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Metal pollution in relation to mass outbreaks of *Dendrolimus punctatus* Walker on *Pinus massoniana* Lamb. in China

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Abstract: Insects with their ecological superpower have enormous capacity to transform small pollution damage in forests to full scale calamities. Acid rain resulting from extensive coal burning is the chief pollutant in China. Acid rain activates from soil deposits toxic metals, which are transferred to trees and further to insects eating them. We studied the levels of the toxic Cd, its antagonists Zn and Cu, and acid rain indicators Fe and Mn in the forest-pest moth *Dendrolimus punctatus* Walker (*Lepidoptera*: *Lasiocampidae*) in variously polluted *Pinus massoniana* Lamb forests in China.

The highest density of *D. punctatus*, as well as the highest Cd levels developed in the moderately polluted forests. Possibly Cd had there broken down the pest resistance of the pines. The paradoxical coexistence of high Cd level and elevated population density of the pest seems to result from the high accumulation of Cd in its ichneumonid parasitoid. In the most heavily polluted forests the Cd level in needles was low, possibly because the strong acid rain had washed away most of the Cd deposit in the soil. It existed there no *D. punctatus* population. Absence of pest insects from the most heavily polluted areas is a common phenomenon.

Key words: metal pollution; *Dendrolimus punctatus* Walker; *Pinus massoniana* Lamb. China

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Introduction

It is generally assumed that acid rain, biospheric ozone, metal fallout or some other pollutants cause forest decline through phytotoxemias which show specific symptoms of disease. It has been shown experimentally that such disease symptoms may really develop in trees when they are exposed to pollutant levels exceeding given tolerance limits. In general, the amounts of pollutants occurring in areas with forest decline are, however, much below the experimentally noted tolerance limits. The hypothetical role of pollutants as causative agents for forest decline has consequently often been rejected also in cases where the forest decline shows a positive temporal and areal correlation to the degree of pollution. This kind of rejection has in general been based on the simple fact that the abundance of pests detected gives a quite sufficient explanation for the death of forest trees.

When viewed holistically, this type of tedious argument about pests may be an oversimplification of the real situation. One must realize that the co-evolutionarily developed pest tolerance of trees is so strong that the pathogens does in general initiate forest decline only in such situations where environmental stresses have weakened tree resistance (Mattson, 1975; Bolsinger, 1989; Führer, 1989; Vogel, 1989; Heliövaara, 1990; Nuorteva, 1990, 1997a, 1997b; Migula, 1997; Sarajishvili, 1997). The spectrum of stresses promoting forest decline may consist solely of natural stresses, but in recent times it includes most often also anthropogenic stresses-such as for example overdimensioned forestry practices, acid rain, metal fallout, NO_x, O_3, climate changes by CO_2 and increasing UV-radiation. Consequently, in our world with continuously progressing industrialization these anthropogenic factors must be considered to be very important promotors of insect calamities.

Ultimately, there exists a danger that anthropogenic stresses grow to such dimensions that forest entomologists are unable to master regional insect devastations (Nuorteva, 1997a; 1997b).

For environmentalists, on the other hand, what has gradually emerged is that the insect-plant relationship is the most sensitive area (Achilles' heel) existing in plants against pollutant damage. In order to understand the importance of this Achilles' heel it is necessary to remember the ecological superpower of insects with their overwhelming biodiversity and their high biomass (a half of all species of organisms are insects; their biomass is higher than that in any other class or phyla of terrestrial animals (Wilson, 1992; 1996). In this constellation the environmentalists must survey the dangers of pollutants to trees through ecotoxicological tests in which the plants are exposed to environmental pollutants in the simultaneous presence of the insect pests (Ortel, 1993 b; Nuorteva, 1999).

For holistic understanding of the pollutant-insect-host plant relationship it is further necessary to consider the results of recent studies on the occurrence of forest pests at different distances from the source of metal pollution (Heliövaara, 1990; Koricheva, 1992; 1994; 1995; Kozlov, 1993; 1995; Zvereva, 1995; 1997; Malyshev, 1997). These studies show that pest damage increases generally with moderate pollution, but is inhibited by the heaviest pollution nearest to the source. It is to understand this in the following way: moderate pollution is beneficial for the pests because it breaks down the pest-resistance of trees, but heavy pollution extends its damaging potency also to the pests. In some single cases, however, only the heaviest pollution is able to break down the insect resistance of plants (Jeffords, 1984).

A further refinement for the understanding of the dramatic triangle between pollutant, insect, and host plant is the fact that pollutants may cause more worse damage in the parasitoids of a phytophage than in the phytophage itself (Ortel, 1989; 1991; 1993a; 1993b; 1995a; 1995c; San, 1993; Bishof, 1995). In this way, toxic pollutants may be beneficial for the phytophage and dangerous for the food plant.

The present knowledge about the role of insects as fortifiers of pollutant damage is still thin, in many respects. One can say that we are still working in a stage of pioneer studies. In order to increase a bit the knowledge, we decided to study from variously polluted *Pinus massoniana* Lamb forests the metal levels in the successional developmental stages of *Dendrolimus punctatus* Walker, in its ichneumonid parasitoid, and in its food. Cd was chosen to be the chief metal of the study, because it has only toxic properties and seems to be an important factor in the development of forest decline (Nuorteva, 1990; 1998a; 1998b; Maavara, 1994). As annexes to Cd we studied Zn and Cu, because they are antagonists for Cd. We analyzed also Fe and Mn, because they indicate increased metal mobility caused by acid rain.

As for *P. massoniana* it is known that it is the most widespread pine in the east and southeast of central China, where it covers about 21% of the forested area. Ecologically, it is important as a recovery species in forest succession.

D. punctatus is one of the most destructive insect pests of pine forests in the east and south of central China (Li, 1987; 1993; Wienhu, 1990; Xiao, 1992). In all, it occurs in 17 provinces and regions. In most cases the mass outbreaks occur in areas with poor soil, weak tree growth, and crude management. The natural enemies are effective inhibitors of mass outbreaks, but they are not successful in all situations. Human attempts to control the mass outbreaks remain often without success, because it is difficult to discover the initial stages of outbreaks. The role of pollutants as promoters of mass outbreaks has not been studied for this species in China.

Air pollution in China is mainly caused by coal-burning, which has centuries-long tradition. Sulphur in coal is the precursor for acid rain, which in turn is able to activate metal deposits in soil. The acidity of precipitation as well as the area affected by acidic rainfall have recently increased dramatically along with the rapid economic growth (Wang, 1995). Pine-ring analyses have shown that levels of S, Fe and Mn have increased strongly since the year 1800, whereas the levels of Cu, Zn and Ni have not changed much (Jiang, 1996). The greatest emissions of the acid-rain precursors occur in northern China, but acid rains occur in considerable degree in the southern part (Wang, 1995; Seip, 1995). Soils are damaged in parts of southwestern China, but the sensitivity shows dramatical local variation (Seip, 1995). Sulphur emissions in Guizhou and Sichuan provinces are found to be especially high. The Chinese government has gradually raised the priority accorded to this key environmental problem (Sinton, 1998).

1 Study areas

The main material of our study originated from four forests representing different degrees of pollution and population density of *D. punctatus*. As material for European comparision we used adults of *D. pini* from nearly unpolluted southern Finland. The study areas looked as follows: (1) "Unpolluted" *P. massoniana* forest in Chang Po Liang Forest farm in Guli Ditrict in Guizhou Province. The acid rain precursors produced by the extensive coal-burning industry in Guiyang City in the same province does not reach Guli. The Guli forest was inhabited by such a sparse population of *D. punctatus* that it was difficult to find eggs and caterpillars. The samples were collected during the vegetation period in 1997. The needles were sampled in April and had developed during the vegetation period of 1996. (2) Moderately polluted *P. massoniana* forest in Zhuzhou in Hunan Province, where it occurs many scattered sources of pollution. The pine forest in question was inhabited by a heavy population of *D. punctatus*. The samples were collected during the vegetation period of 1997. The needles were sampled in April and had developed during the vegetation period of 1996. (3) Heavily polluted *P. massoniana* forest in Wulichong in Guizhou Province, in the near vicinity of Guiyang City, producing strong acid rain through extensive coal-production (Seip, 1995). There existed no population of *D. punctatus* in this forest. *P. massoniana* needles were collected in January 1998 and consisted of needles from the year 1996. (4) Heavily polluted *P. massoniana* forest in Huang Sha Kou, Nan Shan in the vicinity of Chongqing City. There existed no population of *D. punctatus*. *P. massoniana* needles were collected in January 1998 and consisted of needles from the year 1996. (5) "Unpolluted" *P. silvestris* forest in Bromarv on the Baltic coast in southwestern Finland (Nuorteva, 1998). The population of *Dendrolimus pini* was so thin that only adults were accessible (by light trap). Of the pine needle samples only second year samples were considered here.

2 Methods of metal analyses

The metal analyses were performed by a flame atomic absorption spectrophotometer or by a graphite furnace AAS as described in detail by Nuorteva (Nuorteva, 1990). The metal contents are given as ppm (= mg/kg) of the dry weight.

3 Results and discussion

The results of metal analyses are given in Table 1.

In spite of the fact that China has been considered by IIASA to be "on the verge of an acidification problem as widespread and severe as anything seen in North America or Europe", it did not exist essentially more Cd in the pine needles in our Chinese background area than in south Finland. In the moderately polluted area in Zhuzhou, the needles had nearly ten times as much Cd, and an outbreak of *D. punctatus* associated with it. Astonishingly the two still more heavily acid-rain-stressed study areas did not show horribly elevated Cd levels, but levels which did not differ much from the levels occurring in the background area (0.34—0.44 ppm versus 0.26 ppm). This kind of situation has not been observed elsewhere. Because extensive use of coal has centuries-long traditions in China (Seip, 1995; Wang, 1995; Zhai, 1996), one may think that the resulting acid rain has washed away a major part of the Cd deposits in the soil. In this situation acid rain is no longer able to damage trees through dissolved Cd.

One may note that the strongest *D. punctatus* population occurred in Zhuzhou where the Cd level in the food was highest, a mean 1.59 ppm, in the other four areas it was between 0.09—

0.44 ppm. Tentatively, one can say that a population outbreak develops when the Cd level in the food exceeds 1 ppm. By taking the antagonistic metals Zn and Cu into consideration, one can say that a population outbreak develops when the Zn:Cd index in the food is below 80 or the Cu:Cd index below 7. In principle, the metal constellation underlying the population outbreak of *D. punctatus* is very similar to that underlying the development of pemphigid galls in poplar petioles (Nuorteva, 1997 c, 1999). In that study, leaf petioles were protected against gallers when the Cu/Cd index was higher than 7. In suitable plants, gall growth stopped when the index exceeded the limit of 7 through Cu transfer. In the case of *D. punctatus* population no outbreak occurred when the Cu/Cd index of the food was 56, 23, 9 or 7, but occurred when the index was 3.

The existence of a high Cd level in all developmental stages and a simultaneous elevation of the population density seems paradoxical, because this metal is known for its high toxicity and absence of all physiologically beneficial effects. For *D. punctatus* it brings ecological benefit, not only by weakening the host plant, but most possibly also by weakening the parasitoids. The mechanisms of such weakening have been described in detail (Ortel, 1989; 1991; 1993a; 1993b; 1995a; 1995c; San, 1993; Bishof, 1995), and the exceptionally high Cd level observed in the two samples analyzed (Table 1) offer support for this interpretation.

Table 1 Mean metal levels in pine moths and their food plants in China and Finland

	n	Fe	Mn	Zn	Cu	Cd	Zn/Cd	Cu/Cd
"Unpolluted" south-Finnish background area in Bromarv with very sparse *Dendrolimus pini* population on *Pinus silvestris*								
Food plant	9/nn	89	260	49	4	0.18	567	56
Males	3/3	52	4	67	14	0.05	1340	280
Females	5/6	65	5	83	19	0.05	1660	380
Imagines	8/9	60	5	77	17	0.05	1540	340
Lightly polluted Chinese background area in Guli with sparse *Dendrolimus punctatus* population feeding on *Pinus massoniana*								
Food plant	5/nn	1560	180	32	6	0.26	123	23
Larvae	5/21	120	165	118	12	0.27	437	44
Pupae	7/14	82	9	112	12	0.32	350	38
Males	2/4	205	7	74	19	0.20	370	95
Females	2/3	163	6	227	24	0.51	455	47
Imagines	4/7	187	7	140	21	0.33	406	74
Moderately polluted Chinese area in Zuzhou with strong *Dendrolimus punctatus* population feeding on *Pinus massoniana*								
Food plant	10/nn	214	841	60	5	1.59	38	3
Larvae	5/10	106	72	100	11	1.10	91	10
Pupae	4/10	39	6	143	12	1.85	77	7
Males	2/3	193	6	186	20	2.50	74	8
Females	4/7	253	8	290	21	2.80	104	8
Imagines	6/10	235	7	258	21	2.70	95	8
Eggs	1/70	76	6	250	16	0.11	2272	145
Parasite pupa	1/6	140	14	480	11	4.40	109	3
Parasite ad.	1/6	130	14	410	14	4.90	83	3
Two Pinus massoniana forests in two heavily polluted Chinese areas, from which *Dendrolimus punctatus* populations were absent								
Chongqing								
Food plants	5/nn	482	249	42	3	0.34	124	9
Wulichong								
Food plants	5/nn	666	912	41	3	0.44	93	7

Notes: Metal levels are given as ppm = mg/kg on a dry-weight basis; n – number of examined samples and specimens (nn = numerous needles). Zn/Cd and Cu/Cd indexes are also given. The parasitoid in Zhuzhou was an ichneumonid

In general, moths are able to excrete larval Cd, Fe and Mn during pupation with such efficiency that the levels in adult moths become lower than those occurring in the food of the larvae (Muurman, 1989; Pihlajamäki, 1989; Rantataro, 1989; Nuorteva, 1990; 1999; Gintenreiter, 1993). In Zhuzhou this mechanism did not work in *D. punctatus*. The levels in adult moths were nearly similar to those in the food plant (Table 1). Obviously the metal levels exceeded the capacity of the excretory mechanisms. The transfer of Zn and Cu from host plant to adult moths was, on the contrary, fulfilled in the normal manner of slight bioaccumulation.

An extremely low Cd level was noted in the eggs of *D. punctatus* in Zhuzhou (Table 1). This is an expression for the existence of extremely effective egg protective mechanisms. Such mechanisms are common among different kinds of insects (Nuorteva, 1982; 1990; 1999; Hopkin 1989).

The present pilot-type study has uncovered many such views, which are essential when one wants to understand holistically the mode by which pollutants do support the development of mass outbreaks of insects. It is necessary to stress the need to verify the preliminary results reported in this paper through continued studies.

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