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

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RESPONSE OF ENTOMOFAUNA COMMUNITIES TO SPRUCE FOREST DECLINE (KARKONOSZE MTS., POLAND)

ABSTRACT: Deforestation of the Karkonosze region affected by industrial pollution caused large areas of spruce monocultures to have been transformed into a mosaic of landscapes, the main constituents of which are three types of habitats, namely old-growth spruce forests, deforested areas, and young spruce stands. Responses of entomofauna, Diptera in particular, to the new spatial structure of the landscape were studied. Under conditions of anthropogenic transformations of the mountain forest ecosystems, spruce thickets were found to be important in maintaining biological diversity of the entomofauna.

KEY WORDS: entomofauna communities, forest decline, mountain biocenoses, industrial pollution, landscape structure

1. INTRODUCTION

Karkonosze are the most westward range of Sudeten Mts. The highest peak (Śnieżka) reaching 1603 m a.s.l. is characterised by occurrence of well developed alpine zone. However, the mountains reach most commonly the upper montane zone with natural spruce forests from the associations of Plagiotecio-Piceetum hercynicum and P.P.h. filicetosum (1000–1219 m. a.s.l. – the peak of Mumlawski Wierch), and in some parts – the subalpine zone with dwarf-mountain-pine and grasslands (Szrenica Mt. 1362 m. a.s.l.) (Pawłowski 1959). The lower montane zone is covered by man-planted spruce forests that usually grow on acid beech forest sites.

A reason to undertake ecological investigations in this region was a considerable increase in industrial pollution (principally acidification) of the air, soil and water followed by large-scale decline of spruce forests. The situation has been considered to be ecological disaster. Decline of forests affected by industrial pollutants has posed a threat to natural systems in many regions of Europe (Hauchs and Wright 1986, Schulze et al. 1989).

Forest decline in the region of Karkonosze has begun a quarter of the century ago. At present, vast areas of forest ecosystems are already degraded, which poses a problem for economists and scientists. Because spruce forests predominate in plant communities of the Karkonosze region, their destruction is followed by changes in environmental conditions (climate, hydrology, soils), as well as by transformations of structure and functioning of the ecological systems. As an effect of tree stand decline, the spruce monocultures have been altered to a mosaic of mountain landscapes composed principally of patches of living old-growth forests, deforested areas, and spruce thickets of various ages. The thickets developed spontaneously or were planted within reafforestation programme of the degraded areas. In this way, completely different conditions for animals, including insects, have been created.

Assessment of entomofauna response to the radical environmental changes is difficult, because majority research works in the region is faunistic (not quantitative) and describes selected families, genera, or pests and protected species (Gądek 1981, Kuźma 1989, Belachova and Duchanova 1989). This poses much difficulty in studying rates and ways of transformations of insect communities influenced by industrial pollution and widespread deforestation of the Karkonosze region. Other authors (Hartman et al. 1989) have emphasised the lack of information on how the above factors influence soil fauna. This work aimed primarily at analysing ecological consequences of co-existence of fragmented spruce forests in different stages of degradation and regenerating spruce thickets.

2. STUDY AREA, MATERIALS AND METHODS

The entomological studies were performed in the region of Mumlawski Wierch (1219 m. a.s.l.) and in the valley of Kamienna river (900 m. a.s.l.). Both sites are situated in the most westward part of the Karkonosze range and thus exposed to the highest degree to industrial pollutants (Skiba 1995, Zwoździak et al. 1995) derived from other parts of Poland, as well as from Germany and the Czech Republic (Kmieć et al. 1993).

In the past, spruce forests covered the whole area, and the first symptoms of damages were noticed in the valley of river Kamienna in mid 70ties (Director of Karkonosze National Park, personal communication). At present, strips of three habitat types occur over the whole area. The habitats include 1) old-growth spruce forests, 2) deforested areas and 3) natural or man-planted young spruce stands of different ages. Thus, various stages of forest ecosystem degradation or regeneration are represented in the study area (Fig. 1).

The region of Mumlawski Wierch can be described by two important features. Firstly, it represents a pattern of spruce ecosystem transformation typical of the whole Karkonosze region. Secondly, in all sites, even in the most degraded ones, herb layer typical of spruce

2. Spruce forest decline area. (Photo. A. Hillbricht-Ilkowska)

3. Mass occurence of grass species *Deschampsia flexuosa* and *Calamagrostis villosa* in the destroyed spruce forest. (Photo. E. Dąbrowska-Prot)

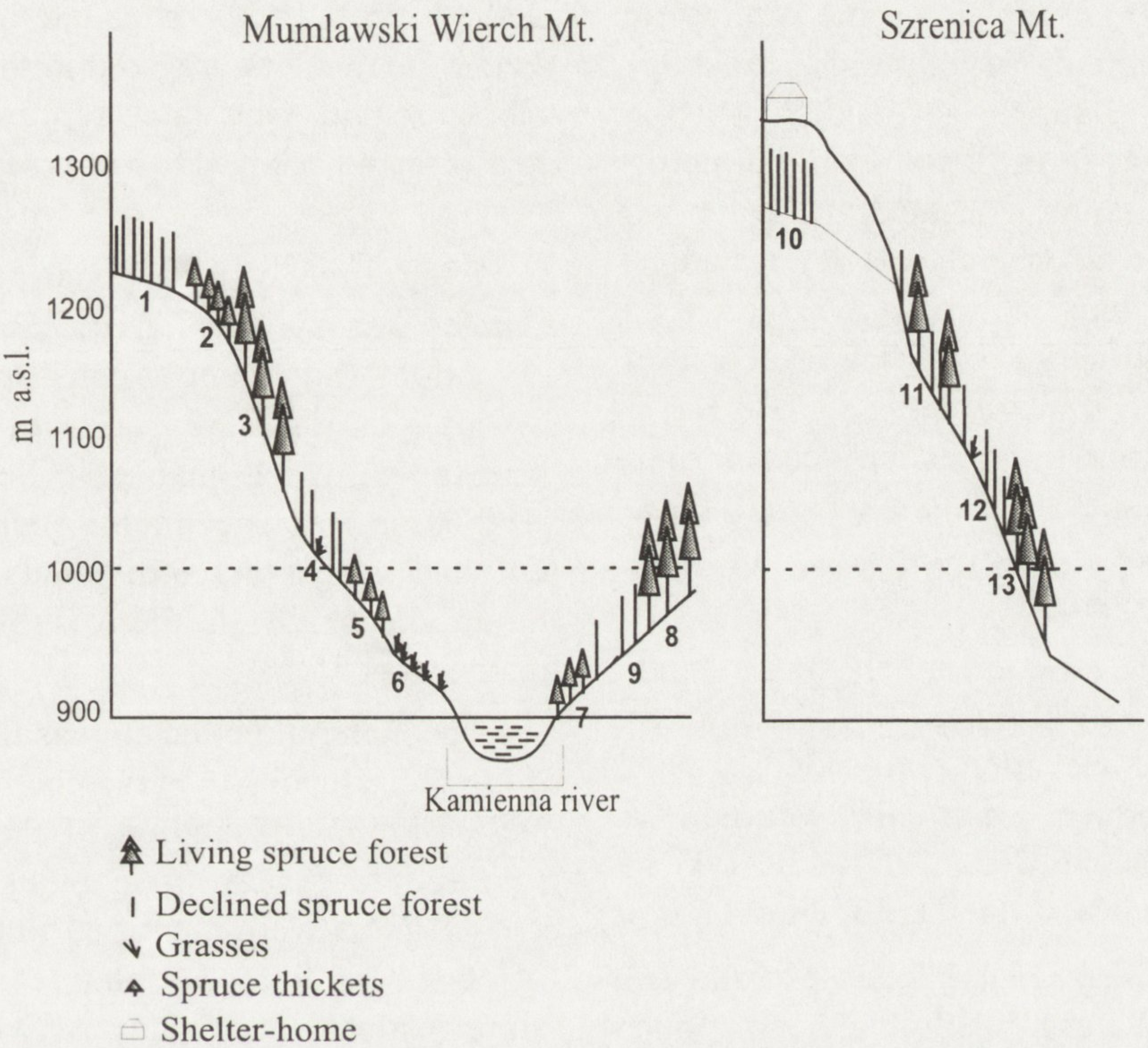

Fig. 1. Location of study sites on Mumlawski Wierch Mt., in the valley of Kamienna river, and on Szrenica Mt in Karkonosze Mts. The broken line denotes bordeline between the lower and upper montane zone.
1–13 – sample plots.

forests has survived though affected to various extent when compare with relatively healthy fragments of mountain spruce forests (Wasiłowska 1999). This allows assessing of the degree of habitat degeneration and to put the sites in the rank order from the least to the most altered ones (degeneration order). A similar rank order can be produced for the spruce thickets based on herb layer similarity between the thickets and the mature spruce forests (regeneration order).

Study sites (in total 9) included all the three types of habitats and extended from the top of Mumlawski Wierch through its slopes to the foothill in the Kamienna river valley on a distance of some 1.5 km (Fig. 1). On the basis of phytosociological records of herb layer vegetation and its transformations (Wasiłowska 1999), two rank orders of increasing degeneration degree were set. In the upper montane zone the rank included station 3, 1 and 4, and in the lower montane zone – station 8, 9 and 6. The rank order of spruce thickets of increasing age was the following: station 2 (12-year-old), station 5 (15-year-old) and station 7 (20-year-old).

Large station 8 was situated in an old spruce forest growing in the habitat of acid beech forest. Although station 3 was also established in a mature spruce forest, the site origin was different. It comprised a fragment (10 hectares) of a natural high-elevation spruce forest (Plagiotecio--Piceetum hercynicum) that remained almost intact, except for some changes in the vegetation structure (e.g. canopy opening). Stations 1–4 and 9–6 represented areas of different degree of deforestation (station 6 located at the foothill of Mumlawski Wierch was deforested the relatively longest time ago – about 15 yaers), and hence, of different degree of herb layer transformations. This layer consisted mainly of extensively expanding grass species, *Calamagrostis villosa* and *Deschampsia flexuosa* (Wasiłowska 1999).

To make a comparison, similar studies were performed on the mount Szrenica at elevation corresponding with the uppermost part of Mumlawski Wierch, i.e. between 1260 and 1000 m a.s.l. (stations 10, 11, 12, 13) (Fig. 1).

On Szrenica, unlike on Mumlawski Wierch, there is well-developed alpine vegetation. Since the end of 19th century tourists has frequently visited the mount. The oldest tourist track of Karkonosze Mts. leads onto the Szrenica peak, and a shelter was established on a glade (Hala Szrenicka) at the beginning of 20th century. The area is completely different than Mumlawski Wierch, the latter peak being fully overgrown by spruce forests and rarely frequented by man. Although both mounts have received similarly large amounts of industrial pollutants (Kmieć et al. 1994, Zwoździak et al. 1995), the forests on Mumlawski Wierch were damaged relatively earlier, because destruction of forest ecosystems had begun in Western Sudeten and extended gradually toward the east (Zwoździak et al. 1995).

In spring, summer, and autumn of the years 1992–1993, 7 field expeditions were organised in order to collect entomofauna with use of a sweep net. The method seemed to be adequate as the insects were much aggregated in the mountainous region. One catch represented an area of about 6 m^2 (Dąbrowska-Prot 1991).

Every time, a series consisting of 10 samples was collected from each of the 13 stations (one sample consisted of 25 sweeps). In total, 80 series of sweeps were made, which enabled collection of 11 thousand of specimens, including 6 thousand of Diptera individuals, contribution of which to the overall insect number was 55.5%.

The material collected was identified to the order level. As being the most numerous group (depending of the season from 42.5 to 71% in the habitats considered), Diptera were identified to the family level, and representatives of the family Chloropidae, many of which are known plant pests, to the species level.

In 1993, entomofauna was collected using pitfall traps. On each sampling plot, 2 jars of one litre capacity and 78 cm^2 of catching area were installed. The traps were open constantly from May to November, and emptied at monthly intervals (Łuczak and Woźny 1999). In this way, the material comprising entomofauna penetration intensity of ground surface was collected.

In this work a number of indices was applied:

– coefficient of variation $SD/\bar{x}$

– Mann-Whitney's U test,

– Pielou's evenness index for 5 trophic groups of Diptera H'/H^0,

– Koch's dispersion index for taxa $[(T–S):(n–1)]/S$, where T – arithmetic sum of the number of taxa present in each habitat, S – number of taxa in the whole area, n – number of sampling sites.

3. RESULTS

3.1. GENERAL CHARACTERISTICS OF ENTOMOFAUNA OF THE KARKONOSZE MTS.

A comparison was made of quantitative characteristics (numbers, biomass) and qualitative richness, as well as participation of Diptera in the entomofauna between the examined Karkonosze region and formerly investigated insect communities that inhabit large areas of mixed deciduous and pine forests of Poland. Habitats of the latter type were examined in the industrialised Upper Silesia region where damages to the environment, similarly as in the Karkonosze Mts., consisted in forest decline and massive occurrence of *Calamagrostis villosa* in the herb layer. The comparison did not prove that the Karkonosze entomofauna was much impoverished quantitatively (Dąbrowska-Prot 1980, 1984a, 1994, Dąbrowska-Prot and Łuczak 1995). Symptoms of qualitative impoverishment of Diptera, the group contributing 60% to the entomofauna of Mumlawski Wierch and Szrenica (Table 1), have not been detected, either. During the 2-year study period, 42 families of Diptera were found. In a comparable material (study period, catching method) from degraded pine forests of Upper Silesia, the number of families was 40 (Dąbrowska-Prot 1980, 1984a), whereas 48 families were found in mixed forests of north-eastern Poland (Masurian Lakeland) (Dąbrowska-Prot 1980, 1991). In a region of intensive agriculture in the west part of Poland, only 35 Diptera families were recorded during long-term studies performed in the diversified agricultural landscape (Dąbrowska-Prot 1980, 1984b).

Table 1. Qualitative structure of entomofauna (in % of taxa abundance) in the regions of Mumlawski Wierch and Szrenica Mt.

Group	Mumlawski Wierch	Szrenica Mt.
Diptera	54.5	58.0
Hymenoptera	14.5	9.5
Heteroptera	12.0	14.0
Homoptera	7.5	10.0
Coleoptera	4.0	4.0
Other	7.5	4.5
% of Diptera in entomofauna biomass	52.5	45.5

Table 2. Families dominant in the Diptera communities of spruce forests of the Karkonosze Mts.

Family	% in the total number of community
Empididae	11.0
Ceratopogonidae	10.5
Chironomidae	9.0
Drosophilidae	9.0
Sciaridae	6.5
Clusiidae	6.0
Chloropidae	4.5
Agromyzidae	4.5

Among Diptera found in the Karkonosze region, 8 families formed a core (60% of the total abundance) (Table 2). The remaining 40% of Diptera belonged to 34 families. A predatory family Empididae was an important contributor although majority of dominant families belonged to saprophages. Very important were also two families Chloropidae and Agromyzidae – pests of natural vegetation and crop plants. Some Diptera families (Ceratopogonidae, Chironomidae) are associated with aquatic environments or wetlands. It is to note that Clusiidae family was also an important contributor.

Larvae of many species belonging to this family inhabit decaying wood, in particular damp tree boles attacked by fungi.

The above picture of the dominance structure of Diptera is characteristic of forest habitats where the dominant group is usually fairly abundant. In this regard, the habitats differ from arable lands, where one Diptera family, in most cases phytophagous one (e.g. Chloropidae) may contribute 70–80% to the total Diptera abundance (Dąbrowska-Prot 1984a and b, 1986).

However, some symptoms of simplification of the entomofauna structure have been noted on the basis of Chloropidae examination. The group increases its contribution to Diptera communities along with increasing intensity of land use, landscape fragmentation, and opening of forest canopies (Dąbrowska-Prot 1984b).

In the spruce forests of Szrenica and Mumlawski Wierch, only 8 Chloropidae species were found, whereas in pine forests of Upper Silesia heavily affected by industrial pollution the species number in a comparable time period was 18, and in mixed forests in the region of Great Masurian Lakes – 25 species.

Five of the 8 species were phytophages with *Oscinella frit*, a species dominant in the Chloropidae fauna of the region, accounting for 72% of the total abundance. The remaining three species were saprophages. No records were made of predatory species that are very characteristic of trophic structure of forest Chloropidae. All 8 species were eurytopic, having wide geographical range of occurrence (Bieszowski 1985).

The presented findings have suggested that the Chloropidae community of spruce forests of the Karkonosze region is similar to those occurring in areas of intensive agriculture. It is composed of a few species having a wide environmental tolerance range, mostly phytophages with strict dominance of one species, usually *Oscinella frit* (Dąbrowska-Prot 1984b).

3.2. EFFECTS OF FOREST DECLINE

3.2.1. NUMBERS AND BIOMASS OF THE ENTOMOFAUNA

In the Karkonosze region, few main environmental factors, both natural and anthropogenic ones have influenced organisms. The former factors include severe climatic conditions: low temperatures, considerable diurnal and seasonal variation in the temperature, hurricanes, high precipitation sums, short growing season, long periods of snow cover presence (Migała et al. 1995). Elevational variation of the Karkonosze region determines considerable microclimatic variation and thereby – elevational distribution of plants and animals, including insects (Bańkowska 1964, Leśniak 1984).

Influence of the above factors on animals has been modified by anthropogenic factors. These include primarily industrial pollution leading to forest decline and hence, to transformations of the spruce monocultures into a mosaic of landscapes composed of old-growth spruce forests, deforested areas, and spruce thickets.

Forest management counteracting the degradation as well as uncontrolled increase in tourist traffic both initiate synantropication processes of flora and fauna of the region. All these environmental factors influence structure, dispersal and functioning of entomofauna in the Karkonosze region. A factor of most severe impact is the rapidly expanding forest dieback. Its ecological consequences can be traced by analysing Diptera communities, the group dominant regarding numbers and biomass of insects found on Szrenica and on Mumlawski Mt. (Table 1).

A comparison of environmental distribution of two Diptera fractions: in the herb and shrub layers and in the ground surface showed much similarity of their patterns. Dipterans were clumped in spruce thickets and mature forests and more abundant in the lower montane zone and then the quality and location of the site influence spatial distribution of Diptera (Fig. 2).

Altitude acts chiefly through the impacts of microclimatic conditions. Thereby, its influence can be examined by analysing insect distribution in particular seasons, i.e. when climatic conditions are more (spring, autumn) or less (summer) important for activity and environmental selectivity of the insects. Preliminary microclimatic studies performed simultaneously in the upper and lower parts of Mumlawski Wierch during early frosts in October demonstrated that herb layer habitats of the uppermost elevations were more humid and cooler by 1–5.5°C than the lower parts of the slope, and by 2–6°C than sites situated in the valley of Kamienna river. For the shrub layer the respective differences amounted to 1–3.5°C and 1–5°C. The measurements were made during sunny and windless weather, and this lowered the site-to-site differences, these being presumably greater during periods of e.g. strong and frequent winds typical of the region (Migała et al. 1995).

Studies on entomofauna distribution performed during early spring (May) soon after snow melting at early stages of plant growth have shown that entomo-

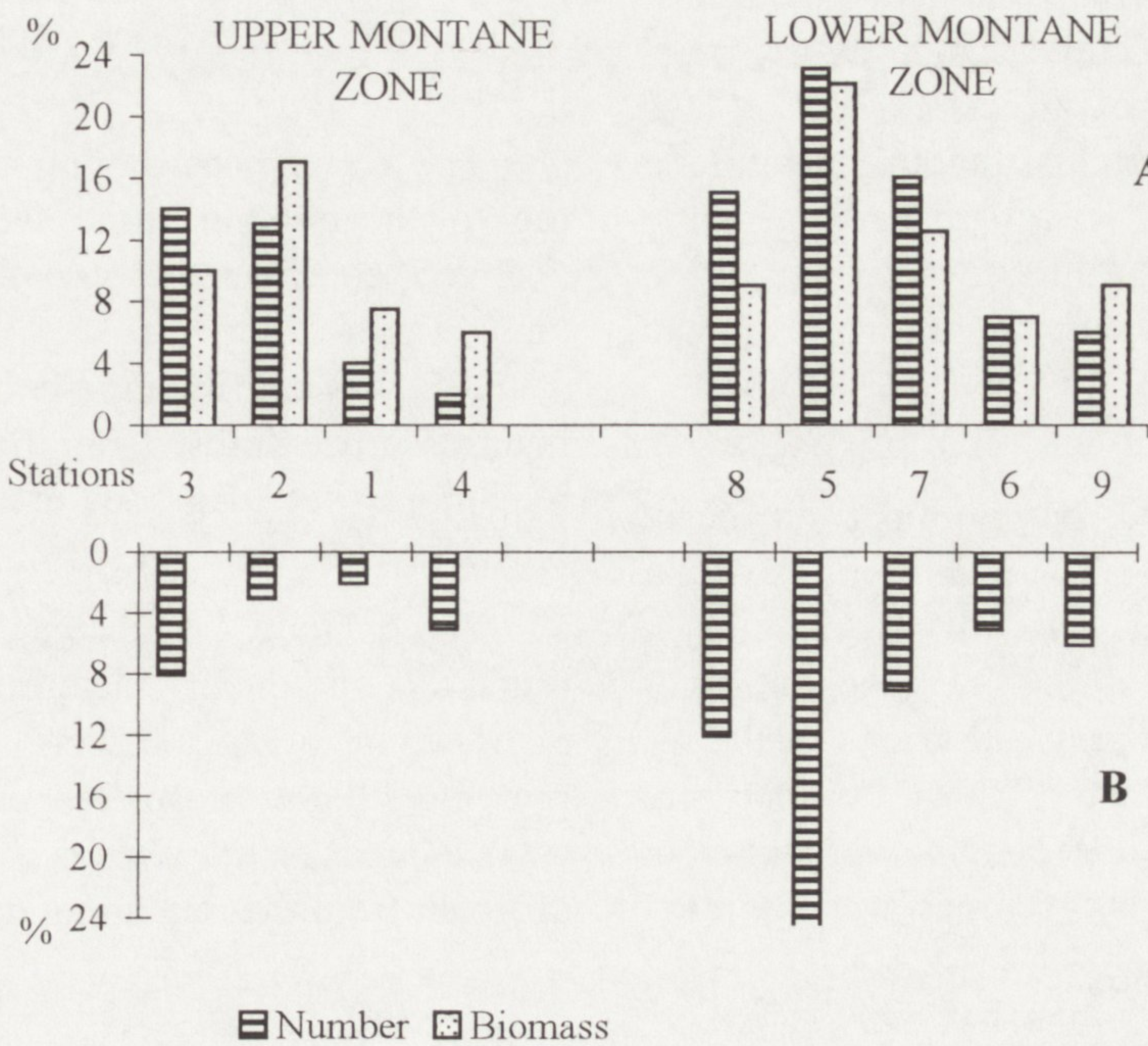

Fig. 2. Spatial distribution of Diptera number and biomass (in %) in the region of Mumlawski Wierch Mt. and in the valley of Kamienna river. A – in herb and shrub layer (sweep net) and B – at the ground layer (pitfall traps) (1-year data).

fauna of the uppermost parts of Mumlawski Wierch was by about 6 times poorer than fauna inhabiting the valley of Kamienna river (Table 3). Then differentiation of environments in insect numbers and biomass was higher in the uppermost parts than at lower elevations by factors of 5 and 4, respectively (Table 3, coefficients of variation).

Except for old-growth spruce forests (stations 3 and 8), statistically significant differences (Mann-Withney's U test) were found in abundance of the whole entomofauna ($p<0.001$) and Diptera ($p<0.01$) between the sites of the lower and upper montane zones. In the upper montane zone, the differences were insignificant only between deforested site (station 4) and other habitats (station 1, 2, 3). On the other hand, on the lower montane zone the mature spruce forest (station 8), and young spruce stand (station 5) differed significantly from every other habitat considered.

It should be noted that during spring, scarce entomofauna representatives of the upper montane zone belonged almost exclusively to Diptera, one of the most mobile groups of insects (Table 3). This may indicate that less favourable climatic conditions that prevail in early growing season cause the higher elevations to be inhabited by insects migrating from the lower elevations.

The differences in insect dispersion have decreased beginning from early spring towards subsequent periods of the growing season. This was an effect of a different rate of the increase in insect numbers at different elevations of the region and particular habitats. For instance, between May and June insect numbers over increased by 10 times at high elevations, while by only 6 times in the low-elevation sites (Table 3, 4). As a consequence, in the period of maximal insect abundance (June) distribution patterns of insect numbers and biomass were similar in habitats of the upper and lower montane zone (Table 4, coefficients of variation). Statistically significant differences ($p<0.001$ for insects and $p<0.05$ for Diptera) in colonisation of various habitats of particular elevation zones occurred only between the degraded areas and the other sites (mature and young spruce stands). On the other hand, no statistically significant differences were found between the upper and lower zone.

In autumn, an opposite tendency took place, namely entomofauna has begun to disappear gradually from less favourable habitats, mainly from the upper montane zone (Table 5). At the same time, the insects inhabiting the uppermost parts of Mumlawski Wierch were mainly present in the mature spruce forest (station 3). Abundance in this site was by 2.5 times higher than in the thickets, and by 10 times – than in the degraded areas (the differences statistically significant at $p<0.05$).

The differences among the sites of the lower montane zone were smaller (Table 5, coefficient of variation). Statistical significance of the differences ($p<0.05$) was confirmed only between the mature spruce forest (station 8) and the remaining sites (degraded areas and saplings).

To conclude, two factors, namely altitude and site quality, determined spatial distribution of the insects during the growing season. In this respect, the devastated areas were always significantly different from the remaining habitats.

Table 3. Characteristics of entomofauna inhabiting the region of Mumlawski Wierch and the valley of Kamienna river during spring, soon after snow melting (mid-May)
I – Living spruce forests, II – Spruce thickets, III – Deforested habitats

Index	Insects number (for 10 samples)		Insects biomass (for 10 samples)		% of Diptera in entomofauna	
Zone	Indiv.	S.D./ $\bar{x}$	mg dw.	S.D./ $\bar{x}$	number	biomass
Upper montane zone		0.855		0.827		
I	57		48.5		95.0	85.0
II	32		44.5		87.5	97.5
III	4		1.5		25.5	3.5
Lower montane zone		0.178		0.215		
I	97		180.0		40.5	17.0
II	136		132.5		62.0	39.5
III	107		206.0		41.0	7.0

Table 4. Characteristics of entomofauna inhabiting the region of Mumlawski Wierch and the valley of Kamienna river at the time of maximal insect abundance (June)
I – Living spruce forests, II – Spruce thickets, III – Deforested habitats

Index	Insects number (for 10 samples)		Insects biomass (for 10 samples)		% of Diptera in entomofauna	
Zone	Indiv.	S.D./ x	mg dw.	S.D./ $\bar{x}$	number	biomass
Upper montane zone		0.536		0.524		
I	364		182.5		62.5	51.0
II	288		155.0		59.0	61.5
III	102		53.0		48.5	72.0
Lower montane zone		0.413		0.444		
I	447		213.5		43.5	39.0
II	320		251.0		56.0	57.0
III	185		93.0		30.0	17.0

Table 5. Characteristics of entomofauna inhabiting the region of Mumlawski Wierch and the valley of river Kamienna during late autumn (October)
I – Living spruce forests, II – Spruce thickets, III – Deforested habitats

Index	Insects number (for 10 samples)		Insects biomass (for 10 samples)		% of Diptera in entomofauna	
Zone	Indiv.	S.D./ x	mg dw	S.D./ $\bar{x}$	number	biomass
Upper montane zone		0.904		1.635		
I	47		44		42.5	18.5
II	19		1.5		31.5	92.5
III	5		0.2		0	0
Lower montane zone		0.193		0.903		
I	62		68		40.5	15.0
II	48		7		2.5	21.5
III	43		28		16.5	17.0

3.2.2. BIOLOGICAL DIVERSITY OF DIPTERA

As stated previously, 42 Diptera families have been found to occur in the region of the studies, this testifying considerable qualitative diversity of the flies. Particular habitats differed greatly among themselves. Number of families that inhabited a habitat ranged between 21 and 32, i.e. between 50 and 75% of all Diptera families recorded in the study region (Table 6). The least diverse Diptera communities were found in the degraded sites. It is noteworthy that sporadically occurring families, i.e. represented by 1–2 individuals over the entire study period, contributed much (from 20 to 37%) to the communities, especially in the degraded sites (Table 6).

According to Koch's dispersion index (1957), Diptera families were distributed throughout the study region by about two times more evenly (index value equal to 0.658) than in e.g. agricultural landscape (0.331), and similarly to forest habitats (0.565) (Dąbrowska-Prot 1991). This indicates that despite considerable devastation, the entire region has still a forest character.

In the lower montane zone, predatory families Empididae and Syrphidae were the dominants (Table 6). In the upper montane zone, the most abundant were several saprophagous families.

Mean individual biomass describing size structure of a community indicates that regardless of site location, the mature spruce forests were mainly inhabited by very small Diptera. In a large area of the devastated habitat (station 4) exposed to strong winds, the individuals were by about 3 times heavier than in the remaining sites (Table 6).

Among dominant Diptera families (Table 2), Chloropidae and Agromyzidae occurred, some of which are known pests of crops and wild plants. The former family was one of the dominants in the spruce thickets of the higher montane zone (station 2) and in the degraded area situated in the valley of river Kamienna (station 9). No statistically significant differences were found in Chloropidae numbers between the upper and lower montane zone.

An analysis of Chloropidae species indicates that environmental conditions prevailing in the Karkonosze region are fairly specific. Most of all, number of the species found in the study region was very small (only 8) (Table 7). The species were as a rule eurytopic, i.e. linked with various types of habitats and geographical regions (Bieszowski 1985). Some 90% of the Chloropidae collected were phytophages associated with crops and herb plants of natural habitats, whereas the remaining 10% belonged to saprophages. No predators were found although such species are characteristic of Chloropidae communities inhabiting forest habitats.

The very simplified Chloropidae structure, with the dominant (50–100%) eurytopic, phytophagous species *Oscinella frit*, exhibited features of impoverished Chloropidae communities occurring in intensively managed agricultural areas (Dąbrowska-Prot 1984b, 1991). In the upper montane zone, Chloropidae inhabited mostly the mature and young living spruce forests, whereas in the lower zone – the younger spruce thicket and the site at the initial stage of destruction (Table 7). However, Chloropidae numbers did not correspond with their qualitative richness.

Because Chloropidae are strongly linked to man-made environments, they serve, beside other Diptera as a good in-

Table 6. Qualitative structure of Diptera communities in the region of Mumlawski Wierch (data from 2-year-period)

Habitat:	Upper montane zone				Lower montane zone				
	living spruce forest	thickets	deforested areas		living spruce forest	thickets		deforested areas	
Index	st.3	st.2	st.1	st.4	st.8	st.7	st.5	st.9	st.6
Family number.	31	32	27	23	26	30	32	21	29
% of sporadic families*	26	19	33	30	20	27	19	30	37
Participation (%) of families constituting about 50% of total Diptera numbers	Ceratopog. 19.5	Clusiidae 15.0	Chironomidae 29.0	Anthomyiidae 17.5	Empididae 16.5	Empididae 16.5	Drosophilidae 18.0	Empididae 18.0	Empididae 16.0
	Empididae 8.5	Chironomidae 12.5	Muscidae 21.5	Sarcophagidae. 12.0	Sciaridae 14.5	Ceratopog. 11.5	Empididae 11.0	Chloropidae 15.0	Ceratopog. 11.5
	Drosophilidae 8.0	Chloropidae 7.5		Clusiidae 12.0	Drosophilidae 9.5	Syrphidae 8.5	Ceratopog. 9.5	Syrphidae 10.0	Syrphidae 10.5
	Limoniidae 7.0	Empididae 7.0		Empididae 7.0	Limoniidae 8.0	Drosophilidae 8.5	Syrphidae 6.5	Sciaridae 8.5	Anthomyiidae 10.0
	Mycetoph. 6.0	Ceratopog. 7.0				Chironomidae 7.0	Sciaridae 6.0		
Mean biomass mg dw indiv.$^{-1}$	0.815	1.148	1.061	2.517	0.780	1.046	1.260	1.583	1.150

* – sporadic families – represented during 2 years of study by 1–2 individuals

Table 7. Characteristics of Chloropidae communities inhabiting the region of Mumlawski Wierch and the valley of Kamienna river (2-years data)

Habitat	Upper montane zone				Lower montane zone				
	living spruce forest	thickets	deforested areas		living spruce forest	thickets		deforested areas	
Index	st.3	st.2	st.1	st.4	st.8	st.7	st.5	st.9	st.6
Number distribution in %	12	24	8	3	3.5	7.5	12	22.5	7.5
Participation (%) in the total number									
Oscinella frit	53	50	65	100	67	90	24	100	80
Oscinella nitidissima	37	18	5			10	3		5
Oscinella angustipennis			5				50		
Oscinella alopecuri		14							
Chlorops meigeni	10	5	5		33		17		5
Tricimba cincta		13	20				3		
Elachptera cornuta							3		5
Tropidoscinis kerteszi									5

dicator of anthropogenic transformations of an area. In early spring when plants and animals started to develop rapidly, over 5 times larger numbers and 3 times greater biomass of Diptera were reported for Szrenica Mt. compared to Mumlawski Wierch. Diptera families of the Szrenica region were also more diversified, with synanthropic forms and Chloropidae contributing much more (by nearly 6 times) to the community (Table 8). Such a picture is presumably an effect of massive tourism in the region of Szrenica. This is in contrast to Mumlawski Wierch that is situated far from the main tourist tracks of Karkonosze Mts.

Table 8. Characteristics of Diptera communities of the upper montane zone of Mumlawski Wierch and Szrenica mountains

Index	Area: Mumlawski Wierch	Area: Szrenica
Abundance * mean number of indiv. 10 samples^{-1}	25	139
Biomass * mg dw 10 samples^{-1}	26.62	77.36
Number of families	17	21
% of synanthropic species**	29	40
% Chloropidae***	2.5	14.0

Significant differences between mountains characteristics – Mann-Witney U test: * $p<0.1$. ** $p<0.05$. *** $p<0.01$

Similar changes were also found in the case of plant communities (Wasiłowska 1999). On Szrenica Mt., synanthropic species and species typical of grasslands and meadows have increased their share in the herb layer. Such species have not occurred on Mumlawski Wierch at all. Moreover, in the surroundings of the shelter on Hala Szrenicka, a synantropic nitrophilous plant community has been formed as an effect of continuous discharge of sewage sludge. Such transformations in composition of plant communities enabled synanthropic Diptera species and phytophagous Chloropidae to appear in the Szrenica region. According to Łuczak's studies (Łuczak and Woźny 1999), the same was true for synanthropic species of spiders.

4. DISCUSSION

Industrial pollutants carried by air masses from central parts of Poland and other countries caused an ecological disaster in spruce forests of the Karkonosze region. This was the reason why the Committee of Scientific Research sponsored a research project that aimed at analysing present state of the Karkonosze environment (climate, geology, soils, hydrology, pollution), causes of the spruce forest die-back and ecological consequences of these phenomena (Fischer 1995). This work refers to the latter problem.

In spite of exceptionally severe environmental conditions, the studies did not reveal quantitative nor qualitative impoverishment of entomofauna inhabiting non-disturbed forest ecosystems of the Karkonosze region when compare with similar lowland ecosystems. Other authors have also emphasised fairly great qualitative richness of the Sudeten entomofauna. For example, Syrphidae species that occurred in the region constituted 40% of all Polish Diptera species (Bańkowska 1964), and beetles from the family Carabidae – as much as 58% (Leśniak 1984). Occurrence of 42 Diptera families was reported in the study region. This number is much different from that reported for spruce forest of northern Bavaria, i.e. 27 Diptera families (Hartman et al 1989). The difference may result from a short, one-year study period or the catching method applied in the latter studies.

Eight Diptera families constituted a main core (about 60% of the total number) of the community of the Karkonosze spruce forests. The core consisted of one predatory family (Empididae), two phytophagous families (Chloropidae and Agromyzidae) and five saprophagous families. The remaining 40% of Diptera numbers were incorporated among 34 families. Such a dominance structure of Diptera community is characteristic of forest habitats, whereas in e.g. arable lands one family may constitute as much as 70–80% of all Diptera (Dąbrowska-Prot 1984 a, b, 1986).

Although Chloropidae, the family being an indicator of anthropogenic transformations of an area (Dąbrowska-Prot 1984a, 1986), was one of the dominants in the Karkonosze region, it was species-poor (8 species) and had a simplified trophic structure (lack of predators). All species found in the region were eurytopic, i.e. characterised by wide geographical ranges of occurrence.

In the trophic Diptera structure of the Karkonosze region saprophages predominated, and among them – groups associated with decaying wood (Fig. 3). Likewise, in spruce forest damaged by acid rains in northern Bavaria, 75% of imagines belonged to two saprophagous Diptera families: Sciaridae and Cecidomyiidae (Hartman et al. 1989).

Such a trophic structure of the insects does not confirm a commonly accepted opinion that in forest ecosystems degraded by industry participation of phytophages is greatly increased. Such an increase was observed in pine forests of the industrialised Upper Silesia region where phytophages from the family Chloropidae and Agromyzidae were the dominants (Dąbrowska-Prot 1980, 1984a). Phytophage outbreaks have been attributed to reduced plant resistance to pests (Kononova 1967, Bormann 1982a, b), as well as to limited activity, or even elimination of main predators and parasites of the phytophages from the habitats (Łuczak 1980, Pętal 1980, Dąbrowska-Prot 1984a).

Saprophage dominance in the Diptera communities in the areas of spruce forest decline, at higher elevations in particular, points out the saprophagous species to be greatly involved in decomposition of organic matter in the soils.

Elevational ranges of occurrence of various organisms in mountains are a commonly known phenomenon, especially when high mountains are considered (Hunter and Yonzon 1993). However, any relief differentiation influences dispersal of organisms susceptible to this environmental factor. This is presumably associated with probability of finding food, avoiding of predators and with searching for sites where climatic conditions are more favourable (Beason et al. 1983).

Investigations of Carabidae communities in the lower and upper montane forest belts of Karkonosze Mts. (Leśniak 1984) did not show any greater differences in the species' numbers (24 species found in the upper, and 25 species – in the lower montane zone).

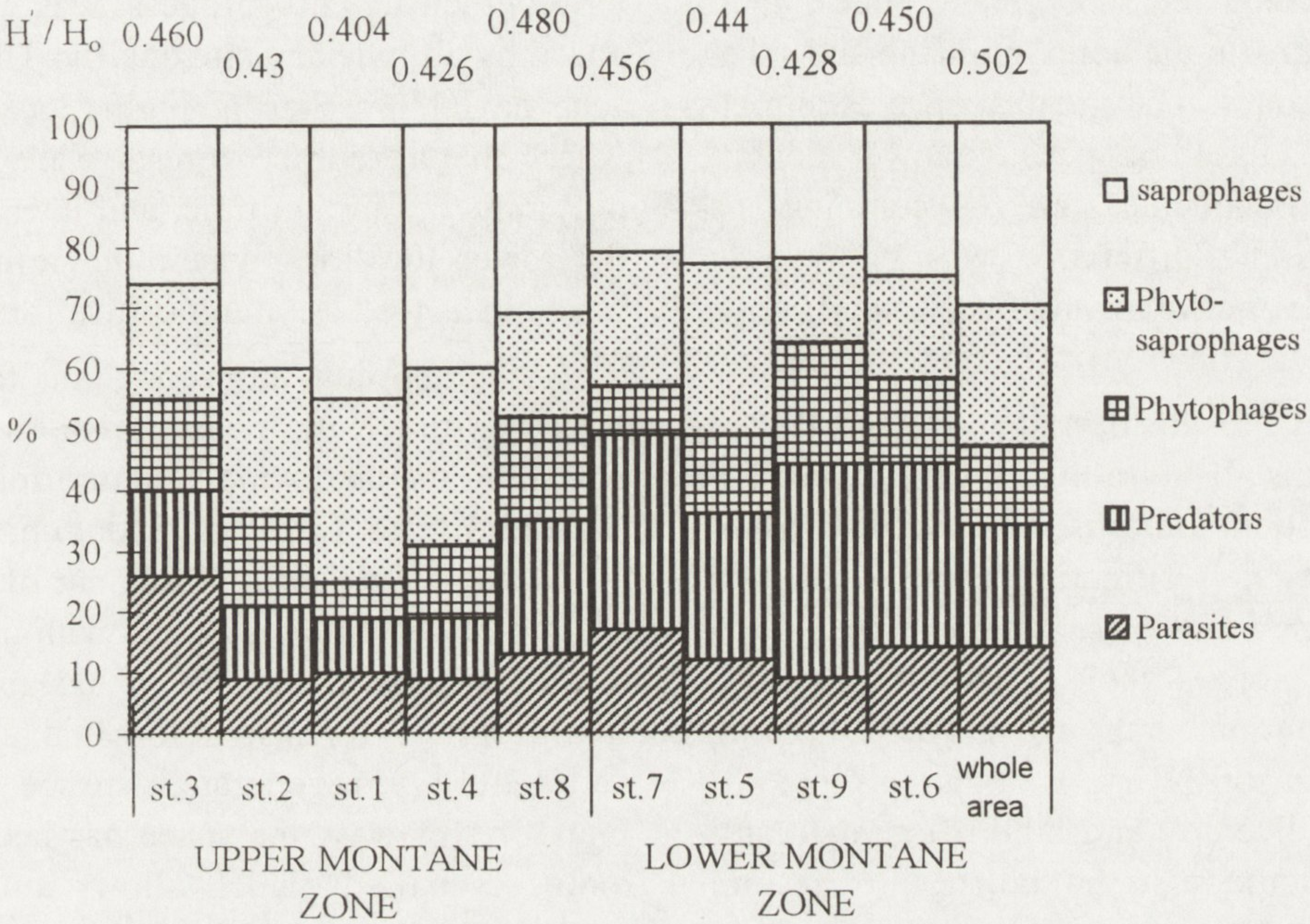

Fig. 3. Trophic structure of Diptera communities (in % in total number of community). At the top of the figure values of evenness index (Pielou 1969) are given (2-year data)

Moreover, dominants in both zones were the same, and only one species in the upper montane zone, and three species in the lower zone were found to occurr exclusively in those zones.

Greater differences were found for another component of epigeic fauna of the Karkonosze region, namely for spiders (Łuczak and Woźny 1999). Of 28 spider species found in the upper montane zone, 11 species (39%) occurred exclusively in the zone, and of 31 species reported for the lower zone, 14 ones (45%) were found solely in that area. Of 42 species found in the whole region studied, only 40% occurred in both zones.

An influence of altitude was much more distinct in the case of insects that easily penetrate herb and shrub layers, namely Diptera species belonging to the family Syrphidae (Bańkowska 1964). The studies were performed throughout the Sudeten region, a part of which are Karkonosze Mts. In the submontane zone (to 400 m a.s.l.), 87 species of Syrphidae were recorded, in the lower montane zone (400–1000 m) – 122 species, in the upper montane zone (1000–1300 m) – 27 species, and in the subalpine zone (1300–1500 m) – only 15 species. Thereby, the richest Syrphidae community was that of the lower montane zone where occurred 82.5% of 148 species reported for the Sudeten Mts. The poorest (10% of Sudeten species) was the community of the subalpine zone.

The elevational zones differed significantly from each other with regard to qualitative structure of Syrphidae. This was an effect of great differences in species numbers. Similarity among the communities expressed by share of common species was very low, because only 3 species were common to all of the 4 elevational zones, 5 species – to three zones (excluding the submontane zone), and 5 species – to the upper montane and subalpine zones. The greatest species similarity was found between the lower montane and submontane zone (64 common species). The difference was by 3 times greater between the lower and upper montane zone (only 23 common species).

The results described suggest that organisms penetrating higher layers of vegetation and thus more exposed to unfavourable climatic conditions (e.g. strong winds) are characterised by a much more variable pattern of elevational distribution than organisms inhabiting surface soil layers. It points out that altitudal diversity and kind of animal activity should also be taken into account when studying effects of spruce forest decline on animal communities.

The studies carried out in the region of Mumlawski Wierch revealed that altitude significantly affected vertical distribution of the entomofauna. This was particularly true in the periods when climatic conditions were very unfavourable, i.e. in spring and late autumn. In early spring, entomofauna inhabiting the upper montane zone was by 6 times less abundant than that of the lower zone, and consisted almost exclusively of Diptera. Of 29 Diptera families found in that period over the whole study area, 17 families (3/4 of that number were single individuals) occurred in the upper montane zone, 21 families – in the lower zone, and 15 families (52% of all Diptera families found) were common to both zones. It seems that during early spring the uppermost parts of the hill could be colonised by insects migrating from the lower elevations.

In autumn, there was an opposite tendency, which means that the insects have vanished from the less favourable environments. This process was influenced by altitude and site quality. The insects have left earlier the higher localities where mature spruce forests were their only refugees in that time, and later on – the lower localities where the refugees were old as well as young spruce forests.

An important anthropogenic factor affecting the Karkonosze fauna was a change in the landscape structure following the spruce forest degradation. The process consisted in replacement of vast areas of spruce monocultures with a mosaic of habitats composed of old-growth living spruce forests, deforested areas, and naturally regenerated spruce saplings. In this way, the space has become more diversified, which allows animals to choose the most suitable habitats.

Preferences of different groups of animals indicator to the three habitat types were different (Dąbrowska-Prot 1994, Sztrantowicz 1994, Łuczak and Woźny 1999). Soil protozoans and web spiders, i.e. relatively poorly mobile groups of invertebrates, have colonised living mature spruce forests. In these forests, about 75% of Protozoa numbers and 50% of spiders were found. Dipterans preferred spruce thickets that have regenerated in the devastated areas (about 50% of the total Diptera number). On the other hand, spiders of ground layer tolerated well the conditions prevailing in the devastated areas (about 52% of the total abundance) where dense herb layer provided the species with sufficient protection against worsened microclimatic conditions (Łuczak and Woźny 1999).

Relatively little and variable per cent of taxa (species, families) of their total number in the study area occurred in particular habitat types. This indicates much environmental selectivity of the animal groups (Dąbrowska-Prot 1994). Of 42 Diptera families occurring in the study area, the degraded sites were inhabited by 50–70% of the families, the mature spruce forests – by 62–74%, and the spruce thickets, sites preferred by the group – by 72–76%. An index of dispersion was by 3 times lower in Protozoa than in Diptera or epigeic spiders. Even in the mature spruce forests, though the site is most favourable to the group, only 46–53% of the species were recorded, whereas in the deforested areas – only 29–40%.

Occurrence of so called sporadic families is very characteristic of the Diptera communities. In natural systems, participation of such taxa is usually small, and an increase indicates disturbance of environmental and biocenotic conditions. In the degraded areas of the Karkonosze region, the sporadic taxa constituted as much as 30–37% of the Diptera families, in the spruce thickets – 19–27%, and in the mature spruce forests – 20–26%.

All the phenomena point out that particular components of spatial structure of the landscape are not equally valuable to various invertebrate groups. This is also indicated by a fairly high percentage of taxa inhabiting only one type of habitat. In the case of Diptera, the most specific communities (index of fauna specificity) were formed in degraded areas, and in the case of protozoans – in mature spruce forests (Dąbrowska-Prot 1994).

Greatly aggregated distribution of animals in the Karkonosze region has some biocenotic consequences. It caused that the functionally interrelated groups, such as spiders and dipterans that form a predator-prey regulation system (Holling 1956, Dąbrowska-Prot et al. 1968, Riechert and Łuczak 1982), have not overlapped in the space. Studies on quantitative relations of those groups have revealed that such a regulation system is likely to exist only in old-growth spruce forests (Łuczak and Dąbrowska-Prot 1995).

In ecological studies in mountainous areas, an additional anthropogenic factor, namely tourism intensity should also be taken into account. Preliminary results have already suggested that in the regions where tourism pressure is high, qualitative structure of fauna and flora may be altered. In the case of insects these are phenological cycle and abundance that undergo changes.

5. SUMMARY

Influence of natural (climate, altitude) and anthropogenic (deforestation, tourism) environmental factors on structure and functioning of entomofauna, dominant Diptera in particular, was analysed (Table 1). The study area was situated in the region of Mumlawski Wierch (1219 m a.s.l.) and a nearby valley of the Kamienna river (900 m a.s.l.) (Fig. 1) in the western part of Karkonosze Mts. exposed to the highest degree to pollution by industrial dusts derived from the interior of Poland, the Czech Republic and Germany.

In order to make a comparison, a similar study was additionally performed in the region of Szrenica Mt. (1362 m a.s.l.) in the upper and lower montane spruce forest belts (Fig. 1). Szrenica Mt. is of typically high mountainous character with well-developed subalpine zone. At the end of 19th century, one of the main tourist tracks of Karkonosze Mts. and two shelters: at the Szrenica peak and on Hala Szrenicka were established.

The studies demonstrated that a factor that significantly affects the pattern of insect dispersal is altitude. Its effect is especially evident during spring and autumn when climatic conditions are unfavourable (Tables 3, 4, 5). The factor had to be taken into account in the studies, the objective of

which was to find how a change in spatial structure of landscape due to spruce forest decline influences entomofauna. The change consisted in transformation of vast areas of the spruce monoculture into a diversified landscape composed mainly of remains of living mature forests, degraded areas devoided of trees, and regenerated young spruce stands (Fig. 1). Such an increase in landscape mosaic has created new environmental possibilities for animals.

It has been found that Diptera, the dominant entomofauna group (Table 1), prefers the old-growth spruce forests and thickets, this having been documented by the largest Diptera numbers (Table 1), biomass (Fig. 2), and taxonomic diversity (Table 6). During spring and autumn, when conditions for insects are critical, the old-growth spruce forests have become especially important as they provided the most favourable conditions for the insects (Tables 3, 5).

The degraded habitats with loose canopies due to the forest stand decline, with altered composition of herb layer due to expansion of grass species, *Calamagrostis villosa* and *Deschampsia flexuosa*, have maintained insect communities, including Diptera (Tables 3, 4, 5) that were much impoverished quantitatively (Fig. 2) and qualitatively (Table 6). Few groups of invertebrates, e.g. epigeic spiders, showed a positive reaction to the canopy opening.

Generally, in the Diptera trophic structure saprophages predominated. This points out the group to have been involved in the processes of soil organic matter decomposition (Fig. 3). Saprophages were dominants in all the sites of the upper montane zone, whereas predators (mainly the Empididae family) had the greatest participation at lower altitudes. The spatial avoidance of spiders and dipterans that are their potential prey has weakened functioning of the predator-prey system. Possibility of controlling over numbers of dipterans, phytophagous ones in particular, was possibly maintained only in the old-growth living spruce forests.

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