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Invertebrate fauna on Norwegian spruce (*Picea abies*) branches in northern Finland

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The invertebrate fauna living on old Norwegian spruce (*Picea abies*) branches was studied in the years 1986 and 1987 in four localities in northern Finland. Three of the study areas, Linnanmaa, Sanginjoki and Muhos, were located close to the coast of the Bothnian Bay. The fourth area, Taivalkoski, lays inland, in the most easterly location of the four. The numbers of invertebrates living on spruce branches varied seasonally, as well as between the individual branches of a sample. They were highest at Linnanmaa, near the city of Oulu, and lowest at Taivalkoski. The most abundant taxa were mites (Acarina), spiders (Araneae) and springtails (Collembola). As regards the total invertebrate index Linnanmaa differed significantly from the other areas. Most of the animal groups showed a similar trend as well. In addition to a geographical cline (from coast to inland), the level of pollution is considered a possible cause of the observed uneven distribution in invertebrate numbers.

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1. Introduction

Pollution induced forest decline, especially in Central Europe and the Kola Peninsula, is known to have progressed to such an extent that trees have completely died out, or are at least in a less healthy condition, over large areas. Pollution changes the invertebrate fauna radically (Katayev et al. 1983). In spite of this, only scattered information exists concerning the effects of air pollutants on the invertebrate fauna living on trees.

Previous studies have concentrated on macroscopic invertebrates occurring on tree trunks (Gilbert 1971, LeBrun 1976) or on certain species, mostly aphids, beetles or moths, which can be regarded as pests (Villemant 1981, Braun & Flückiger 1984, Dohmen et al. 1984, Dohmen 1985, Opperman 1985, Heliövaara 1986, Heliövaara & Väisänen 1986, Neuvonen et al. 1987), while the rest of the fauna has largely been neglected.

In Central Europe it is no longer possible to study the original fauna living on spruce because air pollutants have already radically affected the faunal composition. In northern Finland the emissions are still at a rather low level, and this applies especially to long distance emissions (Tuovinen 1989).

In February 1986 we started a research project the aim of which was to examine the composition of the whole invertebrate fauna living on Norwegian spruce (*Picea abies*) branches, both

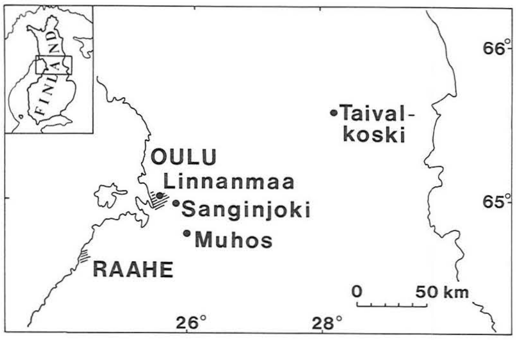

Fig. 1. The research areas. 1 = Linnanmaa, 2 = Sanginjoki, 3 = Muhos, 4 = Taivalkoski. The industrial centres of Oulu and Raahe are shaded.

in unaffected natural surroundings and in areas affected by different intensities of air pollution. In this paper we present the results of a basic survey on the fauna living on the branches of spruce, taking into account the phenology and also bearing in mind local pollution sources.

2. Material and methods

The study plots were located (Fig. 1) at different distances from the coast of the Bothnian Bay: Oulu, Linnanmaa (Grid 27°; 721:42) and Sanginjoki, 15 km to SE (721:44), Muhos, Viitaselkä, 30 km to SE (720:45) and Taivalkoski, Romevaara (721:56). The spruce forests selected for this study were old and characterized by the following features:

Linnanmaa. 5 km from the centre of Oulu. The study area consisted of sparse, spruce dominated mixed forest growing on boggy ground. *Ledum palustre*, *Vaccinium myrtillus* and *Carex globularis* were the type species of the ground layer.

Sanginjoki. The study area was situated on a south facing slope. The upper part of the forest was a pure spruce stand characterized by *V. myrtillus*. Young spruces were also present on the lower parts of the slope. The soil here was damper and the ground cover was characterized by *Polytrichum juniperinum*.

Muhos. The study area consisted of two forest islands (total area 4 hectares) surrounded by pine bogs. The type species of the ground layer were *V. myrtillus* and *V. vitis-idaea*.

Taivalkoski. The spruce stand was old and relatively dark; it faced north. The ground layer consisted of *V. myrtillus*.

The samples (5 spruce branches per study plot) were collected randomly on average once a month in 1986. The sampling was carried out before noon, mostly in dry weather. The branches, about 2 m long and 1.5 kg in dry weight, were cut from the lower parts (height 1.5–3 m) of on average 10–15 m high old spruce. Samples were taken only once from each tree. Before a branch was cut off it was covered by a plastic bag so that flying insects were also caught.

In the laboratory macroscopic invertebrates were picked off manually as the branch was cut into pieces. All of the epiphytic lichens were taken off after moisturizing. In order to dislodge the rest of the invertebrates the lichens and pieces of branch in a sample were kept in extraction cylinders for one month. After 1.5 months of drying at room temperature the wood material, needles and lichens were weighed. The term "dry weight" below refers to the values obtained in this way. As the size of the branches varied, an animal index was calculated (number of animals per 1 kg dry branch material).

The 1986 material consisted of 220 branches with a total dry weight of 186 kg and a total of 75056 invertebrates. In 1987 only three samples (January, June and September) were taken from these four plots. This material consisted of 50 branches with a dry weight of 51 kg and a total of 34110 invertebrates. The material was treated in the same way as described above.

3. Results

At Linnanmaa, near the centre of the town, the spruce branches almost totally lacked epiphytic lichens. The proportion of these of the total dry weight was less than 1 percent, while at the other sampling plots the corresponding figure was about

5 per cent (Table 1). The epiphytic lichen *Hypogymnea physodes* was most abundant on the branches of Muhos and Sanginjoki spruces. On Linnanmaa spruces it was quite scarce. *Usnea* and *Alectoria* spp., which are known to be extremely sensitive to various air pollutants (Ferry et al. 1973, Gilbert 1973), were almost completely absent at Linnanmaa, increasing gradually towards Taivalkoski, where their mean dry weight was almost 30 g per branch.

The invertebrate material obtained consisted mostly of mites (Acarina, Table 2), the most numerous species belonging to the superfamilies Ameronothroidea and Parasitoidea. Springtails (Collembola), homopterans (Homoptera), spiders (Araneae), psocids (Psocoptera) and thrips (Thysanoptera) were also well represented. The total invertebrate index was highest at Linnanmaa and lowest at Taivalkoski (Table 2, Fig. 2). This trend was seen in most animal groups. However, opposite trends were also discernible e.g. among mites of the superfamilies Cymbaeremaeioidea and Liacaroidea, and psocids of the family Reuterellidae (Table 2).

Two-way ANOVA was applied to the 1986 material to study the between-area and between-season differences in animal indices. In all groups except Homoptera, Neuroptera and Acarina there was significant between-season variation. In each main group except Collembola, Homoptera, Lepidoptera and Coleoptera there were significant differences between areas (Table 3). In regard to the total index Linnanmaa differed significantly from the other sites (Duncan's multiple range test). Most of the animal groups showed the same trend (Table 3, Fig. 3).

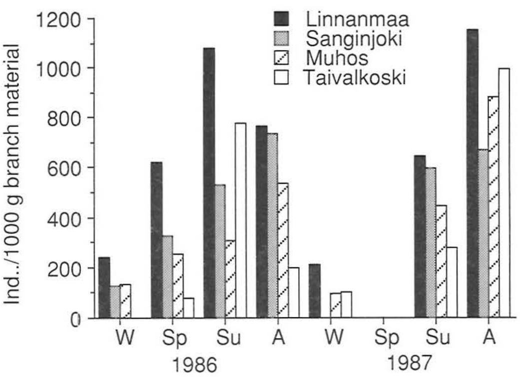

Fig. 2. The mean indices (ind./1000 g branch material) of the total invertebrate numbers at different seasons in 1986 and 1987. W = winter, Sp = spring, Su = summer, A = autumn. In the spring of 1987 no samples were taken, while the 1987 winter sample from Sanginjoki is similarly lacking.

Among total indices there was a significant difference between seasonal variation ($F_{3, 185}$ = 13.77, P = 0.0001) among the 1986 material, the invertebrate numbers being highest in late summer (Figs. 2 and 3). In 1987 the peak of invertebrate fauna abundance was delayed until the late autumn owing to the cold and rainy summer (Fig. 2, Table 4). At Taivalkoski the invertebrate numbers were usually the smallest, the summer of 1986 and autumn of 1987 being exceptions owing to large numbers of springtails.

4. Discussion

Our preliminary results are presented at order level to provide basic information on the faunal

Table 1. Composition of the branch material from the study areas.

	Linnanmaa	Sanginjoki	Muhos	Taivalkoski
Number of branches	65	60	75	75
Dry weight (g)				
Branches	963	758	851	797
Lichens				
Hypogymnia physodes	5.3	30.2	42.5	15.6
Usnea and *Alectoria* spp.	0.05	1.1	4.8	28.4
Percentage of branch weight				
Lichens	0.5	4.0	5.3	5.2
Needles	29.4	21.7	21.4	17.1

composition of invertebrates living on spruce branches in areas suffering from only a slight or moderate pollution level. These results can be employed as a basis for studying more radical changes in polluted environments. The material will be examined at the species level during further analyses.

Although the herbivorous insects living on Norwegian spruce are well documented (see e.g. Saalas 1949), the basic fauna seems to be poorly known. Information is available on winter faunas (Hågvar & Hågvar 1975), on winter predation by birds on invertebrates (Jansson & Brömssen 1981) and on the potential summer diet of birds (Palmgren 1932).

Our results show that the largest invertebrates disappeared from the branches (e.g. Araneae, Fig. 3) in winter, while in material collected by Hågvar & Hågvar (1975) and Jansson & Brömssen (1981) the numbers of these only decreased during the winter. A main cause of this may be the geographical latitude. In our research area the winters are severe, leading to marked differences between winter and summer numbers (Figs. 2 and 3).

Many factors may be involved in the faunal differences observed in this material. One of them is the distance from the sea shore. Linnanmaa, where the highest invertebrate numbers were recorded, is situated nearest to the sea (Fig. 1).

Table 2. The invertebrate indices (ind./1000 g dry branch) and the total catch (including larvae and juveniles) at the order level. For the most important orders examples are given of the most numerous superfamilies and families.

	Linnanmaa	Sanginjoki	Muhos	Taivalkoski	Total catch
Phalangida	0.2	0.1	0.1	0.1	28
Acarina	333	137	194	85	4558
Ameronothroidea	165	19	13	1	12179
Cymbaeremaeoidea	6	23	21	12	3615
Liacaroidea	8	38	100	34	11110
Parasitoidea	104	37	41	0.7	11127
Tetranychidae	16	6	5	33	3551
Araneae	49	28	21	9	6347
Linyphiidae	41	23	13	5	4788
Collembola	106	128	68	123	24507
Isotomidae	5	83	12	46	7815
Entomobryidae	100	43	56	75	16515
Psocoptera	35	51	20	11	5542
Caeciliidae	9	4	2	0.5	889
Elipsocidae	0.6	0.7	2.2	0.3	221
Philotarsidae	1	0.2	1	0.04	151
Reuterellidae	6	17	9	7	2168
Psocidae	3	0.1	0.1	0	233
Heteroptera	5	2	3	0.1	623
Homoptera	66	5	22	12	8692
Psylloidea	12	2	1	0.3	919
Coccoidea	44	16	13	0.3	4385
Aphidoidea	20	35	8	12	4176
Auchenorrhyncha	1	0.1	0.1	0.03	63
Thysanoptera	27	50	17	1	5249
Neuroptera	1	0.7	19	0.2	251
Lepidoptera	1	1	1	0.3	207
Diptera	33	18	18	17	5355
Hymenoptera	7	6	5	1	1121
Coleoptera	2	1	1	0.6	303
Others	0.05	0.1	0.1	0.03	16
Total catch	42022	21461	25017	15329	103829
Total index	668	453	371	260	

The stage of succession, edaphic factors, climate, ground vegetation, position etc, are other possible reasons for the differences. In any case, as noted in Laine et al. (1988), the numbers of certain mites decrease rapidly within just a few kilometres of the most polluted city area, even along the coast. These observations support the conclusions of Gilbert (1971), LeBrun (1976) and Katayev et al. (1983) on the effects of air impurities on faunal composition and invertebrate numbers. Local depositions in the Oulu region are apppreciable (Anon. 1988) and must have an influence on the invertebrate fauna.

Table 3. Results of one-way ANOVA for differences in the invertebrate indices between the study areas in 1986 (* $P<0.05$, ** $P<0.01$, *** $P<0.001$, ns not significant). Duncan's multiple-range test shows the areas which deviate from each other with respect to the taxon in question; the farther the symbol (L = Linnanmaa, S = Sanginjoki, M = Muhos, T = Taivalkoski), the greater the difference. The first symbol (left) shows the area where animal numbers have been the greatest, the last symbol (right) the area where they have been smallest. If there is a space between symbols, the difference between these areas has been statistically significant ($P<0.01$).

	F	Duncan
Total index	8.45 *	L SM MT
Collembola	1.51 ns	LSMT
Psocoptera	11.95 ***	L S MT
Caeciliidae	13.36 ***	L SM T
Elipsocididae	1.56 ns	LSMT
Philotarsidae	12.64 ***	LM ST
Reuterellidae	4.18 **	S TLM
Psocidae	6.37 ***	L SMT
Heteropera	12.63 ***	L MS ST
Homoptera	2.33 ns	LTS TSM
Coccoidea	24.02 ***	L S MT
Aphidoidea	0.71 ns	LSMT
Thysanoptera	11.49 ***	S LM T
Neuroptera	8.59 ***	ML LS ST
Lepidoptera	2.60 ns	LSMT
Diptera	5.61 ***	L TSM
Hymenoptera	14.77 ***	L MS T
Coleoptera	1.77 ns	LSMT
Acarina	29.68 ***	L M S T
Ameronothroidea	21.07 ***	L SMT
Cymbaeremaeoidea	7.71 ***	MS ST L
Liacaroidea	9.74 ***	M TS SL
Oribatuloidea	15.83 ***	M STL
Parasitoidea	47.35 ***	L MS T
Tetranychidae	1.29 ns	LSMT
Araneae	23.00 ***	L SM T
Linyphiidae	19.70 ***	L S MT

The prevailing winds (WSW) disperse air impurities from the industrial cities of Oulu and Raahe to the area east of Oulu. The most important pollution sources are the pulp and fertilizer industries, iron and steel works, a district heating power station and traffic. At Linnanmaa, in the northern part of the city of Oulu, the effects of air contaminants on conifers are seen in the higher level of sulphur and nitrogen in the needles (e.g. Karhu et al. 1987, Orell et al. 1987) and the lack of macroscopic epiphytic lichens (Table 1). An increase has taken place in the numbers of invertebrates living on spruce branches in this area. This is most evident in mites, but can be seen in several other invertebrate groups as well.

An increase or decrease of such potential food plants as algae or lichens will have an effect on the number of herbivores (Gilbert 1971). Some species may have benefitted from the enhanced growth of green algae in the vicinity of the pollution sources in the Oulu area. One of these may be the mite *Ameronothrus dubinini*, which was extremely numerous at Linnanmaa (Laine et al. 1988, Table 2). According to Schulte (1976), *Ameronothrus*-species live on primitive fungi and algae. By contrast, e.g. the mite *Cymbaeremaeus cymba*, which is usually associated with lichens (André 1984), was rare at Linnanmaa but numerous in other plots (Table 2).

In polluted areas the level of some amino acids in the needles is high (e.g. Bolsinger & Flückiger 1989). Certain herbivores living on spruce obviously gain from this situation, which affects the whole invertebrate community. When

Table 4. The mean monthly temperature (°C) and precipitation (mm) in the summers of 1986 and 1987 at Oulu.

	1986		1987	
	°C	mm	°C	mm
May	8.6	51.3	6.6	32.1
June	15.8	14.9	12.5	87.2
July	16.4	30.4	14.2	92.9
August	11.5	122.6	11.2	71.6
September	5.7	48.6	7.7	36.4

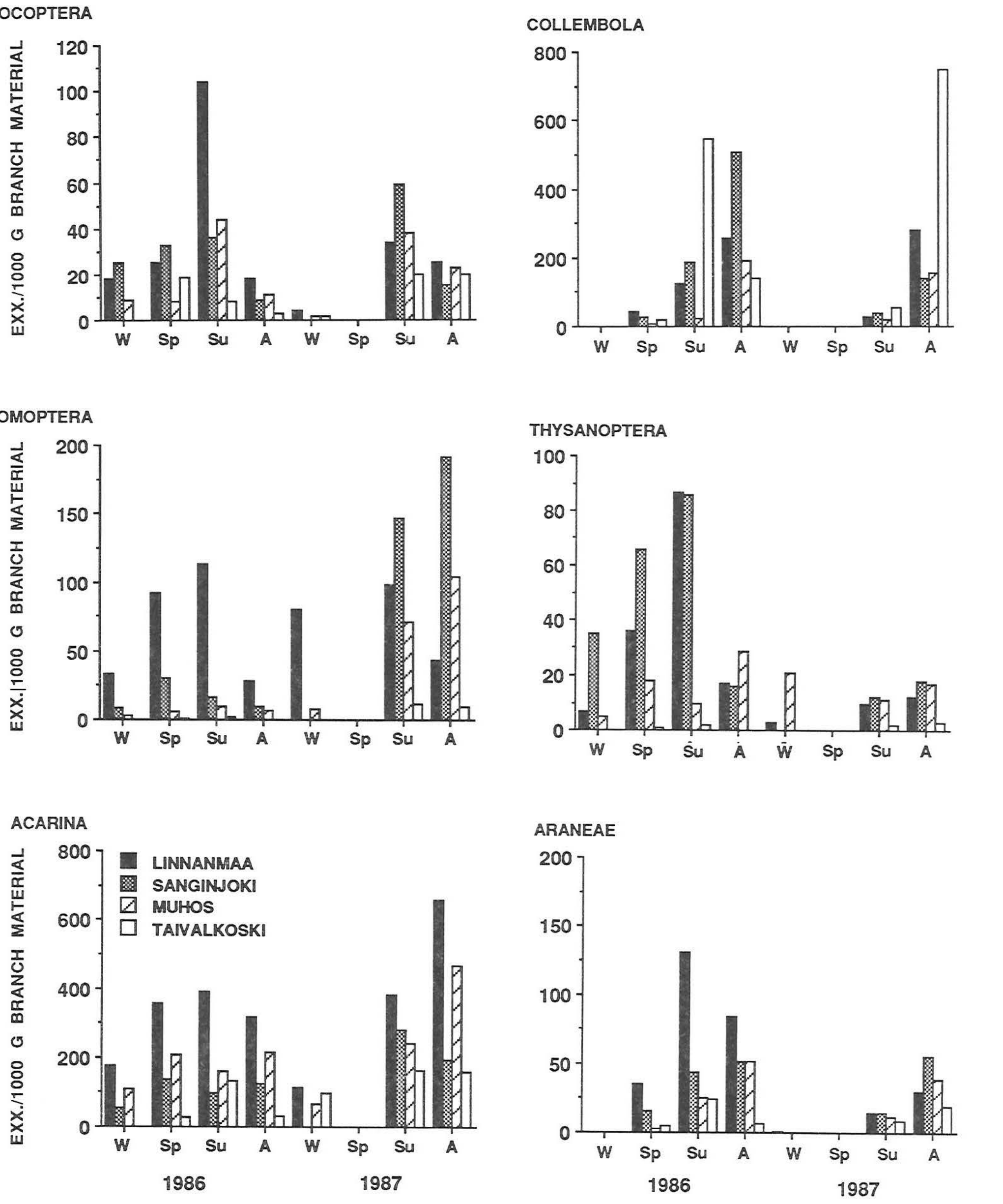

Fig. 3. The mean indices (ind./1000 g branch material) of the most numerous invertebrate orders at different seasons in 1986 and 1987. W = winter, Sp = spring, Su = summer, A = autumn. In the spring of 1987 no samples were taken, while the 1987 winter sample from Sanginjoki is similarly lacking.

there is a lot of aphids on the branches, their honeydew may cause large amounts of food for grazers such as psocids by acting as a 'sticky trap' for spores and providing abundant nutriment for several fungi (New 1970). The abundance of herbivores and grazers will attract predators such as spiders and certain mites or beetle larvae. Thus, on slightly polluted areas the numbers of several groups of invertebrates may rise for various reasons, thereby affecting the diversity of the whole fauna, as was clearly seen in this study.

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