species negatively affected by forestry has received considerable attention in the past few years (Väisänen et al. 1993, Siitonen 1994, Martikainen et al. 2000). The development of a dead wood continuum characteristic of a natural forest may take several hundred years. Forest restoration, mainly by felling trees, has been suggested as a means to rapidly increase the amount of dead wood specifically in protected areas. Such methods have raised questions of risk of bark beetle damage inside and near protected areas. Though unmanaged spruce forests do not necessarily have higher *I. typographus* populations, after disturbances the populations are very likely to rise to epidemic levels (Schlyter and Lundgren 1993). After storm fellings, the adjacent stands too have suffered from the storm and are therefore more susceptible to bark beetle attack (Wermelinger 2004). After restoration measures, this factor is missing.

The objects of this study are to research for monitoring purposes the abundance of Coleoptera, mainly bark beetles, in a forest restoration area and to evaluate the risk of bark beetle damage caused by the restoration measures in the surrounding forests.

2 Materials and Methods

2.1 Site Description

The study area (a forest of 232 hectares owned by the town of Kuopio) is located southwest of Kuopio in central Finland (62º53'N 27º35'E) and is situated in the southern boreal zone. The forests of the study area are primarily herb-rich, spruce-dominated and over 80 years old. All of the area has been previously managed, but is now conserved.

Five square, approximately one-hectare study plots (A–E), were placed in the study area. All of the plots were situated in herb-rich spruce forest. Three plots (A–C) were study plots, where restoration operations were performed, and two (D–E) served as control plots. Plot A is in dense, spruce-dominated managed forest. Plot B is in old spruce-dominated managed forest on a herb-rich slope. In addition to spruce there are some birch, grey alder, aspen and several tall herbs in the field layer. Rot damage has been observed in the trees. Plot C is in spruce-dominated managed forest. Plot D is in old managed forest on a spruce-dominated herb-rich slope. The volume of dead wood is considerably higher than on the other plots. Plot E is in spruce-dominated managed forest, and the amount of dead wood was initially considered to be comparable with typical managed forest (hardly any dead wood).

All of the study plots were clearly spruce-dominated (Table 1). Total volume varied between 311 and 475 m^3/ha (average 377 m^3/ha) . Total volume and the volume of spruce were highest on

Table 1. Stand characteristics of the sample plots.

Plot	Pine	Spruce	Birch	Other	Total	Weighted mean*
Volume, m^3/ha						
A	0	389	0	0	389	
B	11	238	57	5	311	
C	21	252	66	11	350	
D	10	338	0	11	359	
E	0	410	65	0	475	
Basal area, m^2/ha						
A	0	34	0	0	34	
B	1	20	5	1	28	
C	2	22	6	1	31	
D	1	29	0	1	31	
E	0	30	5	0	35	
$D_{1,3}$, cm						
A	.	24	.	.		24
B	28	32	30	15		31
C	27	27	26	28		27
D	37	32	.	30		33
E	.	30	26	31		30
Height, m						
A	.	24	.	.		24
B	24	25	26	10		24
C	24	25	26	10		24
D	23	25	.	24		25
E	.	29	30	29		29
Age, a						
A	.	76	.	.		76
B	60	56	60	30		56
C	80	81	80	80		81
D	133	118	.	40		117
E	.	108	90	90		105

*Weighted mean, weighted by basal area
Class "other" consists of broadleaved trees except *Betula* spp.

plot E and lowest on plot B. The volume of birch was highest on plots C and E (66 and 65 m^3/ha, respectively), volume of pine on plot C (21 m^3/ha) and volume of other broadleaved trees (mainly aspen) on plots C and D (11 m^3/ha).

The median age of spruce varied between 56 and 118 years (Table 1). Median diameter at breast height (1.3 m, weighted by basal area) of spruce was 24–32 cm. The height of the median tree was 24–29 m. The forest on plot A was very dense (large basal area despite the smallest median diameter) compared with the other plots.

During autumn and winter 1999–2000 trees were felled using explosives and with a caterpillar in the study plots (A–C). On each plot there were four approximately 5 × 20 m strips where all trees were felled in the same direction either by using explosives (two strips) or with a caterpillar (two strips). The felled trees were mostly spruce, 10–12 trees on each strip. Explosives produce a splintered stump and stem (similar to a tree broken by strong wind), whereas a caterpillar produces an uprooted tree. Thus, both types were present in all of the study plots.

2.2 Dead Wood Measurements and Beetle Samples

The volume of dead trees was measured separately in the study plots and in their immediate vicinity in July–August of the first summer. On the study plots, the diameter at breast height (DBH) (or diameter (D) at 50% height of a trunk segment) and decay class of each dead tree were recorded. The volumes of the measured tree trunks were calculated using the volume functions based on DBH according to Laasasenaho (1982) for whole trunks and the volume function for a cylinder for trunk segments. In the immediate vicinity of the study plots, the volume of dead trees was measured from four relascope plots on each study plot separately for each tree species, decay class and according to whether the trees were standing or downed. The relascope method selects trees from several (an infinite number of) circle plots that vary in size relative to the size (DBH) of each tree (Philip 2002) The dead trees were classified visually and with the aid of a knife into five (downed trees) or three (standing trees) decay classes (Renvall 1995, field guide of the Finnish Forest and Park Service 1998, respectively). The classification was done based on the decay stage of bark and wood, plants growing on the stem etc. (Tables 2 and 3).

The beetle samples were collected with 20 window traps, 10 of which were in trees (tree traps) and 10 on the ground (ground traps). The tree traps consisted of a 3 × 200 × 300 mm clear acryl plastic sheet, a funnel and a plastic bottle filled approximately one-third with a solution of water, sea salt and detergent. The traps were attached to tree trunks by wedging the plastic sheet inside a split polypore. The ground traps

Table 2. Criteria for decay classification of downed trees (Renvall 1995).

Class	Description
1	Wood hard, a knife penetrates only a few mm. Bark more or less intact. Epiphytic flora chiefly the same as on standing, living trees.
2	Wood fairly hard, knife penetrates 1–2 cm. Pine trunks usually (mostly) decorticated, bark on spruce starting to break up. On pine often patches of epiphytic lichens, on spruce small patches of epixylic cryptogams may be found.
3	Wood fairly soft, usually with harder parts. Knife penetrates fairly easily ca. 3–5 cm; when lifted, crown of trunk usually breaks off. Pine trunks usually decorticated, spruce trunks usually still partly corticated. Pine trunks usually at least partly covered in *Cladonia* lichens, on spruce naked parts covered by a variety of epixylic lichens and bryophytes.
4	Wood soft, extensively decayed. Whole knife blade easily penetrates into wood; when lifted, trunk easily falls apart. Usually without bark or with only small patches left. Extensively covered by bryophytes and lichens (some typical forest floor species), sometimes also dwarf shrubs.
5	Wood very soft, almost completely decomposed. Disintegrates easily between fingers; whole trunk (or its remnants) shrunken, outer surface difficult to determine. Usually almost totally covered by forest floor cryptogams and/or dwarf shrubs, remnants of spruce often bearing seedlings.

Note: the topmost third of the stem is ignored in the classification

consisted of a 3×600×750 mm clear acryl plastic sheet, supported to the ground with 5 mm wire, and a plastic box filled approximately one-third with the same solution as in tree traps. The choice of trap type was made for a previous study that this study was designed to complement.

The traps were placed on the study plots in the beginning of May 2000. There were two tree and two ground traps on each plot, placed in the immediate vicinity of the felled trees. The location of suitable polypores limited the choice of locations for tree traps to some extent. The traps were emptied every two weeks during the summer until the end of September.

The beetles were identified at the species level (Scolytidae, Cerambycidae) or at the family level.

Table 3. Criteria for decay classification of standing dead trees (Finnish Forest and Park Service 1998).

Class	Description
1	Recently died tree, bark and branches not yet fallen off
2	Semi-decayed; on conifers bark partly or entirely fallen (often remnants of bark at the base), on broadleaved trees bark not fallen, but wood has started to soften, most branches have fallen
3	On conifers a dried snag, on broadleaved trees trunk softened, stands only supported by bark

The total catch was counted by trap, trap type, study plot and species/family. The effect of added dead wood (plots A–C versus plots D–E) to the relative abundance of beetles was tested using a relative proportions test and the effect to the number of beetles using a t-test for two independent samples.

The effect of adding dead wood to the abundance of bark beetles was also evaluated using regression models with one independent variable (the volume of dead wood per ha either in decay class 1 or all classes combined). When the dependent variable was the relative abundance of bark beetles, a logistic model was fitted to the data. When the dependent variable was the caught number of bark beetles, a logarithmic transformation was performed on both variables and a linear regression model was fitted to the transformed data.

3 Results

3.1 Dead Wood

The volumes of dead wood (m^3/ha) by study plot, tree species and decay class are presented in Table 4. The volume of dead wood varied between 1,1 and 38,3 m^3/ha. Dead wood was most abundant on plots A and B (38,3 m^3/ha and 34,3 m^3/ha, respectively) and the scarcest on plot E (1,1 m^3/ha). The majority (over 80% of volume) of dead wood was spruce on all plots. The biggest proportions of broadleaves and pine (17% and 2%, respectively) were found on plot C.

Table 4. Volume of dead wood (m^3/ha) on the sample plots.

Species	Decay class	A Total	A >30 cm	B Total	B >30 cm	C Total	C >30 cm	D Total	D >30 cm	E Total	E >30 cm
DOWNED TREES											
Spruce	1	35.2	9.3	19.7	12.7	18.5	10.5	0.5	0.0	0.6	0.0
	2	0.6	0.0	4.6	2.7	1.4	0.6	8.4	7.4	0.0	0.0
	3	1.0	0.0	2.0	0.9	0.4	0.0	4.7	3.7	0.0	0.0
	4	0.0	0.0	0.1	0.0	0.3	0.0	0.3	0.0	0.1	0.0
	5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	37.2	9.3	26.4	16.3	20.6	11.2	13.8	11.1	0.8	0.0
Pine	1	0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Broadleaved	1	0.0	0.0	1.1	0.7	4.1	3.1	0.1	0.0	0.0	0.0
	2	0.0	0.0	0.5	0.0	0.1	0.0	0.1	0.0	0.0	0.0
	3	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	4	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	2.0	0.7	4.3	3.1	0.2	0.0	0.0	0.0
Total	1	35.2	9.3	21.0	13.4	23.0	13.7	0.5	0.0	0.6	0.0
	2	0.6	0.0	5.0	2.7	1.6	0.6	8.4	7.4	0.0	0.0
	3	1.0	0.0	2.0	0.9	0.5	0.0	4.7	3.7	0.0	0.0
	4	0.0	0.0	0.4	0.0	0.3	0.0	0.3	0.0	0.1	0.0
	5	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	37.2	9.3	28.5	16.9	25.4	14.3	14.0	11.1	0.8	0.0
STANDING TREES											
Spruce	1	0.2	0.0	2.3	1.3	0.0	0.0	6.3	3.8	0.1	0.0
	2	0.9	0.0	3.0	2.4	1.0	0.0	2.2	0.8	0.1	0.0
	3	0.0	0.0	0.1	0.0	0.0	0.0	0.8	0.8	0.0	0.0
	Total	1.1	0.0	5.4	3.8	1.0	0.0	9.3	5.4	0.2	0.0
Pine	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Broadleaved	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	2	0.0	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.1	0.0
	3	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	0.0	0.0	0.4	0.0	0.3	0.0	0.1	0.0	0.1	0.0
Total	1	0.2	0.0	2.3	1.3	0.0	0.0	6.3	3.8	0.1	0.0
	2	0.9	0.0	3.2	2.4	1.4	0.0	2.3	0.8	0.3	0.0
	3	0.0	0.0	0.3	0.0	0.0	0.0	0.8	0.8	0.0	0.0
	Total	1.1	0.0	5.7	3.8	1.4	0.0	9.4	5.4	0.3	0.0
TOTAL											
Spruce		38.3	9.3	31.7	20.0	21.6	11.2	23.1	16.4	1.0	0.0
Pine		0.0	0.0	0.2	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Broadleaved		0.0	0.0	2.4	0.7	4.7	3.1	0.3	0.0	0.2	0.0
Total		38.3	9.3	34.3	20.7	26.8	14.3	23.4	16.4	1.1	0.0

On plots with added dead wood (A–C), the majority (73–95%) of downed dead wood belonged to the decay class 1 (due to the restoration measures). The decay class distribution was very similar on plot E, where the total volume, however, was very low. The decay class distribution on plot D was very different from the other plots: only 4% of downed dead tree volume belonged to class 1 and the majority was found in classes 2 (60%) and 3 (33%). Class 4 and 5 dead wood was (nearly) nonexistent on all plots.

Standing dead wood was distributed mainly in classes 1 and 2; the majority of volume (65–100%) was in class 2 on all plots except plot D, where class 1 accounted for 71% of volume. Standing dead wood belonging to decay class 3 was very scarce and only found on plots B (0,3 m^3/ha) and D (0,8 m^3/ha). Bark beetles did not appear to have been the primary cause of death in any of the standing dead trees.

Estimated volume of dead wood in the near vicinity of the study plots varied from 0 (on plots C and E) to 7,8 m^3 (plot B) per hectare. The relascope plots contained a total of 8 dead downed or standing trees. The estimate was 6,8 m^3/ha on plot A and 5,3 m^3/ha on plot D.

3.2 Coleoptera

A total of 22 429 individual beetles were counted from the samples. 4111 of these were caught with tree traps and 18 318 with ground traps. The mean number of individuals on a study plot was 4486; 5286 on plots with added dead wood (A–C) and 3313 on control plots (D–E). The difference is not statistically significant ($t = 1.766$, $df = 3$, $p > 0.1$). The mean number of beetle individuals caught with ground traps was 3664 (8142 per trapping m^2). On plots with added dead wood the number was 4432 (9849 per trapping m^2) and on control plots 2511 (5580 per trapping m^2). The tree traps caught an average of 822 individuals, 836 on plots with added dead wood and 802 on control plots (13 700, 13 933 and 13 367 per trapping m^2, respectively). The number of beetles caught in ground traps per trapping m^2 was thus 77% higher on plots with added dead wood than on control plots. For tree traps the difference was only 4%.

The caught number of beetle families was 50; 32 of these were found in both trap types, 11 only in ground traps and seven only in tree traps. 26 families were caught on all study plots. The most abundant families were Staphylinidae (7167 individuals), Nitidulidae (3879), Scolytidae (3409), Catopidae (2907) and Leiodidae (1160) (Table 5). Together these families constituted 82.6% of the total beetle count.

3.3 Scolytidae

A total of 3409 individual bark beetles were counted from the samples. 2398 of these were found in ground traps and 1011 in tree traps. The mean number of individuals was 901 on plots with added dead wood (A–C) and their mean proportion of all beetle individuals was 17.1%. On control plots the mean number was 354 and mean proportion 10.7%. The difference in mean proportions is statistically highly significant ($Z = 12.23$, $p < 0.001$) but the difference in numbers is not ($t = 0.974$, $df = 3$, $p > 0.1$). The number of caught bark beetle species was 21; 14 of these were found in both ground and tree traps, four in ground traps only and three in tree traps only.

The highest number of species (18) was caught on study plot A, the second highest (17) on plot C and the lowest number (11) on plot E. on plots B and D, 12 species were caught. The most abundant species were *Dryocoetes autographus* (Ratzeburg) (1563 individuals), *Hylurgops palliatus* (Gyllenhal) (598), *Trypodendron signatum* (Fabricius) (the only hardwood species caught) (430), *Hylastes cunicularius* (Erichson) (380) and *Trypodendron lineatum* (Olivier) (178) (Table 6). Together these five species constituted 14.0% of the total number of beetles and 92.4% of the total number of bark beetles.

D. autographus, *H. palliatus* and *H. cunicularius* were among the five most abundant species on all study plots. Other species that were among the five most abundant at least on one plot were *T. lineatum* on plots A, B, C and E, *T. signatum* on plots B,C, D and E, *Crypturgus hispidulus* (Thomson) on plot D and *Pityogenes chalcographus* (L.) on plot A. A total of 18 individuals of *I. typographus* were caught on plots A, B and C.

Table 5. Families of Coleoptera (number of specimens) caught in the window traps.

Family	Study plot					Restoration (A–C)			Control (D–E)			Total		
	A	B	C	D	E	Total	Av.	%	Total	Av.	%	Total	Av.	%
Staphylinidae	1123	2014	1740	1180	1110	4877	1626	30.9	2290	1145	34.6	7167	1433	32.0
Nitidulidae	2010	204	890	707	68	3104	1035	19.6	775	388	11.7	3879	776	17.3
Scolytidae	1560	322	820	271	436	2702	901	17.1	707	354	10.7	3409	682	15.2
Catopidae	716	334	834	475	548	1884	628	11.9	1023	512	15.4	2907	581	13.0
Leiodidae	145	423	179	277	136	747	249	4.7	413	207	6.2	1160	232	5.2
Ptiliidae	244	124	225	116	78	593	198	3.8	194	97	2.9	787	157	3.5
Cryptophagidae	60	207	32	147	268	299	100	1.9	415	208	6.3	714	143	3.2
Elateridae	77	40	135	119	105	252	84	1.6	224	112	3.4	476	95	2.1
Silphidae	63	22	174	111	79	259	86	1.6	190	95	2.9	449	90	2.0
Rhizophagidae	81	26	174	10	5	281	94	1.8	15	8	0.2	296	59	1.3
Cantharidae	72	18	54	49	58	144	48	0.9	107	54	1.6	251	50	1.1
Lathridiidae	75	24	30	23	25	129	43	0.8	48	24	0.7	177	35	0.8
Curculionidae	10	25	49	29	7	84	28	0.5	36	18	0.5	120	24	0.5
Apionidae	0	27	48	1	8	75	25	0.5	9	5	0.1	84	17	0.4
Cisidae	3	18	18	12	3	39	13	0.2	15	8	0.2	54	11	0.2
Hydrophilidae	4	15	13	6	16	32	11	0.2	22	11	0.3	54	11	0.2
Carabidae	11	13	2	11	12	26	9	0.2	23	12	0.3	49	10	0.2
Colonidae	0	37	4	5	0	41	14	0.3	5	3	0.1	46	9	0.2
Lymexylidae	31	2	8	3	2	41	14	0.3	5	3	0.1	46	9	0.2
Salpingidae	5	5	10	2	15	20	7	0.1	17	9	0.3	37	7	0.2
Cerambycidae	5	7	11	2	6	23	8	0.1	8	4	0.1	31	6	0.1
Cucujidae	19	1	4	4	1	24	8	0.2	5	3	0.1	29	6	0.1
Chrysomelidae	4	4	7	4	5	15	5	0.1	9	5	0.1	24	5	0.1
Sphindidae	2	5	5	8	2	12	4	0.1	10	5	0.2	22	4	0.1
Pselaphidae	1	6	2	9	3	9	3	0.1	12	6	0.2	21	4	0.1
Anobiidae	1	14	3	2	0	18	6	0.1	2	1	0.0	20	4	0.1
Lycidae	2	3	9	4	1	14	5	0.1	5	3	0.1	19	4	0.1
Melandryidae	2	3	7	3	1	12	4	0.1	4	2	0.1	16	3	0.1
Scarabaeidae	2	2	4	1	6	8	3	0.1	7	4	0.1	15	3	0.1
Cerylonidae	1	6	0	3	1	7	2	0.0	4	2	0.1	11	2	0.0
Anaspidae	1	2	2	2	0	5	2	0.0	2	1	0.0	7	1	0.0
Ptinidae	0	0	0	4	3	0	0	0.0	7	4	0.1	7	1	0.0
Erotylidae	0	2	2	1	1	4	1	0.0	2	1	0.0	6	1	0.0
Nemonycidae	0	1	1	2	2	2	1	0.0	4	2	0.1	6	1	0.0
Sphaeritidae	0	2	4	0	0	6	2	0.0	0	0	0.0	6	1	0.0
Helodidae	0	0	3	1	0	3	1	0.0	1	1	0.0	4	1	0.0
Trogositidae	0	0	0	2	2	0	0	0.0	4	2	0.1	4	1	0.0
Colydiidae	0	2	1	0	0	3	1	0.0	0	0	0.0	3	1	0.0
Scydmaenidae	0	0	1	1	1	1	0	0.0	2	1	0.0	3	1	0.0
Coccinellidae	0	1	0	1	0	1	0	0.0	1	1	0.0	2	0	0.0
Dermestidae	0	0	1	0	1	1	0	0.0	1	1	0.0	2	0	0.0
Histeridae	0	1	1	0	0	2	1	0.0	0	0	0.0	2	0	0.0
Clambidae	0	1	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Cleridae	0	0	0	1	0	0	0	0.0	1	1	0.0	1	0	0.0
Corylophidae	1	0	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Endomycidae	0	0	0	0	1	0	0	0.0	1	1	0.0	1	0	0.0
Melyridae	0	0	1	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Mycetophagidae	1	0	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Phalacridae	0	1	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Total	6332	3964	5508	3609	3016	15804	5268	100.0	6625	3313	100.0	22429	4486	100.0

Linear regression models were fitted to the ground trap data. The highest explanatory power was found for a model where class 1 dead wood was used as independent variable and the caught number of bark beetles on the plot as dependent variable ($R^2 = 0.7564$, $F = 24.837$, $p < 0.001$). The equation of the model is

$$\mathrm{Log}(kk) = 0.7661 \times \log(V) + 1.3605 \quad (1)$$

kk caught number of bark beetles on the plot
V volume of class 1 dead wood (m^3/ha) on the plot

Of the logistic models fitted to the ground trap data, the best fit was achieved with a model where the total volume of dead spruce was used to explain the relative abundance of bark beetles found on spruce in the beetle sample (Chi-square = 229.509, p = 0.000). The equation of the model is

$$p = 1 / (1 + e^{-1 \times (-3.71531 + 0.06245 \times V)}) \quad (2)$$

p relative proportion of bark beetles found on spruce of all beetles
V total volume of dead spruce

4 Discussion

Window traps are a commonly used means in abundance studies of forest Coleoptera (e.g. Bakke 1999, Siitonen 1994) because of their cheap price and effectiveness. They are usually considered to be neutral and not to attract or repel certain species. According to Økland (1996), however, the polypore in tree traps can have a baiting effect in addition to that of the added dead wood. This effect depends on e.g. polypore species and the abundance of polypores in the area (not recorded), presenting an additional nuisance factor to the tree trap results. The data collected with tree traps should therefore be considered with caution.

In the present study, the highest number of beetles was caught on plot A that has a more abundant herb and bush layer than the other plots. The multitude of factors potentially affecting the catch is reflected in the samples obtained; there is large variation in the catch even between different traps on the same plot. This variation, in turn, results in the low statistical significance of the results when t-test is used. The relative proportions test takes better advantage of the high total number of beetles and results in very high statistical significances.

The relative abundances of Nitidulidae, Ptiliidae, Rhizophagidae and Scolytidae were higher on plots with added dead wood than on control plots. The relative abundances of Cryptophagidae, Elateridae, Leiodidae and Staphylinidae were higher on control plots. At the family level, no consistent difference was found in the abundance of saproxylic species between plots with and without added dead wood. This result is at least partly explained by the short time interval between the restoration measures and this study; many saproxylic species were yet to be benefited by the dead wood addition.

In the families identified to species, Scolytidae and Cerambycidae, the caught species number was significantly (43% and 200%, respectively) higher on the plots with added dead wood. Bark beetles were more abundant on plots with added dead wood than on control plots. The most abundant species were all common or relatively common in Finland. In addition to the abundance of bark beetles, the abundance of their natural enemies has an effect on the risk of bark beetle damage. Of the families found to be more abundant on the plots with added dead wood, bark beetles' natural enemies (predators) are included at least in Nitidulidae and Rhizophagidae (Bakke and Kvamme 1993, Weslien 1992). On the other hand, also the family Staphylinidae, found in the present study to be more abundant on control plots, includes predators. So do families Cleridae, Cucujidae and Histeridae, for which no clear difference was found between plots with and without added dead wood. Still, bark beetles and their associated species were the group that showed the clearest difference between plots with added dead wood and control plots. Due to the longer generation time of bark beetles' natural enemies, the effects of treatments in their abundance may not be visible in short term.

In the study made by Martikainen et al. (2000), most correlations between stand parameters and non-saproxylic species were weak, but nearly

Table 6. Species of Scolytidae (number of specimens) caught in the window traps.

Species	Study plot					Restoration (A–C)			Control (D–E)			Total		
	A	B	C	D	E	Total	Av.	%	Total	Av.	%	Total	Av.	%
*Dryocoetes autographus**	1000	123	296	117	27	1419	473	9.0	144	72	2.2	1563	313	7.0
*Hylurgops palliatus**	156	75	164	58	145	395	132	2.5	203	102	3.1	598	120	2.7
*Trypodendron signatum***	31	46	83	54	216	160	53	1.0	270	135	4.1	430	86	1.9
*Hylastes cunicularius**	148	24	190	12	6	362	121	2.3	18	9	0.3	380	76	1.7
*Trypodendron lineatum**	99	24	24	6	25	147	49	0.9	31	16	0.5	178	36	0.8
*Pityogenes chalcographus**	46	0	13	1	1	59	20	0.4	2	1	0.0	61	12	0.3
*Dryocoetes hectographus**	17	13	20	3	2	50	17	0.3	5	3	0.1	55	11	0.2
*Crypturgus hispidulus**	17	3	7	15	5	27	9	0.2	20	10	0.3	47	9	0.2
*Hylurgops glabratus**	6	3	11	1	3	20	7	0.1	4	2	0.1	24	5	0.1
*Ips typographus**	16	1	1	0	0	18	6	0.1	0	0	0.0	18	4	0.1
*Xylechinus pilosus**	4	4	1	0	5	9	3	0.1	5	3	0.1	14	3	0.1
*Crypturgus pusillus**	5	0	1	2	0	6	2	0.0	2	1	0.0	8	2	0.0
Hylastes brunneus	2	0	4	1	0	6	2	0.0	1	1	0.0	7	1	0.0
*Cryphalus saltuarius**	0	4	1	1	0	5	2	0.0	1	1	0.0	6	1	0.0
*Crypturgus subcribrosus**	4	2	0	0	0	6	2	0.0	0	0	0.0	6	1	0.0
*Polygraphus poligraphus**	3	0	2	0	0	5	2	0.0	0	0	0.0	5	1	0.0
*Xyleborus dispar***	4	0	1	0	0	5	2	0.0	0	0	0.0	5	1	0.0
*Crypturgus cinereus**	1	0	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Hylastes opacus	1	0	0	0	0	1	0	0.0	0	0	0.0	1	0	0.0
*Phloeotribus spinulosus**	0	0	0	0	1	0	0	0.0	1	1	0.0	1	0	0.0
Pityogenes bidentatus	0	0	1	0	0	1	0	0.0	0	0	0.0	1	0	0.0
Total	1560	322	820	271	436	2702	901	17.1	707	354	10.7	3409	682	15.2
Species on spruce *	1522	276	731	216	220	2529	843	16.0	436	218	6.6	2965	593	13.2
Species on broadleaves **	35	46	84	54	216	165	55	1.0	270	135	4.1	435	87	1.9

all correlations between dead wood parameters and saproxylic species richness were strongly positive and statistically significant. This result is in accordance with the regression models fitted to the bark beetle data in the present study. The explanatory power of the models was high as well as their statistical significance. The volume of class 1 dead wood had the highest explanatory power as independent variable. This class includes recently dead wood, which is suitable for bark beetles. Considering that this kind of dead wood was notably more abundant on the plots with added dead wood, the result is in accordance with the finding that bark beetles were more abundant on plots with added dead wood.

Potentially harmful bark beetles, primarily *Ips typographus* and *Pityogenes chalcographus*, were more abundant on plots with added dead wood. These species were virtually missing on control plots, but not found in great numbers on plots with added dead wood, either. Earlier studies (e.g. Hedgren et al. 2003b) clearly suggest that the presence of suitable breeding material increased the risk of attack on nearby stands: *P. chalcographus* was found to attack many living trees but only kill a few. *I. typographus* was found in far fewer numbers, possibly due to the breeding material offered (thin-barked spruce). In another study Hedgren et al. (2003a) found that small numbers of felled trees at stand edges didn't increase the number of *I. typographus* attacks on living trees but rather concentrated the attacks near the felled trees.

There are a number of possible explanations to the scarcity of *I. typographus* and *P. chalcographus* found in the present study. One of the most significant ones is likely to be the timing of the restoration measures. The operations (exploding, caterpillar) were performed during fall and winter 1999–2000 and the downed trees were first attacked by the first bark beetle species to fly next spring. Among early bark beetles are e.g. *Trypodendron* spp. and *Hylurgops palliatus*; both were abundant in the samples. The timing of tree felling has great significance to the likelihood of *T. lineatum* attack. A tree felled or fallen during autumn is more likely to be attacked by this species next spring (e.g. Christiansen and Saether 1968, Dyer and Chapman 1965) than a tree felled in the summer.

Dyer and Chapman (1965) found *Dryocoetes autographus*, a species flying in midsummer, to be a common cohabitant with *T. lineatum*. According to Annila et al. (1972), *H. palliatus* is often found on the same tree trunks with *T. lineatum*. All of these species were very abundant in the study area. As these harmless species invade the tree trunks, potentially harmful species flying later in the summer find little suitable material to reproduce.

Another significant factor are the pre-existing population levels of these species; if the population level of *I. typographus* is low, a temporary increase in the amount of available dead wood is unlikely to cause dramatic results in this respect. Eriksson et al. (2005) found considerable variation in bark beetle colonization of downed spruces in Southern Finland due to local differences in population levels. The population levels of *I. typographus* and *P. chalcographus* were not studied prior to the restoration measures and thus cannot be reliably evaluated. However, they are likely to have been relatively low.

The fact that the felled trees died directly after the operations is also likely to have some significance. The trees felled with a caterpillar resemble trees felled during a storm more closely in this respect than do trees felled with explosives. Trees felled by a storm often retain part of their root connections to the ground and die more slowly. All of the trees in the study area were completely downed during the operations; there were no leaning, damaged trees typical of storm damage. The possible differences of the felling methods used could not be evaluated since the caterpillar and dynamite strips were situated on the same study plots near each other. Hedgren and Schroeder (2004) found the reproductive success of *I. typographus* to be significantly higher in standing dead trees than cut trees and presented root connections as one possible explanation. The possible differences between windfelled and cut trees was not studied.

Trees felled in a fall storm are still alive in the spring and the early-flying, typically secondary bark beetle species cannot invade them (Annila and Petäistö 1978). These conditions increase the risk of *I. typographus* attack later in the summer. In the study made by Annila and Petäistö (1978) the most important species to attack trees felled by a fall storm during the next summer were *I. typographus* and *P. chalcographus*. In this study, *T. lineatum* was observed primarily in stumps of broken trees. The population levels of insects before storm damage also influence the heaviness of attack during the first summer.

It is also possible that the felled strips are too small to create a microclimate favourable to *I. typographus*, a thermophilic species that prefers warm forest edges (Annila 1969, Peltonen 1999) and gaps (Göthlin et al. 2000) over stand interior. Bark beetle species that are known to avoid forest edges like *Hylurgops glabratus* (Zetterstedt), *Xylechinus pilosus* (Ratzeburg), *Polygraphus* spp., *Crypturgus subcribrosus* (Eggers) and *Cryphalus saltuarius* (Weise) (Peltonen et al. 1997) were in the present study at least as abundant on plots with added dead wood than on control plots. This indicates that the restoration measures have not had a significant effect of the microclimate of the stands. Cool summers also inhibit the reproduction of *I. typographus* and mass invasion of living trees can in Finland be expected only if the summers following storm damage are exceptionally dry and warm (Annila and Petäistö 1978).

5 Conclusions

The results of the study presented here show no consistent difference in the abundance of saproxylic species between plots with and without added dead wood. This result is according to expectations because of the short time interval between the restoration measures and this study: many saproxylic species (the target of the restoration measures) were yet to be benefited by the dead wood addition. The effect of added dead wood on the abundance of these target species will be analysed in a further study.

A marked increase on plots with added dead wood was observed in the abundance of several bark beetle species, but a small increase also in some Coleoptera families that include bark beetle predators (such as Nitidulidae and Rhizophagidae). The link between volume of fresh dead wood and bark beetle abundance was very strong, as demonstrated by the regression models created in the study.

Taking into account that the bark beetle species whose abundance increased most as a result of the restoration measures were not dangerous to healthy living trees and that the material suggests an increase also in the abundance of bark beetles' natural enemies, the risk of bark beetle damage in the studied area must be considered insignificant. Still, potentially harmful bark beetles (*Ips typographus* and *Pityogenes chalcographus*) were more abundant on plots with added dead wood, even if present in low numbers. The conditions in the studied area were not favourable for the regeneration of these species; the results should therefore not be interpreted as proof that no mass regeneration of harmful bark beetles can occur in similar situations.

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