Ground-living arthropods along pollution gradient in boreal pine forest

Seppo Koponen & Pekka Niemelä

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We studied the occurrence of arthropods in a polluted pine forest at Harjavalta, southwestern Finland. Significantly fewer beetles (Coleoptera) were trapped near (0.5 km) a smelter and fertilizer factory than at sites further away (3, 5, 9 km). No differences in total numbers (inds./trap) along the distance (pollution) gradient were found for spiders (Araneae), ants (Hymenoptera: Formicidae) or bugs (Heteroptera). Marked differences were observed in diversity and species composition of the studied groups between the most polluted site (0.5 km) and the other sites (3, 5, 9 km). There were permanent arthropod populations (e.g. ants and wolf spiders) living at the most polluted site. Differences in ground-living fauna were explained by changes in ground vegetation due to pollution. The contents of Cu, Fe, Ni and Cr in ants and wolf spiders were clearly highest near the pollution source; those of Cd, Zn and Al were high at all sites.

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1. Introduction

One of the most polluted forest areas in Finland lies in and around the industrial town of Harjavalta, where the greatest pollutors are a smelter and a fertilizer factory. High concentrations of heavy metals and other pollutants have been found in moss samples from the forest floor (Jussila & Jormalainen 1991). Pollutant emission has lasted since the mid-1940s. One consequence of this long-term pollution has been the dramatic destruction of the pine forest in the surroundings of the factories.

The effect of pollution on certain tree-dwelling invertebrates at Harjavalta has been studied previously (e.g. Heliövaara et al. 1987, Heliövaara & Väisänen 1989, Jussila et al. 1991). Only little is known about the effect of pollution on the ground-living arthropod fauna in the area (Koponen & Niemelä 1994a, 1994b).

2. Study area, material and methods

The study area is situated at Harjavalta, southwestern Finland (about 61°20'N, 22°15'E). The forest studied was dry pine forest (*Calluna* and *Vaccinium* types), belonging to the boreal forest zone. Young, 6–12 m tall *Pinus sylvestris* trees grow on sandy soil; site I is located 0.5 km, site II 3 km, site III 5 km, and site IV 9 km from the smelter. There are

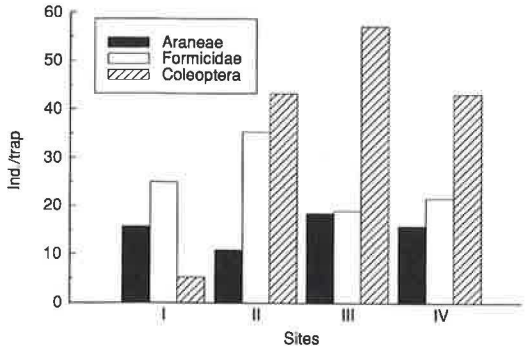

Fig. 1. Density (ind./trap) of spiders (Araneae), ants (Formicidae) and beetles (Coleoptera) at study sites (I–IV) at Harjavalta.

two factories, one a smelter producing copper and nickel, the other a fertilizer factory producing sulphuric acid and fertilizers; the smelter complex being the main pollutor. The main pollutants are Cu, Ni, Cr, Cd, Pb & SO_2; others include Fe, Zn, V, As, Hg and Al (Jussila & Jormalainen 1991). In 1990, the Outokumpu smelter complex at Harjavalta had the worst air pollution record among Finnish factories with respect to Cd and Pb, and one of the worst also with respect to Hg and SO_2 (Wahlström et al. 1992).

The ground layer vegetation at the study sites is as follows (data from Salemaa & Vanha-Majamaa 1993):

Site I (0.5 km): Black needle litter, barren sand spots, almost without vegetation (ground layer coverage 2%)

Site II (3 km): Needle litter, *Cetraria* lichens, no moss; dominant vasculars *Vaccinium* and *Empetrum* (ground layer coverage 37%)

Site III (5 km): *Cladonia* and *Cetraria* lichens, no moss: dominant vasculars *Vaccinium*, *Empetrum* and *Calluna* (ground layer coverage 74%)

Site IV (9 km): *Cladonia* and *Cetraria* lichens, *Pleurozium* moss; dominant vasculars *Vaccinium*, *Calluna* and *Deschampsia* (ground layer coverage 94 %)

At site I the pines have lost most of their needle biomass. At site II they are suffering less damage but still have visible loss of needle biomass. Although little visible effect of pollution on vegetation could be seen at sites III or especially IV, the heavy metal concentration at these sites is also markedly higher than the average for Finnish forests (Jussila & Jormalainen 1991).

The study period was 9 July–19 August, 1992, and the collecting method pitfall trapping (20–36 traps/site). The diameter of the traps was 6 cm, the preservative ethylene glycol, and the traps were provided with covers. The material is deposited in the Zoological Museum, University of Turku.

The heavy metal concentrations of whole arthropods were analysed by wet-ashing (HNO_3/$HClO_4$) and ICP-emission spectrometry. No surface pollutants were included because the animals were washed before the analyses.

3. Results and discussion

3. 1. Fauna

Individual numbers caught (ind./trap) are shown in Fig. 1. Significantly fewer beetles (Coleoptera) were collected at the heavily polluted site I than at sites II–IV. No statistical difference was found along the distance (pollution) gradient in the individual numbers of spiders (Araneae), ants (Hymenoptera: Formicidae) or bugs (Heteroptera). A significant difference in ant numbers was, however, observed between some less polluted sites (II/III and II/IV). The continued occurrence of spiders, and often also ants, in heavily polluted boreal forest areas near smelters has also been shown in the Kola peninsula (Stephanov et al. 1991, Koneva 1993, Koneva & Koponen 1993) and in Sweden (Bengtsson & Rundgren 1984).

Among beetles, a single species (*Coccinella septempunctata*) dominated at site I (53% of beetle inds.) where beetles were generally infrequent. It was common also at site II but infrequent at sites III–IV. The species feeds on aphids, which are known to be abundant in polluted areas; high numbers of aphids on pines near the factory in the Harjavalta area have been observed by Heliövaara & Väisänen (1989). Likewise weevils (e.g. *Hylobius*) were trapped in great numbers at site I; they were abundant at all sites, as were Staphylinidae beetles. Carabids were infrequent at site I but much more abundant at sites II–IV.

Among spiders, wolf spiders (Lycosidae) dominated in the material (57–80% of inds.); at the most

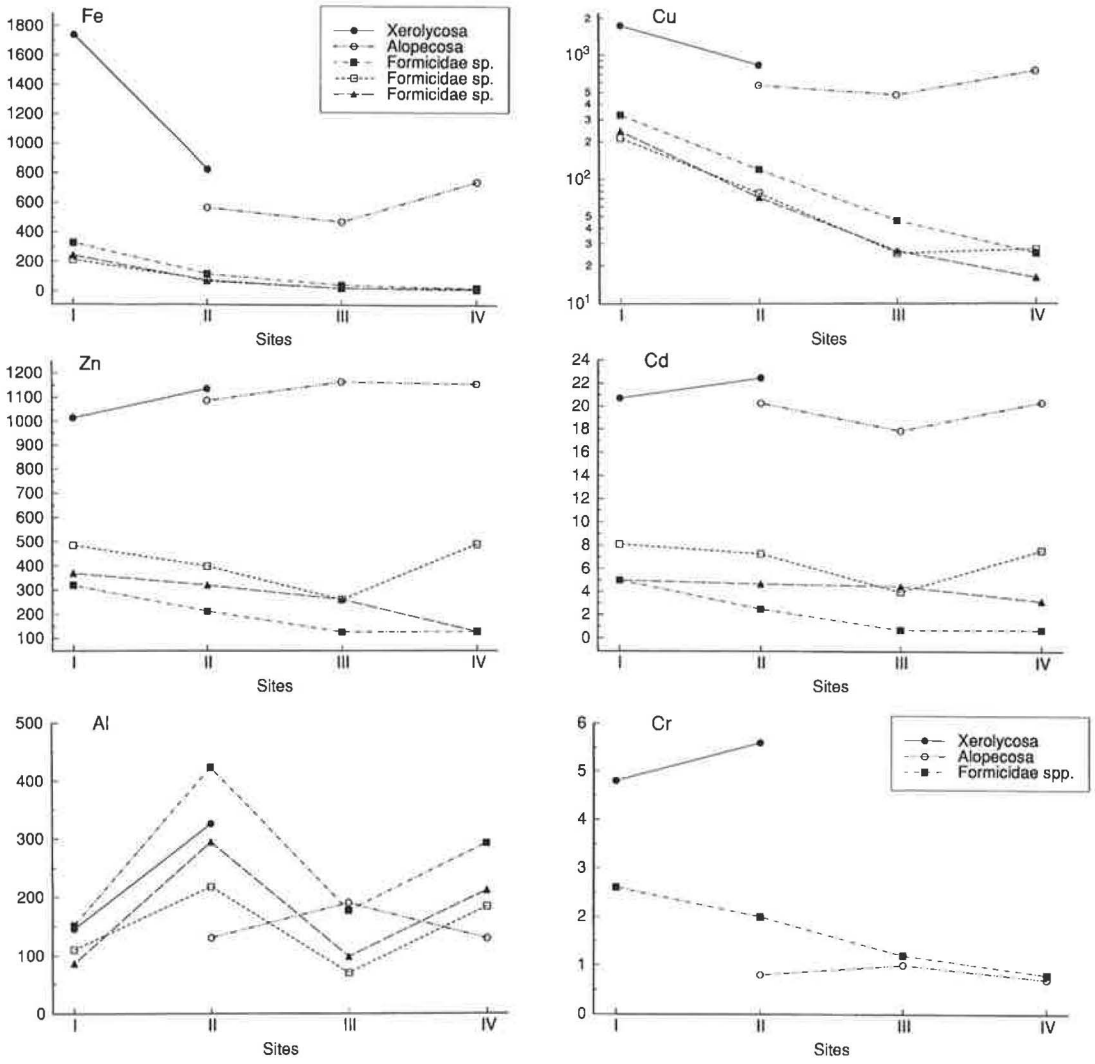

Fig. 2. Metal content (ppm) in wolf spider females (*Xerolycosa nemoralis* and *Alopecosa aculeata*) and in ants (Formicidae spp.) at study sites at Harjavalta. Cu content shown on logarithmic scale.

polluted site the most abundant species was *Xerolycosa nemoralis* (78%), while at other sites *Alopecosa aculeata* was most abundant (43–76%). *Xerolycosa nemoralis* seemed to have a permanent population near the smelter at site I: females with egg cocoons and high numbers of juveniles were trapped. Some pioneer linyphids (*Oedothorax apicatus*, *Erigone atra*, *Agyneta rurestris*) were found only at the most polluted site. Only a few species (e.g. *Zelotes petrensis*) occurred more or less equally at all sites. Typical forest floor linyphids (e.g. *Tapinocyba pallens*, *Silometopus elegans* and *Walckenaeria antica)* were not caught at site I. For a more detailed report on the spider fauna, see Koponen & Niemelä (1994b).

Ten species of ants were collected. A particularly rich fauna was found at the most polluted site I, where eight ant species were trapped (*Camponotus herculeanus*, *Formica aquilonia*, *F. sanguinea*, *Lasius niger*, *Leptothorax acervorum*, *Myrmica lobicornis*, *M. ruginodis* and *M. sulcinodis*). *Lasius niger*, a species characteristic of cultural sites, was

found only at site I, and the closely related *L. platythorax* at the more natural sites II–IV; this is consistent with their known habitat preferences (Seifert 1992 and M. Saaristo, pers. comm.).

In the small material of bugs (10 species and 42 inds.), the highest diversity and abundance (4 species and 20 inds.) were found at the most polluted site I. Due to the absence of ground vegetation, all the bugs in the pitfall traps were typical dwellers of tree foliage, such as the most dominant (65%) species, *Myrmedobia exilis*. At sites II–IV, typical forest floor species were trapped, dominated by *Ligyrocoris sylvestris*.

In general, the ground-living arthropod fauna at the most polluted site I included some pioneer species, thermophilous species and several accidentals (e.g. tree foliage species). The fauna at site II was intermediate between the polluted site I and the more or less (visually) natural sites III and IV. The effect of pollution on the fauna seems to be explained indirectly by changes in ground vegetation rather than by a direct poisoning effect. Permanent populations of ants and spiders were found even at the most polluted site, and no deformations were observed in the arthropods studied.

3.2. Heavy metals

The contents of Cu, Fe, Ni, Cr and Pb in ants and wolf spiders were clearly highest near the pollution source. Statistically significant differences were found in the contents of Cu, Fe and Ni in ants between site I and II, and between site II and more distant sites; there was no difference between sites III and IV (Fig. 2). The contents of Cd, Zn and Al were high at all sites. Higher concentrations of pollutants were usually found in wolf spiders (*Xerolycosa nemoralis* and *Alopecosa aculeata*) than in ants (Fig. 2). This is in accordance with earlier findings, according to which spiders tend to have the highest metal concentrations among predatory arthropods (Heliövaara & Väisänen 1993); presumably because spiders suck the content of their prey, while ants chew theirs.

The Cu content in arthropods near the smelter was of about same magnitude as that found in ants and wolf spiders near a brass mill in Sweden by Bengtsson & Rundgren (1984), but the Pb content was clearly lower at Harjavalta. Al and Zn in ants at Harjavalta was at about the same level as that found in a polluted area near the Raahe iron and steel factories, Finland, while the Fe content in ants was somewhat lower at Harjavalta than at Raahe (Mukherjee 1994). The content of Cu was somewhat higher and that of Zn markedly higher than those given as maximum figures for spiders by Nuorteva et al. (1992).

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Appendix.

The most important taxa detected in the present investigation

Araneae
- *Agyneta rurestris* (C. L. Koch)
- *Alopecosa aculeata* (Clerck)
- *Erigone atra* (Blackwall)
- *Oedothorax apicatus* (Blackwall)
- *Silometopus elegans* (O. Pickard-Cambridge)
- *Tapinocyba pallens* (O. Pickard-Cambridge)
- *Walckenaeria antica* (Wider)
- *Xerolycosa nemoralis* (Westring)
- *Zelotes petrensis* (C. L. Koch)

Coleoptera
- *Coccinella septempunctata* Linnaeus

Hymeroptera (Formicidae)
- *Camponotus herculeanus* (Linnaeus)
- *Formica aquilonia* Yarrow
- *F. sanguinea* Latreille
- *Lasius niger* (Linnaeus)
- *L. platythorax* Seifert
- *Lepthothorax acervorum* (Fabricius)
- *Myrmica lobicornis* Nylander
- *M. ruginodis* Nylander
- *M. sulcinodis* Nylander

Heteroptera
- *Ligyrocoris sylvestris* (Linnaeus)
- *Myrmedobia exilis* (Fallén)