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Insects in burned forests — forest protection and faunal conservation (preliminary results)

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The beetle colonization of fire-damaged trees was studied in seven reserves, which were established in burned forests in south and central Sweden, following extensive forest fires in the summer of 1992. In the spring of 1993, burned pine trees displayed a large range in fire damage from virtually undamaged ones to trees killed by the fire. Spruces were more sensitive than pine, and few fire-damaged spruces had some green foliage left. The pine shoot beetle, *Tomicus piniperda* (Linnaeus) was the main colonizer of pine trees, occurring at all sites, but altogether in only one-third of the trees. On spruce, two bark beetles were common: *Polygraphus poligraphus* (Linnaeus) was found on nearly all sites and altogether on half of the trees, followed in abundance by *Pityogenes chalcographus* (Linnaeus). These common species were accompanied by an assembly of bark and longhorn beetles, commonly occurring on fresh conifer timber. Most of the beetle species clearly preferred the dead or dying trees. However, the species mentioned above as well as *Arhopalus rusticus* (Linnaeus) also attacked trees with more than half of the foliage left. Three fire-favoured species were observed: *Oxypteris (Melanophila) acuminata* (Degeer), *Sericoda (Agonum) quadripunctata* (Degeer) and *Pterostichus quadrifoveolatus* (Letzner). Line surveys indicated little bark beetle dispersal from the burned areas into surrounding forests. Further studies are needed as the primary colonization of the burned trees was obviously not completed during this first year after the fire.

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1. Introduction

Intensified forestry practice during this century has turned the more or less virgin boreal forests of Sweden into well-managed and even-aged stands of pine and spruce (Heliövaara & Väisänen 1984, Esseen et al. 1992, Linder & Östlund 1992). Many insect species dependent on old, dying trees and dead wood material have become rare; a few have gone extinct and

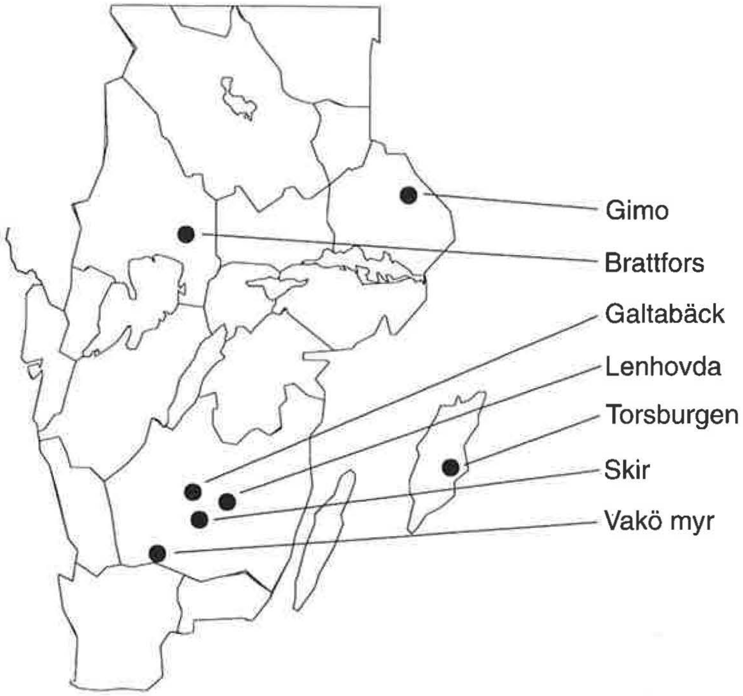

Fig. 1. Map of southern Sweden showing the location of the study areas

many are now considered endangered (Ehnström et al. 1993). The lack of old trees and dead wood also affects other groups of organisms such as mosses, lichens, fungi and organisms related to these (Esseen et al. 1992, Berg et al. 1994). Thus, improving living conditions for all organisms dependent on old trees and/or dead wood is a major challenge for faunal and floral conservation in forestry.

A typical feature of the prevailing forestry practice is the lack of forest fires or even controlled burning, as it was practiced until recently (Zachrisson 1977). Many insect species adapted to forest fires and burned trees have decreased in numbers as these commodities have become increasingly rare in modern forests (Heliövaara & Väisänen 1984, Lundberg 1984). Hence, reserves of burned forests are needed to promote living conditions for these fire-dependent species. On the other hand, burned forests may be suitable breeding grounds for forest pests such as bark beetles, and hence are less desirable from the perspective of forest protection. These conflicting views on forest fires triggered our interest to study burned trees as substrate for bark- and wood-living insects, especially beetles. Thus, our aims were to study: 1) the colonization of burned trees by bark beetles and other bark- and wood-dwelling insects species; 2) how primary colonization depends on tree vigour; 3) and to establish background data on how later successional stages of insect colonization can relate to fire history and primary beetle invasion.

2. Material and methods

In 1992, an unusual number of large and small forest fires occurred in south and central Sweden. Several forest reserves were set aside in these burned areas, and seven of these were included in this study (Fig. 1).

The burned areas varied in size from a few hectares (Galtabäck) to more than 1 000 hectares (Torsburgen and Vakö), and the reserved areas varied correspondingly (Table 1). At Lenhovda and Vakö, a large proportion of the burned area was peatland with a sparse forest cover, while other areas were fully stocked with coniferous forests of different age classes. Most burned forests were pine-dominated, except at Vakö where some spruce stands also became affected by the fire. The earliest fire took place on 10 June (Skir) and the latest on 23 July (Lenhovda).

In the spring of 1993, circular plots were laid out in the burned stands (except Torsburgen and Gimo, which were not inspected until the autumn 1993). The plot sites were selected to cover the range of fire damage and tree vitality of the dominating tree species in the area. Thus, we did not aim at estimating the average fire damage level, but to include the range in fire damage, and hence in substrate quality for bark- and wood-living insects. The number of plots varied from 3 to 12 depending on the size and variability of the fire area in question. Plot size was 100, 200 or 300 m^2 (radius: 5.64, 7.98 and 9.78 m) depending on the stocking, and was selected to yield 10–15 trees per plot. On each plot, each tree exceeding 5 cm in diameter at 1.3 m stem height ("breast height") was numbered and its species and diameter was recorded. The vigour of each recorded tree was also noted according to the estimated amount of green foliage left on the tree using the following classes: 0, 1–10, 11–20, 21–40, 41–60, 61–80, 81–100 per cent of the pre-fire needle biomass still green on the tree.

After classifying tree vigour, all trees were inspected for boring dust indicating bark beetle attack, and notes were made on the presence or absence of boring dust. In a few cases, spruce trees had been attacked by the late-flying bark beetle *Polygraphus poligraphus* (Linnaeus) already in the previous summer, soon after the fire; notes were made on the developmental stages of these beetle attacks (see below). (In this paper, we use the nomenclature of Silfverberg 1992).

In the autumn 1993, plots were laid out at Torsburgen and Gimo as described above. On the other sites, all trees were re-inspected and re-classified with regard to the percentage of healthy foliage. On all sites, all trees were checked for presence/absence of exit holes indicating successful bark beetle colonization. Notes were also taken on the occurrence of the insect species of particular interest when occurring outside the sample plots.

On every third tree, a bark sample (10 cm wide and 30 cm high) was inspected at knee height, breast height and three metres above the ground. In principle, the samples were taken on the side of the tree facing the centerpole of the plot, but the aspect was sometimes modified for practical reasons. On pine, all exit holes of pine shoot beetles (*Tomicus piniperda* (Linnaeus) and *T. minor* (Hartig)) were counted before the bark was removed. On spruce, no quantitative exit hole data were collected. All beetle galleries occurring under the bark were identified to species, and their occupancy of the bark area was estimated in 10% classes. The number of gallery systems of each occurring species was counted, and the developmental stages present in the galleries were recorded. On pine, we also measured the lengths of the egg galleries of the pine shoot beetles. Finally, the bark type was recorded as rough, intermediate or smooth, and the phloem vitality as dead, brownish and dry, white and dry and fresh (i.e. white and moist). When appropriate, the deviation of the trees from an upright position was recorded.

Table 1. Description of study areas.

Study area	Burned area, ha	Reserved area, ha	Time of fire	Scots pine				Norway spruce			
					diam o.b. (mm)				diam o.b. (mm)		
				n	x	s	range	n	x	s	range
Brattfors	189	75	29 June 1992	141	167	52	50–292	1	154	–	–
Galtabäck	7	7	9 July 1992	11	359	50	262–425	20	199	79	83–359
Gimo	150	25	2 July 1992	83	126	32	64–201	38	91	17	59–123
Lenhovda	48	10	23 July 1992	75	233	78	77–492	40	172	88	72–359
Skir	65	2	10 June 1992	14	329	34	289–384	17	261	67	160–423
Torsburgen	1000	167	9 July 1992	130	227	69	87–391	32	172	49	86–281
Vakö	1500	300	10 July 1992	64	203	63	97–337	102	231	91	69–445
Total				518	198	78	50–492	250	192	91	59–445

In addition, all fallen pine shoots (due to pine shoot beetle attack) were counted on 10 m^2 circular plots centered at the centre of the stand plots; counted shoots were removed outside the plot area. At Torsburgen and Brattfors, three and four transects, respectively, consisting of 10 m^2 circular plots at 50 m intervals were laid out from the the edge of the burned areas in different directions into surrounding pine forests. All *Tomicus*-shoots found on the plots extending ca 500 m from the edge of the burned area were counted and removed.

3. Results

3.1. Sample trees

In the spring of 1993, the pine trees displayed a large range in fire damage from virtually undamaged ones to trees killed by the fire. However, no attempt was made to estimate the proportions of trees in different damage classes. Among our sample trees, the majority of the smaller trees had suffered severe foliage losses and many of them were classified as dead (Table 2). The spruces were obviously more sensitive to the fire than the pines, as most fire-affected spruce trees were dead or dying. As the pattern was similar at all sites, only pooled data are given.

The pine shoot beetle, *T. piniperda* was the most common colonizer of the pine trees, occurring at all sites, but altogether in only one third of the trees (Table 3). The longhorn beetles *Acanthocinus aedilis* (Linnaeus), *Rhagium inquisitor* (Linnaeus) and *Arhopalus rusticus* (Linnaeus) as well as the pine weevil *Pissodes pini* (Linnaeus). were also common. The occurrence of the bark beetle *Pityogenes quadridens* (Hartig) (as well as other species preferring the thin bark and branches) was certainly more frequent than the figures indicate, as it was not sufficiently well sampled by the technique used. It is noteworthy that *Trypodendron lineatum* (Olivier) and *Monochamus sutor* (Linnaeus) occurred in few sites and in low numbers.

On spruce, the bark beetle *P. poligraphus* was found on nearly all sites and altogether on half of the tree, followed in abundance by *Pityogenes chalcographus* (Linnaeus) (Table 4). The absence of *Ips typographus* (Linnaeus) is worth mentioning (although some attacks were observed on non-sample trees). Several of the bark and longhorn beetles attack both pine and spruce, and were consequently recorded on both species.

Table 2. Diameter distribution of trees in relation to crown vitality (i.e. percentage undamaged foliage) in spring 1993.

Tree species	Fresh biomass, %	Diameter class o.b., mm					
		–100	–200	–300	–400	400+	Total
Scots pine	0	11	34	4	0	0	49
	10–30	7	73	50	14	2	146
	40–60	1	20	18	5	0	44
	70–90	0	22	30	12	1	65
	100	0	0	0	1	0	1
	Total*	19	149	102	32	3	305
Norway spruce	0	14	50	22	7	0	93
	10–30	0	12	21	16	2	51
	40–60	1	1	4	5	1	12
	70–90	0	1	4	3	1	9
	100	0	3	9	3	0	15
	Total*	15	67	60	34	4	180

* Gimo and Torsburgen, inspected only in autumn 1993, are excluded

Table 3. Occurrence of beetle species on pine trees sampled in autumn 1993.

Study area	Number of trees	Trees attacked by:											
		Tpin	Tlin	Piss	Hpal	Aaed	Rinq	Arus	Pqua	Msut	Pfas	Mcya	Ppol
Brattfors	48	31	0	1	0	18	10	3	1	3	0	0	0
Galtabäck+Skir	11	3	0	0	0	0	2	4	0	0	0	0	0
Gimo	28	7	0	2	1	0	7	2	0	1	0	0	0
Lenhovda	30	5	5	3	1	6	6	0	1	0	1	0	0
Torsburgen	39	6	0	1	0	8	4	2	0	2	0	6	3
Vakö myr	25	5	0	4	0	0	1	0	0	0	0	0	0
Total (n)	181	57	5	11	2	32	30	11	2	6	1	6	3
Total (%)		31.5	2.8	6.1	1.1	17.7	16.6	6.1	1.1	3.3	0.6	3.3	1.7

Tpin = *Tomicus piniperda*; Tlin = *Trypodendron lineatum*; Piss = *Pissodes* sp.; Hpal = *Hylurgops palliatus*; Aaed = *Acanthocinus aedilis,* Rinq = *Rhagium inquisitor*, Arus = *Arhopalus rusticus*; Pqua = *Pityogenes quadridens*; Msut = *Monocamus sutor*, Pfas = *Pogonochaerus fasciculatus*; Mcya = *Melanophila cyanea*; Ppol = *Polygraphus poligraphus*

Table 4. Occurrence of beetle species on spruce trees sampled in autumn 1993.

Study area	Number of trees	Trees attacked by:									
		Pcha	Tlin	Ppol	Hpal	Tetr	Rinq	Piss	Msut	Pfas	Sund
Brattfors	0	0	0	0	0	0	0	0	0	0	0
Galtabäck+Skir	21	9	3	17	1	1	3	1	0	0	0
Gimo	13	9	2	0	4	1	2	0	0	1	0
Lenhovda	8	5	1	4	0	0	0	0	0	0	0
Torsburgen	15	0	0	8	0	0	0	0	2	0	2
Vakö myr	33	4	0	17	1	3	2	1	0	0	0
Total (n)	90	27	6	46	6	5	7	2	2	1	2
Total (%)		30.0	6.7	51.1	6.7	5.6	7.8	2.2	2.2	1.1	2.2

Pcha = *Pityogenes chalcographus*; Tlin = *Trypodendron lineatum*; Ppol = *Polygraphus poligraphus*; Hpal = *Hylurgops palliatus*; Tetr = *Tetropium* sp.; Ring = *Rhagium inquisitor*, Piss = *Pissodes* sp.; Msut = *Monocamus sutor*, Pfas = *Pogonochaerus fasciculatus*; Sund = *Semanotus undatus.*

Table 5. Occurrence of beetle species on pine trees sampled in autumn 1993 as related to tree vitality in spring 1993. Samples from the different study areas pooled; species codes as in Table 3.

Fresh biomass in spring 1993, %	Number of trees	Trees attacked by:											
		Tpin	Tlin	Piss	Hpal	Aaed	Rinq	Arus	Pqua	Msut	Pfas	Mcya	Ppol
0 %	20	4	2	1	1	8	13	1	1	2	0	0	0
10–30 %	59	30	3	7	0	16	6	4	1	1	1	0	0
40–60 %	11	4	0	0	0	0	0	0	0	0	0	0	0
70–90 %	24	6	0	0	0	0	0	2	0	0	0	0	0
100 %	0	0	0	0	0	0	0	0	0	0	0	0	0
Total*	114	44	5	8	1	24	19	7	2	3	1	0	0

* Gimo and Torsburgen, inspected only in autumn 1993, are excluded

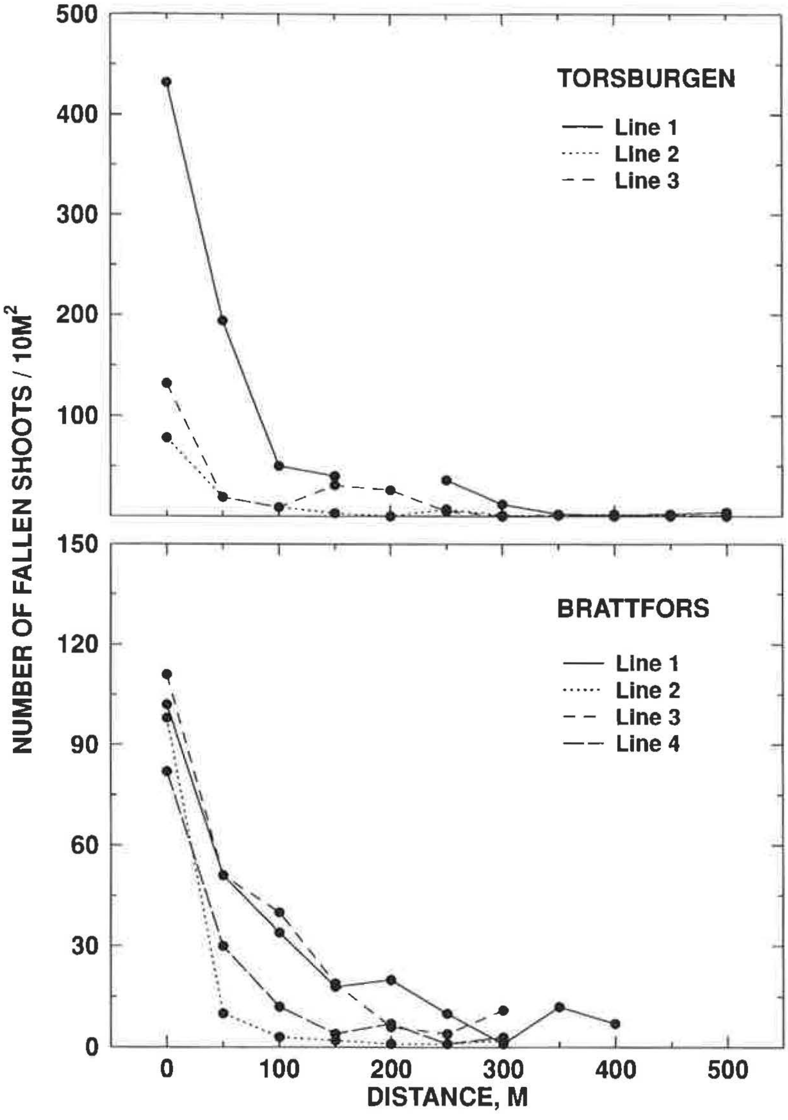

Fig. 2. The number of fallen shoots attacked by *T. piniperda* along transects from the edge of the burned forest into surrounding pine forest at Torsburgen and Brattfors in 1993 (fallen shoots collected in autumn 1993 and spring 1994 were pooled for each sample plot; note different scales on Y-axis; one sample plot excluded at Torsburgen due to open space).

Two species were seen only at the Gotland site: *Semanotus undatus* (Linnaeus) (spruce) and *Melanophila cyanea* (Fabricius) (pine).

Most beetle species clearly preferred the dead or dying trees (Tables 5 and 6). However, *T. piniperda* and *A. rusticus* also attacked pines with more than half of the foliage left; as did *P. poligraphus*, *P. chalcographus* and *Tetropium* (*castaneum* (Linnaeus) or *fuscum* (Fabricius)) on spruce.

3.2. Survey lines

The number of fallen shoots due to *Tomicus* attack declined quickly along the survey lines at Brattfors and Torsburgen (Fig. 2). Although figures are low beyond 100 m from the fire area edge, they indicate that pine shoot beetle had dispersed several hundred meters into the surrounding pine forests. At Torsburgen, shoot numbers were close to zero from 300 m distance, and similar to levels seen in well-managed forests.

No incidence of dead or dying trees due to bark beetle attack were seen in the vicinity of the shoot plots.

3.3. Field observations

The fire-dependent buprestid, *Oxypteris (Melanophila) acuminata* (Degeer), was not recorded on the sample trees. However, directional species-hunting revealed that it was present at three of the study areas: Skir (own observations), Gimo (L-O Wikars, pers. comm.) and Vakö (M. Sörenson, pers. comm.).

We also looked for the fire-dependent ground beetles *Sericoda (Agonum) quadripunctata* (Degeer) and *Pterostichus quadrifoveolatus* (Letzner) The former was seen in varying numbers on all sites (except Brattfors), whereas the latter was seen only at Galtabäck and Vakö.

4. Discussion

As this study so far covers only the first year colonization of the burned trees, little can be concluded about their suitability as brood material for bark- and wood-living insects.

Although our study was not designed to estimate the impact of fire on trees of different species and size, it is obvious that spruce trees were clearly more sensitive to fire-damage than pines. Also, small pines displayed poor fire resistance, whereas large pines often escaped deadly damage. This is well known and well documented in fire-ecological literature, and bark thickness is obviously important for tree survival (Gardiner 1957, Kozlowski & Ahlgren 1974, Kolström & Kellomäki 1993).

Many of the trees were not attacked at all, and for two different reasons. Some trees were so heavily burned that the primary colonizers could not breed in them due to the fact that all the phloem was destroyed by the fire. On the other hand, some of the less fire-damaged trees were still resistant enough to withstand beetle attacks. This finding agrees with earlier observations (Ehnström 1991). Thus, one important conclusion from the forest protection point of view, is that far from all burned trees are or can be utilized by bark beetles and other forest pests. However, recurrent beetle attack on weak trees may gradually render them susceptible.

Most attacks occurred on trees with fresh phloem and less than 30% green foliage left. Thus, the colonizing beetles preferred dead, dying or severely weakened trees. However, a few species displayed a more aggressive behaviour in attacking more vigourous trees (with more green foliage). These potentially more dangerous species were: *T. piniperda* and *A. rusticus* on pine, and *P. poligraphus*, *P. chalcographus* and *Tetropium* sp. on spruce. Of these, all three spruce-living species are known as capable tree killers under certain circumstances (Trägårdh 1939, Saalas 1949, Juutinen 1958, Lekander 1959, Butovitsch 1971). *T. piniperda* is generally con-

Table 6. Occurrence of beetle species on spruce trees sampled in autumn 1993 as related to tree vitality in spring 1993. Samples from the different study areas pooled; species codes as in Table 4.

Fresh biomass in spring 1993, %	Number of trees	Trees attacked by:									
		Pcha	Tlin	Ppol	Hpal	Tetr	Rinq	Piss	Msut	Pfas	Sund
0 %	32	8	4	22	2	1	4	1	0	0	0
10–30 %	18	6	0	12	0	2	1	1	0	0	0
40–60 %	5	4	0	3	0	1	0	0	0	0	0
70–90 %	2	0	0	1	0	0	0	0	0	0	0
100 %	5	0	0	0	0	0	0	0	0	0	0
Total*	62	18	4	38	2	4	5	2	0	0	0

* Gimo and Torsburgen, inspected only in autumn 1993, are excluded.

sidered to be a secondary bark beetle, not capable of attacking healthy trees unless population densities are extremely high (for references, see Långström & Hellqvist 1993). However, the species was very common on burned trees in northernmost Sweden (Ehnström 1977a,b). Little is known about the aggressiveness of *A. rusticus*, but Saalas (1949) mentions that it may attack fairly healthy trees.

The assembly of attacking beetles was, with a few exceptions, fairly trivial and predictable. All the recorded species are common bark- and wood inhabiting beetle species, known as primary colonizers of fresh conifer timber or dying trees (see e.g. Trägårdh 1939, Saalas 1949). One exception was *A. rusticus* which, at some sites, occurred in larger numbers than normally seen. This was especially the case at the Gotland site, which also was the only site for *S. undatus* (spruce) and *M. cyanea* (spruce). The low frequencies of *M. sutor* were surprising as this species has been reported to be attracted to fire-damaged trees (Forsslund 1934). Also, the low numbers of *I. typographus* (which was seen in a few trees outside sample plots) was noteworthy. Obviously, fire-damaged spruce trees are not very suitable for this species. In addition, many of the suitable trees might have been colonized by the late-flying *P. poligraphus* soon after the fire, and hence were not been available for attacks by *I. typographus* in the following spring.

The fire-dependent buprestid *O. acuminata* was observed in three of the study areas, and always outside the sample plots. Thus, is becomes obvious that we have to add habitat-directed "species hunting" to our arsenal of study techniques if we want to get data (at least presence/absence data) on these highly specialized species. Although this species is one of the "fire-specialists" (Lundberg 1984, Wikars 1992, 1994, and references therein), it occurs erratically, and was reported neither by Ehnström (1991) nor by Muona & Rutanen (1994).

As we did not systematically search for the two ground beetles *S. quadripunctata* and *P. quadrifoveolatus* at the study areas and plots, their abundance cannot be quantified. However, we found the former in more sites and in higher numbers than the latter. These observations agree with other studies in Sweden (Lundberg 1984, Ehnström 1991, Wikars 1992), whereas Muona & Rutanen (1994) reported the former but not the latter species.

No signs of excessive dispersal of bark beetles from the burned areas into surrounding conifer forests were seen. No incidence of increased tree mortality due to bark beetles (or other causes) could be seen along the survey lines laid out for counting fallen shoots. The pattern of fallen shoots was similar to what has been seen elsewhere around a local beetle source (Nilsson 1974, Långström & Hellqvist unpubl. data), and hence is by no means alarming.

In conclusion, there is, so far, little concern for bark beetle outbreaks emanating from burned forests, as many of the burned trees are unsuitable for bark beetles. However, the continued inspections in 1994 indicate that the situation has not yet stabilized with respect to tree vigour, and hence, new trees of declining vigour may become available for beetle attack in years to come. Windthrows in surviving stands with weakened roots due to the fire may also create favourable brood material for bark beetles. Thus, primary colonizers will find new trees to attack in coming years. At the same time, secondary cambial eaters will initiate a wave of secondary colonization on trees killed by fire or by the beetles. Thus, future inspections will result in a more diverse assembly of species on the burned trees.

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