POLISH JOURNAL OF ECOLOGY (Pol. J. Ecol.)	47	4	465–476	1999

Effect of industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland)

ELIZA DĄBROWSKA-PROT

Department of Bioindication, Institute of Ecology, Polish Academy of Sciences
Dziekanów Leśny near Warsaw 05–092 Łomianki, Poland, e-mail: ekolog@warman.com.pl.

EFFECTS OF SPRUCE FOREST DEGRADATION ON ABUNDANCE AND DIVERSITY OF THE BIOCENOSES. RESEARCH SYNTHESIS

ABSTRACT: This work presents results of the studies on responses of plant communities and ecologically diverse invertebrate communities to mountain spruce forest decline in the western part of Karkonosze Mts. (south-western Poland). It was examined how distribution and biodiversity and predator-prey relations of invertebrates (Araneae, Diptera, Protozoa) have been affected by fragmentation of the landscape composed of residues of old-growth spruce forests, young spruce stands and deforested areas.

KEY WORDS: spruce forest decline, mountain vegetation, Araneae, Diptera and Protozoa communities, invertebrate distribution

1. INTRODUCTION

Declining of spruce forests affected by industrial pollution has had serious scientific and economic consequences not only in Poland (Schulze et al. 1989). Completely new ecological circumstances have arisen. Over large mountainous areas, even-aged spruce monocultures have been transformed into a diverse landscape, the main core of which, besides old-growth spruce forests, consists of open areas devoid of trees and regenerated spruce saplings of different ages. In Poland, such a situation has occurred in the Sudeten Mountains, primarily in their western parts – in the Karkonosze region (see Fig. 1 in Dąbrowska-Prot 1999a p 366, this volume). An inventory of natural resources made in this region several years ago (aerial photographs) showed that of about 35 thousand hectares spruce stands (Plagiotecio-Piceetum hercynicum and P.P.h. filicetosum) covered as much as 60% of the area, with considerable fraction showing different stages of damages (Zawiła-Niedźwiecki 1992). This was the reason to undertake studies that aimed at analysing changes in structure and functioning of the plant and animal communities affected by tree cover destruction, herb layer transformation and appearance of open areas and regenerated spruce stands in the spatial structure. A slope on Mumlawski Wierch (1219 m a.s.l.) and adjacent valley of the Kamienna river (900 m a.s.l.) served as a model study area (see Fig. 2 in Dąbrowska-Prot 1999a p 369, this volume). This region is situated in the western part of Karkonosze Mts. polluted to the most by industrial dusts (Zwoździak et al. 1995). In order to make a comparison, additional studies were carried out at higher elevations of Karkonosze, i.e. on Szrenica Mount (1362 m a.s.l.). As an effect of gradual forest ecosystem degradation and secondary succession of spruce forests in both areas examined, strips of different stages of degradation and regeneration of the spruce habitats occurred alternately. Such a streaked arrangement of the three habitat types (living, declined, and regenerated spruce forests) (see Fig. 2 in Dąbrowska-Prot 1999a p 363, this volume) is characteristic of the entire affected part of Karkonosze Mts. The studies were performed in each of the habitat types occurring in the upper and lower montane zones.

2. TRANSFORMATIONS OF PLANT COMMUNITIES

First symptoms of spruce forest decline in the Karkonosze region appeared in early 70-ties. The damages were an effect of increased inputs of industrial pollutants (Zwoździak et al. 1995), enhanced acidification of the waters and soils (Zimka and Stachurski 1996), and hence mobilisation of toxic elements (Al, Pb, As, Hg, Cd, U, Be) derived from the granite bedrock (Sachanbiński 1995), as well as deficiencies of biogenic elements, N, K, Mg and Ca in particular (Stachurski et al. 1994, Zimka and Stachurski 1996). All the factors combined with poor activity of soil microorganisms in some habitats (Pietr et al. 1995, Sztrantowicz 1993, 1994) have created very unfavourable conditions for plants. As the years go, the process of forest decline has been intensified leading also to transformations of herb layer vegetation. This process was most distinct in the open areas devoid of tree canopies (Wasiłowska 1999). It principally consisted in a change in quantitative proportions among components of the vegetation, in colonising the degraded areas by grass species, such as *Calamagrostis villosa* and *Deschampsia flexuosa* forming here a dense carpet, and eventually – in diminishing of species characteristic of spruce forests (Wasiłowska 1999).

Progress of the changes in plant communities depended on site location (altitude), and the changes were usually more advanced in the upper montane zone. For instance, coverage index for species characteristic of coniferous forests in an old-growth spruce forest was higher by factor 1.5 in the lower than upper montane zone, and by 2 times higher in a declined low-elevation spruce forest (Wasiłowska 1999). Moreover, species typical of coniferous forests vanished completely from the degraded areas of the upper montane zone, whereas in the lower montane zone the species

4. Natural restoriation of spruce forest in Karkonosze Mts. (Photo. E. Dąbrowska-Prot)

reduced their coverage, and non-indigenous species, mainly those typical of clearings have expanded rapidly.

In the devastated areas, in sheltered places in particular, spruce stands have begun to regenerate naturally, and at lower elevations the process has been supported by man-planting. Vegetation of these areas has gradually regenerated, this being evidenced by recurrence of forest species at the expense of competitive grass species *C. villosa* and *D. flexuosa* (Wasiłowska 1999).

3. RESPONSES OF VARIOUS ANIMAL GROUPS

Elevational variability in abiotic environment, transformation of plant communities leading eventually to their complete degeneration, and related landscape fragmentation have radically altered life conditions of soil and epigeic fauna.

As demonstrated previously (Dąbrowska-Prot 1984), invertebrate abundance does not serve as a good indicator for comparing different areas, because it varies greatly in time and depends on a variety of casual factors. Nevertheless, it can be a valuable indicator of extremal environmental conditions stimulating or limiting mass occurrence of organisms. A comparison of the Karkonosze entomofauna with generally richer insect communities of mixed forests (Pino-Quercetum) in the Masurian Lakeland or with pine forests of the industrialised Silesia region (where degradation also consisted in forest die-back and expansion of *Calamagrostis villosa* in the herb layer) has not indicated any serious quantitative impoverishment of the Karkonosze entomofauna (Dąbrowska-Prot 1984).

However, much less mobile web spiders responded to the altered environmental conditions in Karkonosze much more clearly. Their numbers and biomass constituted only 25% and 12% of the respective values reported for herb layer of coniferous forests in the Upper Silesia region (Łuczak 1994, Dąbrowska-Prot and Łuczak 1995, Łuczak and Woźny 1999).

Many authors have put emphasis on the fact that soil systems have considerable homeostatic capacity, and thereby the soil fauna cannot be a sensitive indicator of environmental quality. For example, even in the Upper Silesia regions devastated to the most by industry, no clear decrease in numbers nor enzymatic activity of microorganisms was found (Badura et al. 1976, Sztrantowicz 1984). The situation observed in the Karkonosze region was much alike (Pietr et al. 1995), and even an increase in abundance of bacteria and other microorganisms, as well as increased enzymatic activity of microorganisms was noticed in the degraded area of the lower montane zone when compare with the mature spruce forest (Andrzejewska and Chmielewski 1995). It is also important that abundance of soil Protozoa was higher in the region of Mumlawski Wierch and Szrenica than that reported for forest soils of Upper Silesia. Moreover, spore participation in the Karkonosze Protozoa community was only 25%, whereas it reached up to 50% in the Silesian community (Sztrantowicz 1993). At the same time, Testacea mortality rate was high in the Karkonosze region, reaching in some circumstances as much as 50% of the total

Protozoa number. Thus, despite the lack of clear differences in protozoan abundance, occurrence of the spores and high mortality rate of the dominant Protozoa group suggested that environmental conditions in the region were unfavourable for protozoans.

Some invertebrate groups have not responded to the altered environmental conditions of the Karkonosze region by lowering of their qualitative diversity. For example, no clear qualitative impoverishment of Diptera, the dominant group in the entomofauna, was found, and number of the Diptera families was even by 10% higher than that recorded in pine forests of the industrialised Silesia region (Dąbrowska-Prot 1999b).

When compare with other regions, Protozoa did not exhibit any decrease in species number either, although some symptoms of relative impoverishment appeared in this soil fauna group (Sztrantowicz 1984, 1993). Similarly to Silesia, dominants in the Karkonosze region were Testacea (85% of the community abundance), the group being best adapted morphologically to unfavourable environmental conditions. Moreover, no flagellates were found in Karkonosze although they occurred in the Silesia region but only in the form of spores.

Table 1. Distribution (in percent of total abundance) of different ecological groups of invertebrates in Mumlawski Wierch region. In frames max. values.

Group	Habitat type: living spruce forests	spruce thickets	Degraded habitats	Coefficient of variability S.D. / $\overline{X}$	Author
Soil Protozoa	74.0	15.0	11.0	1.050	Sztrantowicz 1993, 1994
Collembola	51.0	27.0	22.0	0.456	Andrzejewska, Chmielewski 1995
Web Araneae of the herb and shrub layer	52.0	35.0	13.0	0.590	Łuczak 1994 Łuczak, Woźny 1999
Formicidae	5.0	31.0	64.0	0.888	Andrzejewska, Chmielewski 1995
Epigeic Araneae	30.5	20.5	49.0	0.440	Łuczak, Woźny 1999
Diptera imagines of the herb and shrub layer	32.5	49.0	18.5	0.460	Dąbrowska-Prot 1999b
Diptera imagines of the ground layer	27.0	61.0	12.0	0.750	Dąbrowska-Prot 1999b

Web spiders were found to react negatively. Species number found in the region of Mumlawski Wierch and Szrenica was reduced by 35% when compare with spider community in Silesian forests (Łuczak and Dąbrowska-Prot 1995).

Particular groups of animals differed among themselves regarding responses to spruce forest decline and consequent appearance of deforested areas and spruce saplings in the landscape (Table 1). Soil protozoans, Collembola and web spiders, being weakly mobile groups, have primarily inhabited living spruce forests. Diptera occurring on the ground as well as in the upper herb and shrub layers were most abundant in the spruce saplings. Such a pattern of spatial distribution was characteristic of Homoptera – Auchenorrhyncha (Andrzejewska and Chmielewski 1995). On the other hand, epigeic spiders and ants penetrating ground layer easily tolerated the conditions typical of the devastated areas, with dense herb layer providing them with sufficient protection against extremal microclimatic conditions prevailing here (Łuczak and Woźny 1999). Coefficients of variability (Table 1) suggest that environmental selectivity of Protozoa is almost twice that of the other animal groups. This indicates particular sensitivity of the former organisms to environmental conditions. The only optimal habitats for the group were mature spruce forests.

Variation in the animal abundance across the habitats examined was followed by qualitative differentiation of the animal communities. Spatial distribution of the taxa measured by the Koch's dispersion coefficient (Table 2) was least regular in the case of the soil fauna (Protozoa). By contrast, the area was colonised most evenly by mobile forms, easily penetrating different habitats (Diptera).

Despite considerable ecological diversity of the invertebrate groups investigated, all of them were relatively selective with regard to the environment,

Table 2. Spatial dispersion of taxa (Koch's index, 1957*) and taxonomic diversity of various habitats expressed as per cent (max. and min.) of taxa occurring in a given habitat to the total number of taxa.

Group	Habitat type: living spruce forests % min – max	Habitat type: degraded habitats % min – max	Habitat type: spruce thickets % min – max	number of taxa	Index of taxa dispersion
Soil Protozoa (species)	46 – 58	20 – 40	30.5	15	0.220
Epigeic Araneae (species)	36 – 39	29 – 49	22 – 29	42	0.270
Web Araneae of the herb and shrub layer (species)	32 – 36	22 – 43	39 – 51	69	0.485
Diptera imagines of the herb and shrub layer (families)	68 – 75	56 – 70	73 – 78	41	0.675

* Koch's index of dispersion: $\frac{(T-S):(n-1)}{S}$

S – number of taxons in whole area,

T – sum of taxons of inestigated sites, n – number of sites.

and this was confirmed by the values of dispersion coefficient ranging between 0.220 and 0.675. Maximum value of the index is equal to 1.0 and is characteristic of completely even distribution of taxa. In the case of lowland non-disturbed forest areas, the index estimated for Diptera was about 0.8 (Dąbrowska-Prot 1991). Considerable selectivity of the Karkonosze fauna has also been confirmed by share of the families or species found in particular habitat types and percentage participation of the taxa in their total number estimated for the study area (Table 2). The species number indicates fairly low richness of the fauna of particular habitats in relation to possibilities existing in the entire terrain. In most habitats examined, number of taxa did not exceed 40–50% of the total number found in the region. Although Diptera were an exception, it should be remembered that the analysis related to the family level. Additionally, it turned out that the most diverse habitats regarding taxonomic richness of the fauna were those degraded where the differences between minimal and maximal percentage of taxa found ranged from 14% for Diptera to 21.5% for web spiders. The respective values for the living mature spruce forests were 2.5% (epigeic Araneae) and 12% (Diptera), and for young forests from 0% to 12% (web Araneae) (Table 2).

Table 3. Taxonomic specificity of the animal communities expressed by per cent of taxa occurring exclusively in a given habitat type

Group	Habitat type			Σ
	living spruce forests	degraded habitats	spruce thickets	
Soil Protozoa (species)	20.0	0	6.5	26.5
Epigeic Araneae (species)	33.5	16.5	7.0	57.0
Web Araneae (species)	8.5	17.5	13.0	39.0
Diptera imagines (families)	2.5	10.0	7.5	20.0

The described phenomena indicate that the invertebrates had the most mosaic pattern of distribution in the declined spruce forests. This is also confirmed by high percentage of taxa inhabiting only one, fixed type of habitat (Table 3).

Differences in dispersal of the taxa over the landscape are reflected by trophic structure of Diptera in particular habitat types (Table 4). In the devastated sites, participation of phytophages, predators and parasites decreased when compare with the living spruce forests, whereas participation of saprophages increased by more than 50%. Shannon-Pielou's index values (Table 4) indicates disturbed quantitative proportions among trophic groups in that type of habitat. A similar phenomenon was observed by Hartman et al. (1989) in declined spruce forests, where saprophagous dip-

Table 4. Trophic structure of Diptera communities

Indicator	Habitat type: living spruce forests	degraded habitats	spruce thickets
% in number of Diptera communities:			
phytophages	16	6	15
saprophages and phytophages	45	75	64
predators and parasites	40	19	21
Proportions of numbers : $\frac{\text{Phytoph.+predat.+parasit.}}{\text{Saprophag+phyto–saproph.}}$	1.25	0.328	0.583
Shannon-Pielou's index for 5 trophic groups H'/H^0	0.460	0.404	0.425

terans clearly predominated. In the spruce thickets, a gradual restoration of the trophic structure characteristic of spruce forests has occurred. In the degraded areas, dipterans were principally involved in processes of dead organic matter decomposition, this having been documented by a low ratio between phytophage, predator and parasite numbers (grazing chain) and saprophage and phyto-saprophage numbers (detritus chain). In the old-growth spruce forests, dipterans contributed, besides decomposition, to biocenotic processes based on predator-prey and plant-phytophage interactions.

From the point of view of biocenotic control in mountainous regions, predator-prey interaction is of particular importance. There are two reasons, namely a fairly low contribution of predatory forms to invertebrates and their aggregated spatial distribution. Predatory dipterans (Table 4), similarly to web spiders (Table 1), were most abundant in the living mature spruce forests. Both groups of predators have been considered to control over numbers of other insect groups, including various trophic groups of Diptera (Laurence 1952, Crane 1961, Downes 1970, Riechert and Łuczak 1982, Riechert and Harp 1987). They exhibit a "functional reaction" on their prey, which qualify them as effective predators (Holling 1956, 1959). Unlike predators, dipterans that are their potential prey inhabited most numerously spruce thickets (Table 1). Thus, spatial separation of predators from their potential prey has taken place. This phenomenon was found to limit to a high degree proper functioning of the predator (spiders) – prey (Diptera) system and possibilities of controlling over numbers of the latter group in degraded spruce forests (Dąbrowska-Prot and Łuczak 1995, Łuczak and Dąbrowska-Prot 1995).

Particularly evident responses to the environmental changes showed soil Protozoa (Sztrantowicz 1993, 1994, Dąbrowska-Prot and Łuczak 1995). In the old-growth spruce forests, the habitat most favourable for the group, protozoans were by as many as 5 times more abundant than in the thickets,

Table 5. Taxonomic structure of soil Protozoa and their mortality rates in particular habitat types (after Sztrantowicz 1993, 1994, modified)

Indicator	Habitat type: living spruce forests	degraded habitats	spruce thickets
% participation number of:			
Testacea (T)	42.0	88.0	82.0
Ciliata (C)	36.0	10.5	12.0
Amebae (A)	22.0	1.5	3.0
Proportions of numbers			
T : C : A	2 : 1.5 : 1	58 : 7 : 1	27 : 4 : 1
% of spores	12	42	9
% of dead Testacea	17	49	40

whereas by 7 times more abundant than in the degraded areas (Table 1). It may thus be assumed that structure of the communities was characteristic of healthy spruce forests. The main features of this structure included a fairly equal proportions of three morphologically different protozoan groups, namely Testacea, Ciliata and Amoebae, small participation of spores and a relatively low mortality rate of Testacea (Table 5).

In the degraded areas, overall Protozoa abundance was greatly reduced (Table 1). Qualitative structure of the community has been modified in such a way that Testacea, the goup least sensitive to changes in environmental conditions, contributed as much as 90% to the community abundance, while naked amoebans considerably decreased their numbers (Table 5). Almost 45% of the protozoans occurred in a form of spores. Southwood (1978) defined such an animal life strategy as "escape in time" from unfavourable environmental conditions in contrast to the changes in dispersal pattern in the field named "escape in space". Testacea mortality reached there 50% of their total abundance.

In the spruce thickets, total abundance of Protozoa was slightly increased (Table 1). A tendency to reconstruct the proper structure was also observed. Participation of ciliates and amoebans was raised, share of spores was reduced by 5 times, and mortality of Testacea – by 10% (Table 5).

A limited influence of protozoans on soil processes in Karkonosze Mts. (e.g. on reduction of microorganism's abundance and decomposition of dead organic matter) resulted from small Protozoa numbers, aggregated distribution, as well as a rapid shift towards spore forms and increased mortality when life conditions have been worsening.

It turned out that protozoans are good indicators of environmental quality. Studies on heavy metal accumulation by bilberry *Vaccinium myrtillus* pointed at the plant to be useful for monitoring purposes, as well. However, changes in population properties, such as density, plant shape or fruiting should be considered, rather than the magnitude of heavy metal accumulation itself (Wasiłowska and Gworek 1999).

4. CONCLUSIONS

One of fundamental problems in landscape ecology is a role of various landscape components (habitats, ecosystems) in maintaining a high level of numbers, biomass, taxonomic diversity of organisms, as well as in functioning of the natural systems. In the case of Karkonosze Mountains (see Fig. 1 in Dąbrowska-Prot 1999a p 366, this volume), compact monocultures of spruce forests affected by industrial pollution have transformed into a mosaic of landscapes (see Fig. 2 in Dąbrowska-Prot 1999a p 369, this volume). Under these new circumstances, an important factor determining the properties of animal communities, migration intensity across the landscape in particular, is a system of three main habitats, namely living mature spruce forests, thickets and areas devoid of trees. Impact of air pollutants and their deposition to the soil and water on plants and animals is to be added to the above factors.

Considerable aggregation of animals is a striking feature of the Karkonosze region. This mainly applies to animals of poor mobility (e.g. Protozoa), and is followed by formation of communities greatly diversified qualitatively and quantitatively when considering particular habitats (mature spruce forests, degraded areas, spruce thickets) or different sites within a given habitat type (Table 1).

Co-occurrence of mature spruce forests and thickets is of special importance in maintaining a relatively rich fauna under such unfavourable climatic and environmental conditions as in Karkonosze Mts. Besides soil Protozoa occurring chiefly in the old-growth spruce forests, web Araneae and Diptera colonised usually mature spruce forests and thickets.

The degraded areas were poorly colonised by various organisms, except for epigeic spiders and ants, the group being able to find sufficient refugee in the well-developed herb layer.

Degradation of the forest habitats has led not only to a drop in quantitative and qualitative richness of the fauna, but also to a change in proportions among various ecological groups, this having been exemplified by Protozoa (Table 1, 2, 3). In the degraded areas, share of Testacea, the group well isolated from the external environment, was doubled when compare with the living mature spruce forests. In contrast, naked amoebans decreased their numbers. Moreover, participation of spores was increased by the factor of 4. Within the spruce thickets, structure of the protozoan communities has changed towards that typical of stabile old-growth spruce forest ecosystems (Table 5).

Apperance of young woods in agricultural landscape of Masurian Lakeland was also found to be important for maintenance of rich fauna. These were birch-aspen woodlands growing spontaneously on wastelands that have maintained great biodiversity of that region. In the Karkonosze region, properly managed spruce thickets have played an equally important role.

The studies revealed considerable changes in functioning of the natural systems of the Karkonosze region. Low abundance and biomass of many animal groups, including Protozoa, a shift towards spore forms, as well as an increase in mortality rate, all the factors indicate limited importance of the group in functioning of the soil system, especially in decomposition of dead organic matter. On the other hand, saprophage predominance in dipterans testifies increased importance of this animal group in transformation of dead organic matter (Table 4).

Attention should also be given to disturbances in functioning of "predator-prey" systems. For example, as an effect of partial spatial separation of web spiders from their main prey – dipterans, proper functioning of the system (biocenotic control) is possible only in old-growth spruce forests.

Results of this study have confirmed particular usefulness of soil Protozoa for assessment of environmental quality of mountainous regions. Such ecological parameters as proportions among morphological types, participation of spores, mortality rate of Testacea, the group most resistant to environmental conditions, can be successfully used for monitoring purposes. The same applies to properties of *Vaccinium myrtillus* population (density, plant shape, and fruit abundance).

5. REFERENCES

Andrzejewska L., Chmielewski K. 1995 – Reakcje zespołów mikroflory i fauny bezkręgowców gleby i warstwy zielnej na degradację środowisk leśnych Karkonoszy [Responses of microflora and invertebrate fauna of the soil and herb layer to degradation of forest habitats of Karkonosze Mts.] (In: Problemy ekologiczne wysokogórskiej części Karkonoszy [Ecological problems of high-elevation parts of Karkonosze Mts.] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 269–285.

Badura L., Gawłowska H., Górska B., Morozowska L., Smyła A., Zwoliński J. 1976 – Porównawcze badania nad występowaniem bakterii, promieniowców i grzybów mikroskopowych w glebach leśnych skażonych emisjami przemysłowymi [Comparative studies on occurrence of bacteria, Actinomycetes and microscopic fungi in the forest soils contaminated by industrial pollutants] – Prace Nauk. Uniw. Śląskiego, Acta Biol. 145: 7–38.

Crane A. E. 1961 – A study of the habits of *Rhamphomyia scutellaris* Coquillett (Diptera: Empididae) – Wasmann J. Biol. 19: 247–262

Dąbrowska-Prot E. 1984 – The effect of industry on biocoenoses (In: Biocoenosis in an industrial landscape, Ed. E. Dąbrowska-Prot) – Pol. ecol. Stud. 10: 187–205.

Dąbrowska-Prot E. 1991 – The role of forest islands in the shaping of the structure and functioning of entomofauna in an agricultural landscape (In: Forest islands in the landscape of the Masurian Lakeland: origin, location in space, research problems, Ed E. Dąbrowska-Prot) – Ekol. pol. 39: 481–516.

Dąbrowska-Prot E. 1999a – Environmental characteristics of the Karkonosze Mts. region and the problems of spruce forest decline (In: Effects of the industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland)] Ed. E. Dąbrowska-Prot) – Pol. J. Ecol. 47: 365–371.

Dąbrowska-Prot E. 1999b – Response of entomofauna communities to spruce forest decline (Karkonosze Mts, Poland) (In: Effects of the industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland)] Ed. E. Dąbrowska-Prot) – Pol. J. Ecol. 47: 409–428.

Dąbrowska-Prot E., Łuczak J. 1995 – Biocenotyczne konsekwencje wypadania lasów świerkowych w Karkonoszach [Biocenotic consequences of spruce forest decline in Karkonosze Mts.] (In: Problemy ekologiczne wysokogórskiej części Karkonoszy [Ecological problems of high-elevation parts of Karkonosze Mts.] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 287–302.

Downes J. A. 1970 – The feeding and mating behavior of the specialized Empididae (Diptera); observations on four species Rhamphomyia in the high Arctic and a general discussion – Can. Entomol. 102: 769–791.

Hartman P., Scheitler M., Fischer R. 1989 – Soil fauna comparisons in healthy and declining Norway spruce stands (In: Forest decline and air pollution, Eds E. D. Schulze, O. L. Lange and R. Oren) – Ecological Studies 77, pp. 137–150.

Holling C. S. 1956 – The components of predation as revealed by a study of small mammal predation on the European Sawfly – Canadian Entomologist 91: 293–320.

Holling C. S. 1959 – The functional response of predators to prey density and its role in mimicry and population regulation – Mem. Ent. Soc. Can. 54: 1–60.

Koch L. F. 1957 – Index of biotal dispersity – Ecology 38: 145–148.

Laurence B. R. 1952 – The prey of some Empididae and Dolichopodidae (Diptera) – Entomol. Monthly Mag. 88: 156–157.

Łuczak J. 1994 – Kształtowanie się zespołów pająków sieciowych w zachowanych i zniszczonych świerczynach w Karkonoszach [Forming of communities of web spiders in living and destroyed spruce forests of Karkonosze Mts.] (In: Karkonoskie badania ekologiczne II) [Ecological studies in Karkonosze Mts. II] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 311–315.

Łuczak J., Dąbrowska-Prot E. 1995 – Araneae communities and the functioning of predator – prey system (spiders-dipterans) in the devastated Karkonosze mountain forest – Proc. European Coll. of Arachnology, pp. 116–124.

Łuczak J., Woźny M. 1999 – Effect of spruce forest decline on spider communities in Karkonosze Mts. (In: Effect of industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland) Ed. E. Dąbrowska-Prot) – Pol. J. Ecol. 47: 429–447.

Pietr S. J., Fischer Z., Tyrawska D., Bajan C. 1995 – Biologiczne procesy rozkładu substancji organicznej w glebach Karkonoszy [Biological processes of organic matter decomposition in the soils of Karkonosze Mts.] (In: Problemy ekologiczne wysokogórskiej części Karkonoszy [Ecological problems of high-elevation parts of Karkonosze Mts.] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 131–168.

Riechert S. E., Harp J. M. 1987 – Nutritional ecology of spiders (In: Nutritional ecology of insects, mites and spiders, Eds F. Slansky and J. G. Rodriques) – John Willey and Sons Inc., pp. 654–672.

Riechert S. E., Łuczak J. 1982 – Spiders foraging: behavioral responses to prey (In: Spider communication mechanisms and ecological significaces, Eds. P. N. Witt and J. S. Rovner) – Princeton, New Jerey, 353–385.

Sachanbiński M. 1995 – Środowisko geochemiczne Karkonoszy [Geochemical environment of Karkonosze Mts.] (In: Problemy ekologiczne wysokogórskiej części Karkonoszy [Ecological problems of high-elevation parts of Karkonosze Mts.] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 11–34.

Schulze E. D., Lange O. L., Oren R. 1989 – Forest decline and air pollution – Ecological Studies 77, pp. 475.

Southwood T. R. E. 1978 – Escape in space and time – concluding remarks (in: Evolution of insect migration and diapause, Ed. H. Dingle) – Springer Verd, New York, Berlin, pp. 277–279.

Stachurski A., Zimka J. R., Kwiecień M. 1994 – Forest decline in Karkonosze (Poland) I. Chlorophyll, phenols, defoliation index and nutrient status of the norwey spruce (*Picea abies* L.) – Ekol. pol. 42: 289–316.

Sztrantowicz H. 1984 – Soil Protozoa as indicators of environment degradation by industry (In: Biocoenosis in an industrial landscape, Ed E. Dąbrowska-Prot) – Pol. ecol. Stud 10: 67–91.

Sztrantowicz H. 1993 – Formowanie się zespołu mikroorganizmów glebowych w różnie odkształconych ekosystemach leśnych Karkonoszy [Forming of communities of soil microorganisms in degraded forest ecosystems of Karkonosze Mts.] (In: Karkonoskie badania ekologiczne I [Ecological studies in Karkonosze Mts. I] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 133–138.

Sztrantowicz H. 1994 – Formowanie się zespołów mikroorganizmów glebowych w środowiskach różnie odkształconych ekosystemów leśnych Karkonoszy [Forming of communities of soil microorganisms in degraded forest ecosystems of Karkonosze Mts.] (In: Karkonoskie badania ekologiczne II [Ecological studies in Karkonosze Mts. II] Ed. Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 321–325.

Wasiłowska A. 1999 – Changes of herb-layer vegetation in mountain spruce forests under the influence of industrial pollution and the forest decline. (In: Effect of industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland) Ed. E. Dąbrowska-Prot) – Pol. J. Ecol. 47: 381–398.

Wasiłowska A., Gworek B. 1999 – Bilberry (*Vaccinium myrtillus* L.) as an indicator of environmental state of spruce forests in Karkonosze Mts. (In: Effect of the industrial pollution and spruce forest decline on the biocenoses of Karkonosze Mts. (south-western Poland) Ed. E. Dąbrowska-Prot) – Pol. J. Ecol. 47: 449–463.

Zawiła-Niedźwiecki T. 1992 – Lasy – diagnoza z orbity [Forests – a diagnosis from the orbit] – Wiedza i Życie 11: 60–64.

Zimka J. R., Stachurski A. 1996 – Forest decline in Karkonosze Mts (Poland). Part II. An analysis of acidity and chemistry of atmospheric precipitation, troughfall and forest streamwaters – Ekol. pol. 44: 153–177.

Zwoździak J., Kmieć G., Zwoździak A., Kacperczyk K. 1995 – Presja zanieczyszczeń przemysłowych w ostatnim wieloleciu, a stan obecny [Industrial pollution pressure in the past and present] (In: Problemy ekologiczne wysokogórskiej części Karkonoszy [Ecological problems of high-elevation parts of Karkonosze Mts.] Ed Z. Fischer) – Oficyna Wyd. Instytutu Ekologii PAN, pp. 79–96

(*Received after revising August 1999*)