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EFFECT OF SULPHUR CONTAMINANTS ON MACROINVERTEBRATES IN THE KARKONOSZE MOUNTAINS (SUDETEN, POLAND)

The sensitivity of various epigeic macroinvertebrates to sulphur contaminants was assessed and, if possible, the identification of taxa that may be bioindicators of sulphur-related anthropogenic stresses in forested, mountainous ecosystems was carried. Invertebrates sampled using continuous pitfall trapping and core sampling were identified to at least family level. Sulphur pollutants exert a determinal effect on overall numbers of earthworms, some spider families (the complete lack of *Salticidae* and *Zoridae* in the deforested area) and beetles of the *Carabidae* family. Probably these groups may have the potential as early bioindicators of industrial pollution in forest environments. Other invertebrates appeared to be insensitive or tolerant to the effects of sulphur contaminants. Because of the plant (tree) cover destruction and changes of microclimate and a potential pool of preys it is difficult to attribute the results only to toxicological impacts. Our results need further studies.

1. INTRODUCTION

Sulphur compounds are among the main pollutants contributing to soil acidification and posing a threat to ecosystem equilibrium [1]. Sulphur contamination in the Sudeten is mainly the consequence of industrial emissions of sulphur dioxide. These are anthropogenic contaminants, derived mainly from brown coal combustion in Poland, Czech Republic and Germany [2] and, to some extent, from local boiler houses and furnaces. As a result of industrial emissions the decline of spruce forests in the Karkonosze Mountains and fall of soil pH have taken place. Numerous research proved the great influence of soil acidification on various components of ecosystem; however, only few papers deal with invertebrates, which are a common, well-known key factor in terms of biodiversity of forest environment [3].

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The objective of this work was to assess the influence of sulphur contaminants on epigeic fauna under natural conditions (field studies) and, if possible, to identify taxa that may serve as bioindicators of such a type of pollution in the future. Groups, whose sensitivity to sulphur pollution was previously observed, were identified to at least a family level [4], [5], the remaining ones were studied at higher taxonomic level only. The identification to the species level was omitted deliberately because of its uselessness for bioindication, as the taxonomy of most invertebrates under study is very difficult, thus identification could be performed only by experts.

2. MATERIAL AND METHODS

2.1. STUDY SITES

The study sites were located in the area of Szrenica (1362 m a.s.l) and Mumlawski Wierch (1240 m a.s.l) and within the Kamienna River Valley (900 m a.s.l.) (the Karkonosze Mts., the Sudeten) during 2007–2008. The area of Mumlawski Wierch is perceived as one of the regions most seriously affected by the ecological disaster in the Karkonosze Mts. The surface of the sites studied consisted of mother rock (biotit granite) and soil (podzol–peat) [6], [7]. The characteristics of these sites are listed in table 1. The forest dominating in the area of Mumlawski Wierch and Szrenica is

Table 1

Environmental characteristics of sites understudy.
S and S-SO_4 concentrations exceeding permissible values are printed in bold

Site no.	Total S (mg/100 g)	S-SO_4 (mg/100 g)	pH	Average plant richness /m^2
1	**190.50**	**10.96**	4.1	6.2
2	**182.38**	**5.56**	3.4	6.8
3	55.36	1.48	6.29	8.9
4	**192.68**	**7.64**	4.60	5.8
5	**195.26**	**5.36**	5.0	4.5
6	**165.46**	**17.76**	5.6	4.6
7	86.50	3.67	5.9	3.2
8	37.52	**5.33**	6.3	3.6
9	**187.62**	4.74	5.6	3.5
10	29.08	1.00	6.6	8.9
11	**225**	**5.67**	5.45	6.7
12	**193.8**	1.06	4.5	6.8
13	**335.8**	**16**	3.5	1.5

a spruce forest; however, certain study sites occuppied the area devoid of trees (sites 11–13 in the region of Mumlawski Wierch and sites 1–6 in the area of Szrenica). The above sites are characterized by the various level of plant degeneration (from the sites with preserved natural trees layer through the biotopes devoid of trees or with dominating grasses such as *Deschampsia flexuosa, Calamagrostis villosa* in the herb layer to the sites spontaneously overgrown by young spruce). Additional information on the research is given by various authors who described the process of large-area forest decline in the Sudeten [2], [4], [6], [7]. Within the area under study 13 sites were selected, differing from each other in soil's sulphur content. A comparison of data from the sites where the contamination was very high (above 100 mg of sulphur/100 g of soil) with these where the sulphur content only slightly exceeded the permissible values (up to 100 mg of sulphur/100 g of soil) allowed the assessment of potential effect of sulphur pollution on epigeic invertebrates.

2.2. METHODS

Research was restricted to the macroinvertebrate communities inhabiting epigeic layer and moving on the ground surface. The samples were taken for 5 months from May to the end of September. When collecting spiders from the litter and ground surface the traps of Barber were used (a 0.33 dm^3 jar with an opening diameter of 56 mm). At each site 5 traps were sunk into the ground with the rim flush, filled with ethylene glycol and covered with a shield. Samples were emptied three times in the season 2007 and three times in 2008 (May, July, September).

To supplement the pitfall trapping, soil was directly sampled in order to estimate the densities of epigeic fauna. The soil samples were collected in selected sites. Then they were dried in the Tullgren funnels and the invertebrates extracted were collected in water. Additionally, various habitats were penetrated in order to find the representatives of epigeic fauna.

The soil samples collected were used to determine: pH (potentiometrically), total sulphur (nephelometrically) and sulphate sulphur (turbidimetrically). The chemical analysis was performed in a professional laboratory (Chemical-Agricultural Laboratory in Wrocław).

The results obtained were statistically analyzed (one-way ANOVA with Fisher's least significant difference test and *t*-test).

3. RESULTS

The level of sulphur content characteristic of the sites under study is shown in table 1. All sites were to a certain extent polluted with sulphur. In sites 1, 6 and 13, at the lowest pH the sulphur contamination was the highest. They are localized in the deforested areas of Mumlawski Wierch (site 13), Szrenica (site 6) and Hala Szrenicka (site 1). On the other hand, sites 3, 7, 8 and 10 were characterized by a relatively low sulphur level. Sites 7, 8 were localized at the foot of Szrenica Mt. (near the bottom station of cable railway, close to the ski track "Puchatek"), the site 10 was situated within the Kamienna River Valley. Although rated as low polluted, the site no. 3 was a deforested area in the region of Szrenica peak.

Table 2a

Pitfall catches of macroinvertebrates in sites 1–4.
Samples were collected 3 times per season, 5 traps in one site

Taxa	Site 1 Hala Szrenicka, deforested area of upper mountainous zone. Mean/SE		Site 2 Hala Szrenicka, deforested area of upper mountainous zone. Mean/SE		Site 3 Region of Szrenica, deforested area of upper mountainous zone. Mean/SE		Site 4 Region of Szrenica, deforested area of upper mountainous zone. Mean/SE	
Collembola	263.5	112.5	32.3	7.40	260.6	108.1	50.6	41.2
Staphylinidae	19	11	8	0.3	11.3	0.2	0	0
Carabidae	60	0.5	23.5	0.35	12	0.8	12	0.2
Opiliones	11	0.8	0	0.0	24	0.7	0	0
Heteroptera	20.1	0.07	0	0.0	0	0	0	0
Formicidae	59.5	39.5	44	0.70	84	58.6	69	33
Cybaeide	11.3	0.9	0	0	0	0	0	0
Linyphiidae	22.3	15.3	0	0	21	0.6	12	9.8
Mollusca	13.4	0.3	0	0	0	0	0	0
Acarina	36.5	20.5	0	0	38	5	0	0
Amaurobidae	0	0	0	0	0	0	0	0
Liocarnidae	0	0	0	0	0	0	6.3	0.9
Gnaphosidae	0	0	0	0	0	0	0	0
Clubionidae	0	0	0	0	0	0	0	0
Zoridae	0	0	0	0	0	0	0	0
Salticidae	0	0	0	0	0	0	0	0
Curculionidae	0	0	0	0	0	0	0	0
Lumbricidae	0	0	0	0	0	0	0	0
Elateridae	0	0	0	0	0	0	0	0
Lycosidae	0	0	0	0	0	0	0	0
Homoptera	0	0	0	0	0	0	0	0
Diplopoda	0	0	0	0	0	0	0	0
Agelenidae	0	0	0	0	0	0	0	0

Invertebrates caught extremely rare in highly polluted sites belonged to the *Lumbricidae* family (table 2a–c), only their few representatives were collected in the polluted soil samples ($DF = 1, 11$; $F = 7.6$; $P < 0.05$). The number of spiders of the *Linyphiidae* family found in the sites whose pollution with sulphur was highly differentiated did not differ significantly ($DF = 1, 11$; $F = 0.36$; $P > 0.05$). But in the most deforested sites

(sites 11, 12 and 13), the highest number of linyphiids were observed. Such spider families as *Salticidae*, *Zoridae* were present only in mature spruce forest (table 3). Of the *Coleoptera*, the carabid family was negatively affected by sulphur pollutant. Their representatives were not recorded at the most polluted sites (no. 6, no. 13; *t*-test = 2.57; $P < 0.05$). However, no significant differences were observed between the sites moderately and the low-level contaminated. For other invertebrates (*Stapyliniidae, Opiliones, Formicidae, Collembola, Acarina*), any significant differences in the number of individuals have not been observed in the sites studied.

Table 2b

Pitfall catches of macroinvertebrates in sites 5–9.
Samples were collected 3 times per season, 5 traps in one site

Taxa	Site 5 Ski lift to Szrenica. Thicket, upper mountainous zone. Mean/SE		Site 6 Ski lift to Szrenica. Thicket, upper mountainous zone. Mean/SE		Site 7 Lower ski lift station. Mature spruce forest, lower mountainous zone. Mean/SE		Site 8 Lower ski lift station. Mature spruce forest, lower mountainous zone. Mean/SE		Site 9 Kamienna River. Mature spruce forest, lower mountainous zone. Mean /SE	
Collembola	201	120	86	0.5	0	0	32.3	7.36	19.3	5.2
Staphylinidae	11.5	0.5	12.1	0.07	0	0	12	0	0	0
Carabidae	0	0	0	0	22	1	33	0.7	0	0
Opiliones	16	5	43.2	0.1	11	0	0	0	8	4.9
Heteroptera	0	0	32	20	0	0	15	7	0	0
Formicidae	59.3	32.06	26	9.2	0	0	90.5	19.5	0	0
Cybaeide	0	0	0	0	0	0	0	0	0	0
Linyphiidae	19.3	9.6	12.5	0.3	22	0	0	0	0	0
Mollusca	22.5	0.5	11	0	0	0	0	0	12.5	0.3
Acarina	21.6	8.2	17.5	5.5	0	0	0	0	11.2	0.1
Amaurobidae	0	0	4.2	0.4	0	0	0	0	0	0
Liocarnidae	0	0	0	0	0	0	0	0	0	0
Gnaphosidae		0	0	0	0	0	0	0		0
Clubionidae	0	0	0	0	0	0	0	0	4.6	4.6
Zoridae	0	0	0	0	0	0	0	0	2.3	0.1
Salticidae	0	0	0	0	0	0	0	0	1	0
Curculionidae	12	0	0	0	32.2	0.1	11	0.6	0	0
Lumbricidae	0	0	0	0	11.1	0.0	11	15.5	0	0
Elateridae	0	0	0	0	0	0	8.1	0.07	0	0
Lycosidae	12.1	0.07	0	0	0	0	12.2	0.14	0	0
Homoptera	0	0	31	0	0	0	0	0	0	0
Diplopoda	0	0	0	0	0	0	0	0	0	0
Agelenidae	0	0	12	0	0	0	8.3	0.2	0	0

Table 2c

Pitfall catches of macroinvertebrates in sites 10–13.
Samples were collected 3 times in season, 5 traps in one study site

Taxa	Site 10 Kamienna River. Thicket, upper mountainous zone. Mean /SE		Site 11 Region of Mumlawski Wierch, thicket, upper mountainous zone. Mean/SE		Site 12 Mumlawski Wierch, deforested area, upper mountainous zone. Mean/SE		Site 13 Mumlawski Wierch deforested area, upper mountainous zone. Mean/SE	
Collembola	41.6	41.2	263.1	0.07	202	23.8	56.8	0.5
Staphylinidae	17.3	9.8	23.6	0.4	26.3	12.2	9	3
Carabidae	0	0	0	0	0	0	0	0
Opiliones	12	4.9	0	0	0	0	23.4	0.2
Heteroptera	0	0	0	0	0	0	0	0
Formicidae	16	5	31.5	0.3	44.3	18.8	77	43
Cybaeide	0	0	0	0	0	0	0	0
Linyphiidae	44	11	42.8	0.6	26.2	10.5	12.5	0.3
Mollusca	0	0	41.3	0.2	32	5.1	44.7	0.4
Acarina	105	0	100.3	0.2	71.5	40	0	0
Amaurobidae	0	0	0	0	0	0	0	0
Liocarnidae	0	0	0	0	0	0	0	0
Gnaphosidae	0	0	1	0.9	10.4	0.4	0	0
Clubionidae	8.9	0.5	0	0	0	0	0	0
Zoridae	0	0	0	0	0	0	13.5	0.3
Salticidae	0	0	0	0	0	0	0	0
Curculionidae		0	0	0	0	0	0	0
Lumbricidae	23	0	0	0	0	0	0	0
Elateridae	0	0	0	0	0	0	0	0
Lycosidae	0	0	0	0	11	0	27	4
Homoptera	0	0	0	0	0	0	10.5	2.5
Diplopoda	44	0	0	0	16.5	0.5	0	0
Agelenidae	11	0	0	0	12.8	0.4	0	0

Table 3

Mean seasonal abundance (individuals in 10 samples) and percentage abundance
of epigeic spider families in three habitat types of sites studied

Family	Spruce forests	%	Deforested areas	%	Thickets	%	Whole area (%)
1	2	3	4	5	6	7	8
Linyphiidae	90.5	29.9	93.3	30.8	118.6	39.3	**66**
Lycosidae	12.2	19.6	38	61	12. 1	19.4	**13.6**
Cybaeidae	11.3	100	–	–	–	–	**2.5**

1	2	3	4	5	6	7	8
Amaurobidae	–	–	–		4.2	100	**0.9**
Agelenidae	8.3	18.9	12.8	29	23	52.1	**9.6**
Liocarnidae	–	–	6.3	100	–	–	**1.4**
Gnaphosidae	–	–	10.4	91	1	9	**2.5**
Clubionidae	4.6	34	–	–	8.9	66	**2.9**
Zoridae	2.3	100	–	–	–	–	**0.5**
Salticidae	1	100	–	–	–	–	**0.2**
Total	**129.2**		**160.8**		**167.8**		**100**

What is interesting, *Mollusca* (*Gastropoda*, *Arionidae*) were abundant only in the sites, where the sulphur content was very high ($DF = 1, 11$; $F = 5.2$; $P < 0.05$).

4. DISCUSSION AND CONCLUSION

Although industrial emissions have been limited or even completely reduced, in the area of the Karkonosze Mountains the soil is sill highly contaminated with the sulphur compounds. Such a pollution results in a low pH of soil (high acidification), loss of vegetation cover and different species composition of epigeic invertebrate fauna. Some taxa, e.g. earthworms, spiders (a complete lack of *Salticidae* and *Zoridae* in the deforested area) and the beetles of *Carabidae* family, are probably adversely affected by high sulphur level, which is confirmed by other studies [8]. Others invertebrates appeared to be insensitive or tolerant to the effects of sulphur contamination. Because of the plant (tree) cover destruction, the changes in both microclimate and a potential pool of prey it is difficult to attribute their results only to adverse sulphur impact. My results showing the negative effects of sulphur compounds on carabid beetles are confirmed by previous studies [3]. However, these beetles seem to be insensitive to lower or even medium sulphur level. The fauna of epigeic spiders collected in the sites under study was poor in both species and individuals. Linyphiids were most abundant in the deforested, highly contaminated sites which contradicts the results of CÁRCAMO et al. [8], but confirms GUNNARSSON's findings [5] showing that in spruce habitat, linyphiids spiders became more abundant relative to larger web-making spiders in the sites exposed to air pollution. Above all, the differences in spider abundance between the sites could result from the habitat type (mature spruce forest, deforested areas, spruce thickets) and altitude. This influence of altitude was observed when comparing spider communities in similarly degraded habitats of two elevation zones [9]. In the upper mountainous zone, the number of spiders is slightly lower than in the lower zone having direct impact on the community density [9]. Probably, only a correct identification of a species could answer the question whether spiders could respond directly to the level of sulphur compounds or/and to the other habitat features. Unfortunately, the taxonomy of most spider families is very difficult, thus only specialists could correctly identify their species.

In summary, it should be stressed that further studies in this field are needed as the contradictory findings relating to the usefulness of beetles and spiders as bioindicators [3], [5], [8].

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WPŁYW ZANIECZYSZCZEŃ SIARKOWYCH NA MAKROBEZKRĘGOWCE NA OBSZARZE KARKONOSZY (SUDETY, POLSKA)

Przedstawiono badania nad wpływem zanieczyszczeń siarkowych (siarka ogólna i siarka siarczanowa) na bezkręgowce. Podstawowym celem było znalezienie taksonów, które mogą być bioindykatorami tego typu zanieczyszczeń. Na badanym obszarze wyznaczono 13 stanowisk badawczych, różniących się poziomem zanieczyszczenia (od stosunkowo niskiego po bardzo wysokie). Stwierdzono, że zanieczyszczenia siarkowe mają największy wpływ na przedstawicieli *Lumbricidae,* pająki z rodzin *Salticidae* i *Zoridae* oraz na chrząszcze z rodziny *Carabidae.* Prawdopodobnie te taksony mogą być wykorzystywane jako bioindykatory skażeń siarkowych, jednakże moje badania wymagają kontynuacji. Pozostałe grupy występowały na obydwu typach stanowisk. Mięczaki stwierdzono jedynie na stanowiskach znacznie zanieczyszczonych.