Bull.Br.arachnol.Soc. (1986) 7 (3), 83-86

The use of spiders (Araneae) as ecological indicators*

I. H. S. Clausen
Institut for Populations Biologi,
Universitetsparken 15,
DK-2100 København Ø,
Denmark

Introduction

This paper deals with the use of spiders in biological monitoring, focusing on the general description of biotopes and on monitoring of pollutants.

Spiders can be found almost everywhere and usually in abundance. Being mobile and relatively short-lived they may adjust more rapidly to changes in the environment than, for example, higher plants and lichens. As they are predaceous, there is a potential for biological concentration of toxic matter such as heavy metals.

Description of biotopes

In the terrestrial environment it has long been routine to characterise and describe biotopes by means of the flora, especially vascular plants; analysis of the flora is widely accepted as a measure of the "general ecological state" of the biotope. Is it possible to use spiders in a similar way?

Numerous workers have shown that different biotopes have specific spider faunas, and in gradient analyses the species are not evenly or randomly distributed; the general impression is that spider faunas give a pattern similar to that of vascular plants (e.g. Barnes & Barnes, 1955; Duffey, 1966, 1968; Schaefer, 1970; Allred, 1975; Curtis, 1978; Heublein, 1982). This is not the same as saying that the number of spider species simply fluctuates closely with the number of plant species. In fact, the number of spider species is not well correlated with the number of plant species, but depends to a much greater extent on the spatial structure and microclimate of the environment (e.g. Duffey, 1966, 1968; Robinson, 1981; Greenstone, 1984; Clausen, 1984b). Thus, in a synecological study (Børgesen *et al.*, 1984) it was found that the correlation between the number of spider species (S) and the number of plant species (vascular plants) was insignificant (Spearman's rank correlation coefficient = r_S= 0.049, $p > 0.25$, $n = 10$), while the correlation between S and the percentage cover of vascular plants was significant (r_S= 0.685, $p < 0.025$, $n = 10$).

Like plants, different spider species have different requirements. For example, consider the following species list from a habitat in Denmark: *Clubiona subtilis* L. Koch, *Tibellus maritimus* (Menge), *Hyctia nivoyi* (Lucas), *Attulus saltator* (Simon), *Aelurillus v-insignitus* (Cl.), *Phlegra fasciata* (Hahn), *Pardosa agricola* forma *arenicola* (O. P.-C.), *Alopecosa fabrilis* (Cl.), *Arctosa perita* (Latr.), *Theridion impressum* L. Koch, *Tapinopa longidens* (Wider), *Metopobactrus prominulus* (O. P.-C.), *Erigone arctica* (White). From their knowledge of the requirements of the different species, most northern European arachnologists would readily deduce that the collector had visited a coastal dune habitat. In fact, it might even be possible to tell which sampling method had been used, or which vegetation layer had been sampled.

In Børgesen *et al.* (1984) cluster analysis based on Sørensen's similarity index, QS (Southwood, 1976), gave the same main groupings with spider data as when floristic data were used. Moreover, there was a very significant correlation between $QS_{spiders}$ and QS_{plants} ($r = 0.657$, $p < 0.0005$, $n = 45$).

Therefore, theoretically, it seems that the spider fauna may be as suitable for the characterisation of biotopes as are vascular plants. What drawbacks might there be? First, it may be quite difficult for non-arachnologists to identify spiders, so in any case the use of spiders would be restricted to more thorough investigations. Second, there would also be a need for standardisation of sampling methods, as different methods collect very different parts of the spider fauna. In Børgesen *et al.* (1984) two sampling methods, pooter (Southwood, 1976) and handsorting of vegetation from a quadrat, both of which were supposed to collect from the vegetation, gave completely different catches with respect to species. One must also be aware of temporal variations; although the species composition may vary at specific sites, the similarity between sites might vary much less. Barnes & Barnes (1955), MacMahon & Trigg (1972), Norberg (1978), and Jansson & Brömsson (1981) indicate that the species composition varies rather little within the two main seasons of the year. However, in Curtis (1978) the cluster analysis dendrograms show considerable variation throughout the year, but data based on harvestmen (Opiliones) are also included in the analysis.

Monitoring of pollutants

Faunal analysis

The analysis of density, frequency, species richness and indicator species has been used successfully with many kinds of organisms in freshwater pollution studies and with lichens in air pollution work. There has been relatively little investigation of the effect of pollutants on arthropods in the terrestrial environment, and only a few authors have attempted to evaluate whether observed effects could be used as a measure of pollution levels (Freitag & Hastings, 1973; André, 1977; André *et al.*, 1982; Clausen, 1984b).

Spider faunas on trees have been studied in relation to SO_2 pollution by Gilbert (1971), André (1977), and Clausen (1984b). A trend in relation to SO_2 is seen in all three papers. In André (1977) the density of spiders is negatively correlated with the SO_2 burden, while in Gilbert (1971) and Clausen (1984b) the correlation is insignificant, though Clausen (1984b) found significant differences in density of spiders between pollution zones with the lowest values in the most polluted areas.

*This paper was presented at a symposium on spider ecology and behaviour held at Furzebrook Research Station in June 1985.

It is possible that the density of spiders on trees is predominantly related to the supply of prey, which is related to the primary productivity on the trees and the mass of "tourists"; this results in great variance and a semi-bell-shaped density/SO_2 curve (Clausen, 1984b). It may thus be significant that the relative density of spiders (compared with total arthropods) is better correlated with SO_2 levels than absolute density, as shown by André (1977) ($r_s{}^* = -0.811, p < 0.0025$; and $r_s{}^* = -0.762$, $p < 0.005$ respectively (one-sided); $n = 12$ in both cases).

The number of spider species might be a more promising indication of the SO_2 burden, the correlation between the two factors being $r_s = -0.975$, $p < 0.05$ (one-sided), $n = 5$ (Clausen, 1984b), and $r_s{}^* = -0.733$, $p < 0.005$ (one-sided), $n = 12$ (data from H. M. André, pers. comm.). Gilbert (1971) did not find the number of spider species to be significantly correlated with SO_2 levels, but the number of individuals as well as species was surprisingly small, probably because of the sampling method, viz., "invertebrates seen". Much of the correlation between the number of species and SO_2 level can probably be explained by the marked changes in structural diversity associated with the epiphytic flora, especially the lichens. Also, there may be a more direct toxic effect, but how great this is it is difficult to say.

Apart from SO_2, spider faunas have been analysed in relation to heavy metals, notably lead (Pb). Only in extreme cases of high environmental concentrations has there been noted an effect on the spider fauna which could most reasonably be explained by heavy metal pollution (Strojan, 1978; Bengtsson & Rundgren, 1984; Clausen, 1984b), and it must be concluded that spiders in general are not very sensitive to heavy metals. However, Clausen (1984b) found a significant positive correlation between the relative frequency of *Clubiona* spp. (compared with total spider fauna) and lead burden, and a similar correlation was also found between Clubionidae spp. (compared with total spiders) and heavy metal (Pb, Cu and Zn) pollution by Bengtsson & Rundgren (1984) for their sampling period in August 1979 (in the two other periods n is only 5): $r_s{}^* = 0.676, p = 0.05$ (one-sided), $n = 8$. In addition it has been found that *Clubiona* spp. have a lower lead content than other spiders with a two-year cycle, especially in high pollution zones (Clausen, 1984a, b), which may favour the genus in competition with other spiders.

There is still a long way to go in the study of spider faunas in relation to specific pollutants. Leblanc & DeSloover (1970), working with lichens, introduced an "Index of Atmospheric Purity", IAP (in French IPA). André (1977) constructed an IAP based on the total fauna: $IAP_f = \sum_{i=1}^{s} \frac{q_i f_i}{100}$, where q_i = the mean number of other species with which species i co-occurs, and f_i = frequency of i. André (1977) found a significant and relatively high correlation between $IAP_{lichens}$ and IAP_f ($r_s = 0.74$, $p < 0.01$, $n = 12$). In freshwater biology, the so-called level of saprobity (X) has been much used (Sladecek, 1973). X is weighted with respect to the frequencies of species in different pollution zones (x), and with respect to the values of species as indicators of specific pollution zones (g).

$$X = \sum_{i=1}^{s} h_i g_i x_i \,/\, \sum_{i=1}^{s} h_i g_i,$$

where h_i is the abundance of the individual species. Such an index, of course, may also be developed for terrestrial organisms with respect to specific pollutants.

The drawbacks of the IAP and X are especially that they require very large samples in different areas of pollution to establish the values of q, g and x, and these values must be calibrated for each major geographic area because of climatic and genetic differences. These indices, however, do have an advantage over diversity indices like Shannon-Wiener's (H) and Simpson's (D), as they are based on actual biological observations of the organisms involved, while the diversity indices are based mainly on mathematical considerations (Goodman, 1975; May, 1981). H and D calculated from data in Clausen (1984b) showed no trend in relation to air pollution, and the difference between the extreme values of H was insignificant: $t = 0.009$, $d.f. = 32$, $p > 0.25$ (Zar, 1974), the ranges of H and D being 1.41-1.83 and 0.64-0.74, respectively. H has been used in the air pollution studies of Lebrun (1976) and André (1977), but their results are contradictory as they found a positive and a negative correlation, respectively, between H and pollution levels. H and D should certainly be used with caution, if at all.

Measurement of heavy metals

Lichens have been used successfully as metal collectors in studies of atmospheric heavy metal pollution, i.e., lichens are collected and their metal concentration is used as a measure of the atmospheric burden (Hawksworth & Rose, 1976; Andersen *et al.*, 1978; Pilegård, 1978; Moseholm, 1981).

Heavy metals in spiders have been measured by Williamson & Evans (1972: Pb), Price *et al.* (1974: Pb), Wade *et al.* (1980: Pb, Zn), Bengtsson & Rundgren (1984: Pb, Cu) and Clausen (1984a: Pb), and they all note elevated values of lead in the animals close to pollution sources. Clausen (1984a) showed that the lead concentration in *Araneus (Nuctenea) umbraticus* Clerck in northeastern Zealand, Denmark, was as good a measure of the atmospheric burden as was the concentration in the lichen *Lecanora conizaeoides* Nylander ex Crombie. It is certain that part of the lead "in" *A. umbraticus* reflects atmospheric levels directly, as about 25% of the lead can be washed off. Added to this that *A. umbraticus* eats the old web prior to producing a new one, and that some of the lead ingested with prey animals is from surface deposits, it seems likely that a significant part of the lead within the spiders originates directly from the air. Also, a behaviour like grooming may be important in the transfer of metals from the surface into the body. If,

* indicates that the calculation was made by Clausen.

from Wade *et al.* (1980), one calculates the correlations between lead concentrations in Arachnida (spiders and harvestmen) and distance from road or ppm lead in vegetation, it is seen that ppm lead in arachnids is more closely correlated with ppm lead in the plants than with distance from the road: $r_S^* = -0.679$ ($0.05 < p < 0.1$) and $r_S^* = 0.893$ ($p = 0.01$), in both cases one-sided and $n = 7$. It may be noted that the first r_S is insignificant while the latter is highly significant. Such a result is in good agreement with the hypothesis that a large part of the lead in spiders originates from the air, as almost all of the lead in non-root parts of the vegetation is associated with or derived from particles deposited on the surface, lead not being very mobile within plants (Little & Wiffen, 1977, 1978; Hughes *et al.*, 1980). The lead in the vegetation thus probably reflects sedimentation conditions as well as concentration. Finally, if a significant part of the internal lead in spiders originates from atmospheric particles, one would expect the regression line for internal lead in *Araneus* as a function of lead in *Lecanora* to be parallel with the regression line for lead washed off *Araneus* as a function of lead in *Lecanora*, and this was in fact found by Clausen (1984a).

A major difference between the *Araneus*- and *Lecanora* measurements is probably that the lead concentration in *Araneus* reflects atmospheric levels from not more than 2 years prior to sampling, while that in the lichen reflects a period of 4 to 5 years or more. The lichen is, in most cases, easier to collect, but it is impossible to distinguish individuals, and all age groups are mixed together. With *Araneus*, measurements can be made on single individuals irrespective of size, which makes it easier to collect sufficient numbers, and makes it possible to compare the lead content of different age groups. The negative correlation between body size and lead concentration noted in other invertebrates (Schulz-Baldes, 1973; Boyden, 1974, 1977; Williamson, 1979, 1980) has also been found in spiders, but it is so weak that it can hardly be detected at any one locality, and will not influence conclusions about lead levels. The difficulties with the use of spiders in heavy metal measurements are mainly the contamination of samples in the laboratory and, in some cases, the problem of finding enough specimens.

Perhaps in future work tests should be made for differences between species of *Araneus* with respect to (1) heavy metal content, and (2) differences in the relations between metals in spiders and metals in the air. Another point of concern is the possibility of antagonistic/synergistic effects between different pollutants. Also, chemical speciation may be important (Hughes *et al.*, 1980). Thus, when one speaks of lead in the atmosphere one actually refers to all sorts of lead compounds with different qualities. Unfortunately, the chemical speciation processes are very hard to study.

Conclusions

Description of the spider fauna gives the same general picture of the biotope as does description of the vascular plant flora.

As yet, the number of spider species seems to be the only clear trend in relation to SO_2 levels.

Clubionids are probably less sensitive to lead than most other spiders, resulting in an increased relative frequency of these spiders with increased lead pollution.

The distribution of spider species in relation to pollutants, especially SO_2, should be studied in order to calculate q-values and g- and x-values in the Index of Atmospheric Purity and "saprobity" index respectively.

The Shannon-Wiener and Simpson indices of diversity do not seem to show any trend in relation to air pollution.

In North Zealand, lead concentration in the spider *Araneus umbraticus* is as good a measure of the atmospheric lead level as lead in the lichen *Lecanora conizaeoides*. Most probably a significant part of the lead in spiders originates directly from the atmosphere.

Acknowledgements

I should like to thank Lisbeth W. Børgesen and Ole Chr. Hansen, Institute of Population Biology, Copenhagen, and Mary Petersen, Zoological Museum, Copenhagen for reading through this paper; H. M. André, Laboratoire d'Écologie Générale et Expérimentale, Université Catholique de Louvain, Belgium, for kindly sending me his data; and "Dr. Phil. Axel Hemmingsens legat" for financial support.

References

ALLRED, D. M. 1975: Arachnids as ecological indicators. *Gt Basin Nat.* **35**: 405-406.

ANDERSEN, A., HOVMAND, M. F. & JOHNSEN, I. 1978: Atmospheric heavy metal deposition in the Copenhagen area. *Environ.Pollut.* **17**: 133-151.

ANDRÉ, H. 1977: Introduction a l'étude écologique des communautés de microarthropodes corticoles soumises a la pollution atmospherique. II. Recherche de bioindicateurs et d'indices biologique de pollution. *Annls Soc.r.zool.Belg.* **106**: 211-224.

ANDRÉ, H. M., BOLLY, C. & LEBRUN, Ph. 1982: Monitoring and mapping air pollution through an animal indicator: A new and quick method. *J.appl.Ecol.* **19**: 107-111.

BARNES, R. D. & BARNES, B. M. 1955: The spider population of the abstract broomsedge community of the southeastern Piedmont. *Ecology* **36**: 658-666.

BENGTSSON, G. & RUNDGREN, S. 1984: Ground-living invertebrates in metal-polluted forest soils. *Ambio* **13**: 29-33.

BOYDEN, C. R. 1974: Trace element content and body size in molluscs. *Nature, Lond.* **251**: 311-314.

BOYDEN, C. R. 1977: Effect of size upon metal content in shellfish. *J.mar.biol.Ass.U.K.* **57**: 675-714.

BØRGESEN, L. W., CHRISTENSEN, S. N., CLAUSEN, I. H. S., CLAUSEN, M. W., HANSEN, O. C., MADSEN, P. B. & REHDER, S. 1984: *En flora- og faunaundersøgelse i Nordmarken, Læsø.* A report at the Institute of Population Biology, University of Copenhagen.

CLAUSEN, I. H. S. 1984a: Lead (Pb) in spiders: A possible measure of atmospheric Pb pollution. *Environ.Pollut.*(Ser.B) **8**: 217-230.

CLAUSEN, I. H. S. 1984b: Notes on impact of air pollution (SO_2 & Pb) on spider (Araneae) populations in North Zealand, Denmark. *Ent.Meddr.* **52**: 33-39.

CURTIS, D. J. 1978: Community parameters of the ground layer araneid-opilionid taxocene of a Scottish island. *Symp.zool.Soc.Lond.* **42**: 149-159.

DUFFEY, E. 1966: Spider ecology and habitat structure. *Senckenberg.biol.* **47**: 45-49.

DUFFEY, E. 1968: An ecological analysis of the spider fauna of sand dunes. *J.Anim.Ecol.* **37**: 641-674.

FREITAG, R. & HASTINGS, L. 1973: Kraft mill fallout and ground beetle populations. *Atmos.Environ.* **7**: 587-588.

GILBERT, O. L. 1971: Some indirect effects of air pollution on barkliving invertebrates. *J.appl.Ecol.* **8**: 77-84.

GOODMAN, D. 1975: The theory of diversity-stability relationships in ecology. *Q.Rev.Biol.* **50**: 237-266.

GREENSTONE, M. H. 1984: Determinants of web spider species diversity: Vegetation structural diversity vs. prey availability. *Oecologia (Berl.)* **62**: 299-304.

HAWKSWORTH, D. & ROSE, F. 1976: *Lichens as pollution monitors.* Studies in Biology no. 66. London: Edward Arnold.

HEUBLEIN, D. 1982: Untersuchungen zum Einfluß eines Waldrandes auf die epigäische Spinnenfauna eines angrenzenden Halbtrockenrasens. In: *Hecken und Flurgehölze- Struktur, Funktion und Bewertung.* Akademie für Naturschutz und Landschaftspflege, Laufener Seminarbeiträge 5/82.

HUGHES, M. K., LEPP, N. W. & PHIPPS, D. A. 1980: Aerial heavy metal pollution and terrestrial ecosystems. *Adv.ecol.Res.* **11**: 217-372.

JANSSON, C. & BRÖMSSON, A. von 1981: Winter decline of spiders and insects in spruce *Picea abies* and its relation to predation by birds. *Holarctic Ecology* **4**: 82-93.

LEBLANC, F. & DESLOOVER, J. 1970: Relation between industrialization and the distribution and growth of epiphytic lichens and mosses in Montreal. *Can.J.Bot.* **48**: 1485-1496.

LEBRUN, Ph. 1976: Effets écologiques de la pollution atmosphérique sur les populations et communautés de microarthropodes corticoles (acariens, collemboles et ptérygotes). *Bull.Soc.Ecol.(Fr.)* **7**: 417-430.

LITTLE, P. & WIFFEN, R. D. 1977: Emission and deposition of petrol engine exhaust Pb I. Deposition of exhaust Pb to plant and soil surfaces. *Atmos.Environ.* **11**: 437-447.

LITTLE, P. & WIFFEN, R. D. 1978: Emissions and deposition of lead from motor exhausts II. Airborne concentrations, particle size and deposition of lead near motorways. *Atmos.Environ.* **12**: 1331-1341.

MACMAHON, J. A. & TRIGG, J. R. 1972: Seasonal changes in an old-field spider community with comments on techniques for evaluating zoosociological importance. *Am.Midl.Nat.* **87**: 122-132.

MAY, R. M. 1981: Pattern in multi-species communities. *In* R. M. May (ed.), *Theoretical ecology. Principles and applications.* 2nd ed.: 197-227. Oxford: Blackwell Scientific Publications.

MOSEHOLM, L. 1981: *Biomonitering af bly omkring accumulatorfabriken A/S LYAC, lavundersøgelse, 1981.* Report from COWICONSULT, Teknikerbyen 45, DK-2830 Virum, Denmark.

NORBERG, R. Å. 1978: Energy content of some spiders and insects on branches of spruce (*Picea abies*) in winter; prey of certain passerine birds. *Oikos* **31**: 222-229.

PILEGÅRD, K. 1978: Airborne metals and SO_2 monitored by epiphytic lichens in an industrial area. *Environ.Pollut.* **17**: 81-92.

PRICE, P. W., RATHCKE, B. J. & GENTRY, D. A. G. 1974: Lead in terrestrial arthropods: Evidence for biological concentration. *Environ.Entomol.* **3**: 370-372.

ROBINSON, J. V. 1981: The effect of architectural variation in habitat on spider community: An experimental field study. *Ecology* **62**: 73-80.

SCHAEFER, M. 1970: Einfluß der Raum in Landschaften der Meeresküste auf der Verteilungsmuster der Tierwelt. *Zool.Jb.*(Syst.) **97**: 55-124.

SCHULZ-BALDES, M. 1973: Die Miesmuschel *Mytilus edulis* als Indikator für die Bleikonzentration im Weserästuar und in der Deutschen Bucht. *Mar.Biol.* **21**: 98-102.

SLADECEK, V. 1973: System of water quality from the biological point of view. *Arch.Hydrobiol.,Beih.,Limnol.* **7**.

SOUTHWOOD, T. R. E. 1976: *Ecological methods, with particular reference to the study of insect populations.* London: Chapman and Hall.

STROJAN, C. L. 1978: The impact of Zn-smelter emissions on forest litter arthropods. *Oikos* **31**: 41-46.

WADE, K. J., FLANAGAN, J. T., CURRIE, A. & CURTIS, D. J. 1980: Roadside gradients of lead and zinc concentrations in surface-dwelling invertebrates. *Environ.Pollut.*(Ser.B) **1**: 87-93.

WILLIAMSON, P. 1979: Comparison of metal levels in invertebrate detritivores and their natural diets: Concentration factors reassessed. *Oecologia (Berl.)* **44**: 75-79.

WILLIAMSON, P. 1980: Variables affecting body burdens of lead, zinc, and cadmium in a roadside population of the snail *Cepaea hortensis* Müller. *Oecologia (Berl.)* **44**: 213-220.

WILLIAMSON, P. & EVANS 1972. Lead: Levels in roadside invertebrates and small mammals. *Bull.environ.Contam.& Toxicol.* **8**: 280-288.

ZAR, J. H. 1974: *Biostatistical analysis.* Englewood Cliffs, NJ: Prentice-Hall.