Notes on the impact of air pollution (SO_2 & Pb) on spider (Araneae) populations in North Zealand, Denmark

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Spiders were collected from linden tree *(Tilia)* trunks in North Zealand, Denmark, and the relationships between density, relative frequency, and number of systematic groups and pollution levels were investigated. Significant correlations were found between the number of systematic groups and SO_2 (negative), and between the relative frequency of *Clubiona* spp. and Pb (positive).

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Introduction

As spiders are predatory they may, theoretically, be potential accumulators of toxic materials such as heavy metal compounds. Spiders doubtless play a significant role in terrestrial ecosystems and often are the dominating predatory invertebrates. It is thus of interest to know the influence of the activities of man on spider populations. The aim of this investigation was to study spider populations in relation to two of the most important air pollutants, sulphur dioxide (SO_2) and lead (Pb). The realtively simple tree-trunk ecosystem was chosen, and in order to standardize, only linden trees *(Tilia)* along boulevards were analysed.

Materials and methods

In October 1977, pieces of waste cork (ca. 400 cm^2 per piece), with corrugated cardboard on one side, were tied to the linden trunks (the cardboard on the side facing the tree) 3-7 m above the ground. Thirty pieces were placed at each of the following five localities in North Zealand in Denmark:
Ledreborg Allé at Lejre, UTM: 32U PG87.
Kongelundsvej in the small forest Kongelunden, UTM: 33U UB46.
Vestvolden near Glostrup, 314 m - 580 m north of the major road Roskildevej and about 500 m east of a secondary metal smelter belonging to the firm P. Bergsøe & Søn, UTM: 33U UB37.
Allégade in Frederiksværk, UTM: 33U UC10.
Nørre Allé in Copenhagen, UTM: 33U UB47.
Prior to use the cork pieces were heated to 100°C for one hour to kill all spiders.

The cork paper pieces were taken down in February 1978, and hibernating spiders were extracted in large Tullgren funnels and sorted by hand.

During spring, summer and autumn in 1978 and 1979, spiders were collected from the trunks by brushing and hand-sorting (summer samples).

Atmospheric SO_2 levels were estimated according to Johnsen & Søchting (1973) (Table 1), and the lead burden was expressed as lead concentrations in the spider *Araneus umbraticus* Clerck, 1757 and in the lichen *Lecanora conizaeoides* Nylander ex Crombie (Clausen, 1984) (Table 1). The actual SO_2 levels in 1977 – 1978 are somewhat lower than estimated because of antipollution campaignes, but according to data from »Storkøbenhavns Luftforureningsudvalg«, Stormgade 20, DK-1555 København V, the pollution gradients are the same in 1977 - 1978 as in the early 1970's.

Systematics and nomenclature of spiders follow Locket & Millidge (1951 and 1953) and Locket, Millidge & Merret (1974).

Results

A list of species is given in Table 2. The distribution of spider individuals was not normal, but rather contagious as illustrated by the great variances (Table 2).

The distribution of species was very skewed, with a few dominating species. At all localities the dominant group was juvenile *Philodromus* sp. No adult *Philodromus* were found; the juveniles disappeared from the tree trunks ind early summer, and not until early autumn the genus was seen again, still only represented by juveniles. Most of the *Philodromus* individuals were probably *P. aureolus* (Clerck, 1757), as 15 of 16 specimens reared to adults were *P. aureolus* and one was *P. cespitum* (Walckenaer, 1802).

Neither density nor size of the spiders showed a clear trend in their relations to SO_2 or Pb, but the number of systematic groups clearly decreased with increasing SO_2 levels (Fig. 1, Table 3). The results in Fig. 1 and Table 3 are based on the combined data from cork samples and summer samples, but the same trend is found when data are not combined.

There was a weak, though significant, correlation between the relative frequency of *Clubiona* spp. and the atmospheric lead burden (Fig. 2); Spearman's rank correlation coefficient (r_S) for percentage of *Clubiona* spp. on ppm Pb in *Araneus umbraticus* being 0.456 ($P<0.025$ and N=24). The number of samples (N) is larger than 5 because of subdivision of localities.

	SO_2 ug per m^3	Pb ppm of dry-weight in	
		A.um.	L.con.
Ledreborg Allé	10	5.0	15
Kongelunden	10	3.1	21
Frederiksværk	100	6.8	234
Nørre Allé	120	48	422
Vestvolden	90	96	6838

Table 1. SO_2 and Pb levels at the five localities. SO_2 figures have been estimated from Johnsen & Søchting (1973). Pb figures are from Clausen (1984). SO_2 levels are probably a little lower at Ledreborg Allé as compared to Kongelunden. A.um. = *Araneus umbraticus*, L.con. = *Lecanora conizaeoides*. Ppm = parts per million = ug/g.

Tabel 1. SO_2 og Pb niveauer på de fem lokaliteter. SO_2 værdierne er skønnet udfra Johnsen & Søchting (1973). Pb værdierne er fra Clausen (1984). SO_2 belastningen i Ledreborg Allé er formentlig noget lavere end i Kongelunden. A.um. = Araneus umbraticus, *lL.con.* = Lecanora conizaeoides. *Ppm = milliontedele = ug/g.*

Discussion

A sample size (number of localities) of only five obviously makes a correlation analysis very weak, as the critical value of r_S for N = 5 and a = 0.05 is 0.900. Though the correlation between density of spiders and SO_2 levels is insignificant (Table 3) there *are* significant differences between localities with respect to density (Kruskal-Wallis analysis, $P<<0.001$), with a general decline in numbers towards areas with higher SO_2 levels. The greatest numbers of spiders were obtained at the moderately SO_2 polluted site Vestvolden. It thus seems that there is at first a slight increase in density with increasing SO_2 levels, followed by a distinct decline. It is remarkable that this picture is seen in other studies as well (André, 1977; Charles & Villement, 1977; Freitag & Hastings, 1973; Gilbert, 1971). These studies (including spiders and several other arthropod groups) all note a significant effect of air pollution on the density of the fauna. Also Lebrun (1976) noted an effect of SO_2 pollution. In the present paper it is proposed that as the more brached and foliaceous lichens are replaced by the crustose lichens *Lecanora conizaeoides* and *Lepraria incana* (Linnaeus) Ach. and the algae *Desmococcus* spp., the primary production increases. At higher pollution levels even these relatively tolerant species are injured, and primary production decreases. The production of primary-, and thus of secondary-, consumers most certainly follows the primary production, resulting in a semi-bell-shaped curve of density on SO_2 burden. As can be seen especially in André (1977) and in the present paper, density varies greatly within pollution zones. It seems likely that part of this varia-

	Ledreborg Allé N = 30		Kongelunden N = 30		Vestvolden N = 28		Frederiksværk N = 30		Nørre Allé N = 30	
Segestria senoculata (Linnaeus, 1758)	50 ± 10	x					13 ± 6			
Amaurobius fenestralis (Stroem, 1768)		x								
Amaurobius sp.		x	1 ± 1	x						
Lathys humilis (Blackwall, 1855)	3 ± 3		60 ± 10	x	2 ± 1		8 ± 4	x		
§ *Clubiona brevipes* Blackwall, 1841	50 ± 10		50 ± 9		160 ± 30	x	2 ± 1		40 ± 6	x
C. corticalis (Walckenaer, 1802)					4 ± 3		101 ± 21	x	10 ± 5	
§ *C. pallidula* (Clerck, 1757)	20 ± 4		20 ± 6		90 ± 10				1 ± 1	
Scotophaeus sp.			1 ± 1							
Micaria subopaca Westring, 1861				x					1 ± 1	
§ *Anyphaena accentuata* (Walckenaer, 1802)		x	± 1							
Diaea dorsata (Fabricius, 1777)	3 ± 2		2 ± 2							
Oxyptila praticola (C.L. Koch, 1837)			2 ± 2							
Philodromus sp.	290 ± 30	x	330 ± 30	x	370 ± 40	x	128 ± 16	x	140 ± 16	x
Xysticus sp.			1 ± 1							
Salticus cingulatus (Panzer, 1797)		x		x		x				
Tegenaria sp.	4 ± 2									
Textrix denticulata (Olivier, 1789)							4 ± 2			
Cryphoeca silvicola (C.L. Koch, 1834)				x						
Pardosa sp.						x				
Anelosimus sp.			120 ± 20		30 ± 8		20 ± 6			
Dipoena sp.									1 ± 1	
Steatoda bipunctata (Linnaeus, 1758)	1 ± 1	x			40 ± 10	x	4 ± 3	x	3 ± 2	x
Theridion familiare O.Pickard-Cambridge, 1871	2 ± 1		20 ± 6	x		x	6 ± 2	x	10 ± 4	x
Th. mystaceum L. Koch, 1870		x		x				x	1 ± 1	x
Th. tinctum (Walckenaer, 1802)	1 ± 1		20 ± 5	x	20 ± 4	x	2 ± 1	x	3 ± 2	x
Th. pallens Blacvkall, 1834	5 ± 3		10 ± 4		3 ± 2		16 ± 4			
Theridion sp.				x						x
Meta merianae (Scopoli, 1763)		x								
M. segmentata (Clerck, 1757)		x	1 ± 1							
Tetragnatha sp.				x						
Araneus diadematus Clerck, 1757	1 ± 1	x	4 ± 2		20 ± 3	x			1 ± 1	
A. gibbosus (Walckenaer, 1802)	1 ± 1		6 ± 3							
A. group IX (sensu Locket & Millidge, 1953)					1 ± 1					
A. umbraticus Clerck, 1757	2 ± 1	x	20 ± 4	x	7 ± 2	x	4 ± 2	x		x

	Ledreborg Allé N = 30		Kongelunden N = 30		Vestvolden N = 28		Frederiksværk N = 30		Nørre Allé N = 30	
Araneus sp.				x						
Zygiella atrica (C.L. Koch, 1845)		x			2± 1	x				
Z. x-notata (Clerck, 1757)								x		
Zygiella sp.						x				
Drapetisca socialis (Sundevall, 1832)		x		x						
Lepthyphantes minutus (Blackwall, 1833)				x		x				
L. group I (sensu Locket & Millidge, 1953)		x		x		x				
Moebelia penicillata (Westring, 1851)	80±20	x	40± 7	x	10± 4	x			60±20	x
Syedrula innotabilis (O.Pickard-Cambridge, 1863)		x		x						
Tapinocyba sp.	1± 1									
Walckenaera sp.			1± 1							
Linyphiinae sp.		x		x						x
Total	530±50		730±60		750±70		310±40		280±30	

Table 2. Number of spiders per m^2 of cork ± standard error. x: present in »summer samples«. N =number of samples. §: Individuals of *Clubiona brevipes* and *C. pallidula* younger than subadult (genitalia not discernible) could not be separated.

Tabel 2. Antal edderkopper pr. m^2 kork ± standardfejl. x: Tilstede i »sommerfangster«. N = antal korkstykker. §: Små individer (kønsorganerne ikke erkendbare) af Clubiona brevipes *og* C. pallidula *kunne ikke adskilles.*

tion is caused by the operation of factors like other pollutants and urbanization. Also it is certain that »tourists« play a significant role in tree ecosystems (Gilbert, 1971; Southwood et al., 1982; Toft 1976).

Most probably, the decline in numbers of systematic groups as SO_2 levels increase is due largely to the decline in structural diversity associated with the epiphytic flora, though direct toxic effects and the degree of urbanization cannot be ruled out as important factors. Several authors have noted that the number of spider species is dependant on the spacial structure of the habitat (Duffey, 1966 & 1978; Elbourn, 1970; Huhta, 1971; Kajak, 1978; Lowrie, 1963; Robinson, 1981; Turnbull, 1973; Williamson & Evans, 1972), and it thus seems sound to emphasize that factor. A significant decline in numbers of species is also seen in André (1977) and in Gilbert (1971). If the correlation between number of species and SO_2

	no. of species	no. of genera	no. of families	no. of individuals per m^2
SO_2	-0.975+	-0.975+	-1.000+	-0.600
Pb	-0.600	-0.600	-0.700	0.100

Table 3. Spearman's rank correlation (r_s) between pollution levels and number of systematic groups and density. N (number of samples) in all cases 5. +: $P \leqslant 0.05$.

Tabel 3. Spearman's rank korrelation (r_s) mellem forureningsniveauer og antallet af systematiske grupper og tætheden. N (antal »prøver«) i alle tilfælde 5. +: $P \leqslant 0,05$.

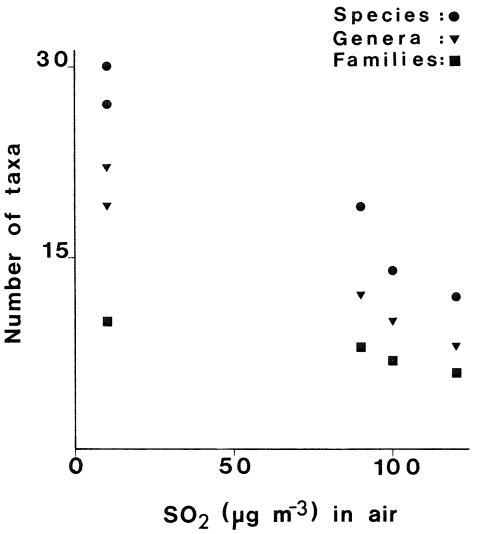

Fig. 1. Number of species, genera and families as a function of the SO_2 burden. Filled circles: species, triangles: genera, squares: families.

Fig. 1. Antal arter, slægter og familier som funktion af SO_2 belastningen. Boller: arter, trekanter: slægter, firkanter: familier.

burden is calculated the following figures result:

André (1977): $r_S = -0.708$, $P < 0.01$, $N = 12$
Gilbert (1971): Total: $r_S = -0.650$, $P < 0.05$, $N = 8$
Predators: $r_S = -0.892$, $P < 0.005$, $N = 8$

It is noteworthy that, contrary to what is noted by Gilbert (1971), the predators seem to be more affected than non-predators.

Reports on effects of Pb on populations of spiders and other arthropod groups are contradictory and not convincing (Maurer, 1974; Musket & Jones, 1980; Przybylski, 1979; Williamson & Evans, 1972 & 1973). Strojan (1978) found a significant decline in numbers of litter arthropods with increasing Pb burden. But the effect may equally well be a result of high concentrations of serveral other heavy metals. The present paper confirms the impression that the effect of Pb on arthropods is generally weak or obscure. An exception seems to be a positive influence of Pb on the relative frequency of *Clubiona* spp.. Clausen (1984, Table 2) measured Pb in *Araneus umbraticus, A. diadematus* Clerck, 1757, the three *Clubiona* species, *Philodromus* sp., *Steatoda bipunctata* (Linnaeus, 1758), and *Moebelia penicillata* (Westring, 1851). Compared to the other species with a two-year cycle (all but *M. penicillata) Clubiona* spp. generally exhibit lower lead concentrations, this being especially true at the more polluted sites Nørre Allé and Vestvolden (Mann-Whitney U-test: $U = 324$, $P < 0.0005$, $n_1 = 11$, $n_2 = 24$, and $Z = 17.216$, $P << 0.01$, $n_1 = 74$, $n_2 = 87$ respectively). It may thus be, that *Clubiona* spp. are favoured somewhat in competition with other spiders at lead polluted sites because of a lower lead uptake.

Conclusions

The relation between spider density and SO_2 levels is not simple, bus probably forms a more or less bell-shaped curve.

There is a significant decline in number of spider species with increasing SO_2 levels.

The relative frequency of *Clubiona* spp. is positively correlated with Pb pollution, possibly because of their lower lead burden as compared to other 2-year cycle species.

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Sammendrag

Edderkopper blev indsamlet på lindestammer *(Tilia)* i Nordsjælland på følgende lokaliteter:
Ledreborg Allé ved Lejre, UTM: 32U PG87.
Kongelundsvej i Kongelunden, UTM: 33U UB46.
Vestvolden ved Glostrup, 314 m -580 m nord for Roskildevej og ca. 500 m øst for den sekundære metalsmelter P. Bergsøe & Søn, UTM: 33U UB37.
Allégade i Frederiksværk, UTM: 33U UC10.
Nørre Allé i København, UTM: 33U UB47.

Indsamlingen foregik ved hjælp af pyntekorkstykker forsynet med bølgepap på bagsiden. Disse korkstykker blev sat op på stam-

merne efteråret 1977 og nedtaget i februar 1978. Dyrene blev herefter uddrevet i Tullgren-tragte. Supplerende indsamlinger blev foretaget i sommerhalvårene 1978 og 1979 ved børstning af stammerne og »håndindsamling«.

Tætheden af edderkopper viste ikke en statistik sikker sammenhæng med forureningen, skønt der var statistisk sikre forskelle mellem lokaliteterne med hensyn til tætheden af edderkopper. Det foreslås, at primærproduktionen øges ved moderat SO_2

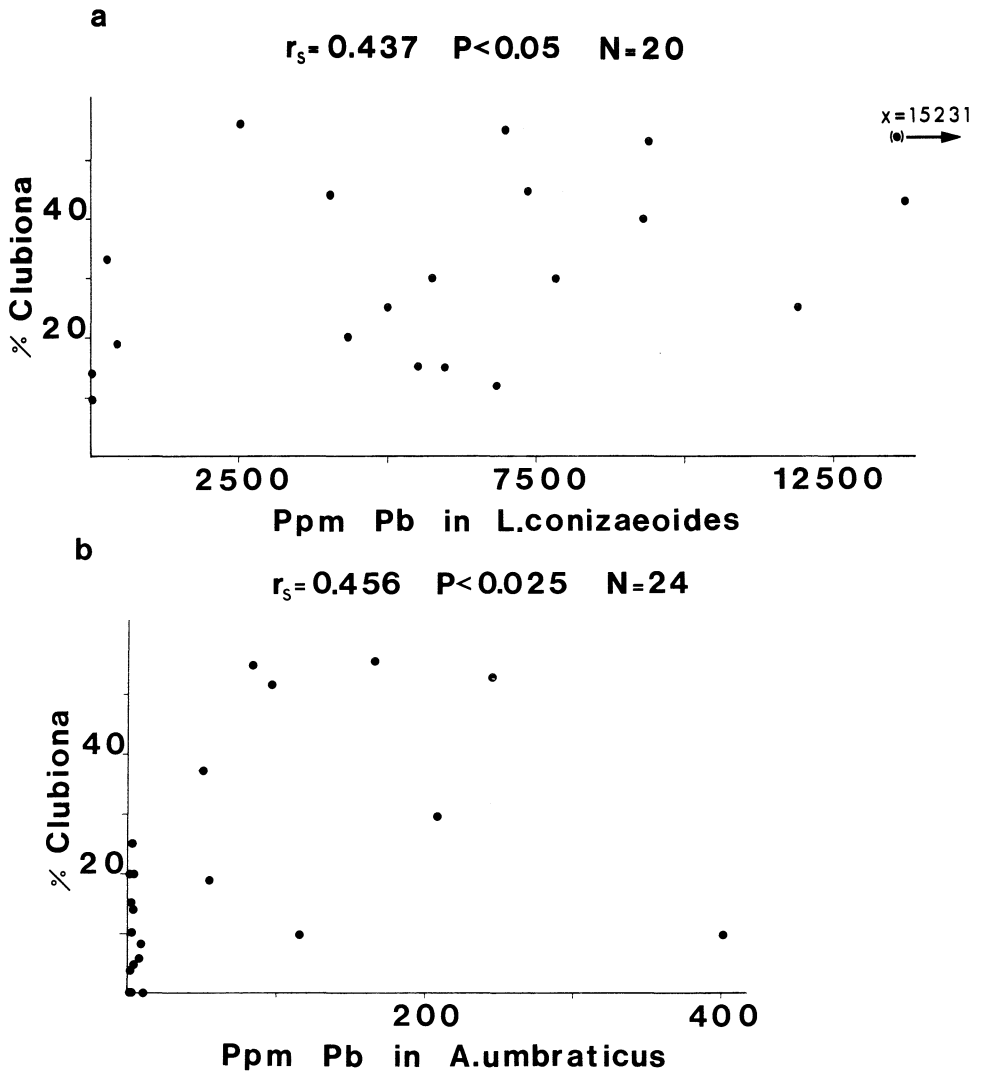

Fig. 2. Relative frequency of *Clubiona* spp. as a function of lead concentrations in:
a) the lichen *Lecanora conizaeoides* and
b) the spider *Araneus umbraticus,*
r_S = Spearman's rank correlation coefficient. N = number of observations. P = level of significance. Ppm = parts per million = ug/g (dry-weight).

Fig. 2. Relative hyppighed af Clubiona *spp. som funktion af blykoncentrationer i:*
a) laven Lecanora conizaeoides *og*
b) edderkoppen Araneus umbraticus.
r_S = Spearman's rank korrelations koefficient. N = antal observationer. P = signifikansniveau. Ppm = milliontedele = ug/g (tørvægt).

forurening på grund af, at de grenede og buskede laver erstattes af de skorpeformede laver *Lecanora conizaeoides* Nyl. ex. Chromb. og *Lepraria incana* (Linnaeus) Ach. og af algerne *Desmococcus* spp., der antages at være mere produktive end de to førstnævnte grupper. På stærkt forurenede lokaliteter skades også disse organismer og primærproduktionen falder. Det synes rimeligt at antage, at edderkoppetætheden vil følge primær- og sekundærproduktionen.

Antallet af edderkoppegrupper (arter, slægter eller familier) faldt med stigende SO_2 forurening (Fig. 1, Tabel 3), rimeligvis på grund af den formindskede rumlige variation som følge af de grenede og buskede lavers forsvinden.

Den relative hyppighed af *Clubiona* spp. var positivt korreleret med blyforureningen (Fig. 2). En forklaring kan være, at *Clubiona* spp. optager mindre Pb end de øvrige toårige edderkopper på de stærkest forurenede lokaliteter Nørre Allé og Vestvolden (Mann-Whitney U-test: $P < 0{,}0005$ og $P << 0.01$ henholdsvis).

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