Journal of Ecological Engineering
Volume 14, No. 4, Oct. 2013, pp. 9–17
DOI: 10.5604/2081139X.1066214

Research Article

THE INFLUENCE OF POST-FLOTATION TAILINGS POND "WARTOWICE" (LOWER SILESIA) ON THE BIODIVERSITY OF MACROINVERTEBRATES

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Received: 2013.07.22
Accepted: 2013.09.06
Published: 2013.10.10

ABSTRACT
In this paper the biodiversity studies on macroinvertebrates were conducted in the area post-flotation tailings pond "Wartowice", which poses a serious threat to the environment. The analysis of the biodiversity was done with two methods: the use of biodiversity indices along with taxonomic identification to family level and with the application of morphospecies method. Both were assessed concerning their usefulness. Macrofauna was sampled in a five sites characterized by different level of pollution. We found the dependence of macroinvertebrates structure on habitat type. Both methods, although not very accurate, were found suitable for the assessment of such disturbance type.

Keywords: biodiversity, macroinvertebrates, family level, morphospecies, tailings, copper.

INTRODUCTION

In the area of Lower Silesia, in the "Old Copper Mining Region" landfill sites, which are excluded from use, are still present. Extracting copper ores between Bolesławiec and Złotoryja ended in 1990's along with the deposits depletion by a mine "Konrad". During 40 years of exploitation the plant produced the 35 mln m^3 of waste, which was deposited in three tailings ponds. The end of extracting copper ores, was also the end of the use of these three settlers. These post-flotation tailings ponds require reclamation now, which is extremely tough [Grabas et al. 2012, Spiak et al. 2012]. In this paper we focused on "Wartowice" tailings pond No. 3, whose reclamation causes many problems resulting from the pond size – 232 ha, changeability of the basin surface of waste depending on meteorological conditions, water erosion and peculiar properties of the deposited waste which are disadvantageous to the growth of plants including: granulometric composition (small pores), small aeration and big retention of rain water, which is unavailable to plants, bad air-water conditions, weak affluence with assimilable nutrients, deficiency in the organic matter and the chemical composition and waste dryness. Compounds as CaO, SiO_2, Al_2O_3, MgO, K_2O dominate in the chemical composition of the waste [Grabas et al. 2012]. The influence of such transformations on plant communities was investigated extensively [Spiak et al. 2012]. However, none of the studies was devoted to invertebrates. It has been proved that invertebrates are sensitive to habitat structure [Jung et al. 2008]. However, some findings concerning the sensitivity of different taxonomic groups to different pollutants are contradictory [Gunnarson at al. 2004; Horvath et al. 2001]. What is more, sensitive species may be replaced by tolerant ones, which give similar results concerning species diversity although species composition can be completely different [Clements and Newman 2002].

In this paper the biodiversity of macroinvertebrates, and hence the ecological state of post-flotation pond "Wartowice" was analyzed. The analysis of the biodiversity was done as a comparison of two methods: the use of biodiversity indices altogether with the taxonomic identification to family level and with the application of morphospecies method. It is a common knowledge that species level identification is the most accurate level in bioindication and disturbance assessment, although it requires a high amount of labor and specific knowledge. In the case of such a big group as macroinvertebrates, the identification of all taxons requires plenty of work to do by many specialists (e.g. there are only a few specialists in Acari in Poland focusing mainly on local species diversity, what makes identification of this group to the species level practically impossible). The objective of this work was to assess the influence of post-flotation sludge on macroinvertebrates (field studies) to answer the question if there is an impact of such type of land contamination on macroinvertebrates assemblages, and if so, is it possible to asses them by the application of simplified methods (arthropod morphospecies method or family level taxonomic identification), which were estimated in relation to their usefulness.

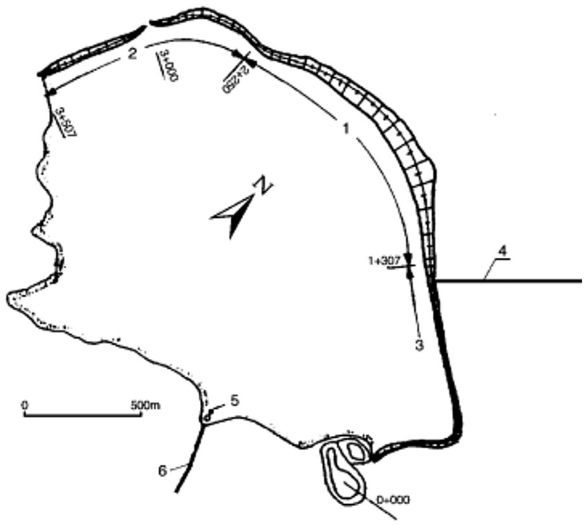

Fig. 1. Localization of „Wartowice" tailings pond according to Lewiński & Wolski [2007]: 1 – main banking, 2 – side banking, 3 – side banking, 4 – pipeline supplying the waste, 5 – overflow tower, 6 – pipeline with sludge water

MATERIAL AND METHODS

In the mining of ores of non-ferrous metals, including copper ores, because of the low content of pure element in the extracted raw material (a few per cent) waste constitutes about 90% of material. The extracted copper ores are processed with the use of crumbling, grinding and classification and finally separation of minerals in the process of flotation. The created waste stream was directed by the hydrotransport system to post-flotation tailings pond collecting the slime which appeared after the process of flotation of rock [Spiak et al. 2010].

The studied post-flotation tailings pond is located near Wartowice and Iwiny in the Warta Bolesławiecka municipality, in the Lower Silesia region. Figure 1 shows the location and the overall appearance of the pond (Fig. 1). The end of exploitation caused draining almost the whole area. A basin water, supplied with rain, is present only in the southern part of the pond. The inhibition of plants growth and development, as well as other biochemical and biological processes, is a result of the disadvantageous chemical composition of deposits after the flotation of copper ores. Table 1 depicts chemical composition of post-flotation deposits [Mizera 2002, Spiak et. al. 2010]. Heavy metals are present there, mainly copper and lead, whose contents exceed permissible values for the soil on industrial lands. Alkaline pH of sludge (7.5–8.0) and exaggerated amount of calcium and potassium inhibit phosphorus uptake by plants, although the amount of phosphorus is limited already. Waste is characterized also by a low nitrogen content. These factors also influence the development of plants diseases settling the pond [Spiak et al. 2010]. Additionally such factors as grain composition inappropriate for plants (dominance of the superfine faction), small aeration, big retention of rain waters or deficiency in the organic substance influence greatly the process of plants succession [Spiak et al. 2010]. Even dgough many years passed from the exploitation of tailings pond, only a little part of its surface is covered with the flora, although the object is located near the areas with lush vegetation.

The evaluation of invertebrates diversity which does not require the high-level taxonomical proficiency was applied (Eng. RBA – Rapid Biodiversity Assessment) in the presented studies [Oliver and Beattie 1996]. This method called morphospecies method consists of grouping individuals, which is done by non-specialists, according to their most important morphological features based on observation with the "naked eye", rather than according to the rules of taxonomy. It is useful for the evaluation of the biodiversity for difficult taxons, such as invertebrates or nonvascular plants [Oliver and Beattie 1996].

The other most often applied method of biodiversity assessment based on the taxonomical

Table 1. The average chemical composition of post- flotation sludge from „Wartowice" tailings pond [Mizera 2002, Spiak et al. 2012]

Compound	Content [% mass]	Compound	Content [% mass]
Na_2O	0.107	As_2O_5	0.008158
Li_2O	0.0118	SeO_2	0.000052
K_2O	3.25	MoO_3	0.001103
CaO	22.75	CrO_3	0.0132
MgO	3.96	WO_3	0.000011
SO_3	0.462	CdO	0.0000406
BO_2	0.1004	PbO	0.00396
ZnO	0.0082	CoO	0.002866
P_2O_5	0.1749	NiO	0.00287
Al_2O_3	11.74	BeO	0.001836
Fe_2O_3	2.58	V_2O_5	0.01835
SiO_2	53.90	CuO	0.22199
Mn_2O_5	0.268	Ag_2O	0.00218
SrO	0.0542	TiO_2	0.124
BaO	0.0212	ZrO_2	0.00217
SnO_2	0.000684	HgO	0.00019
TlO_2	0.0001843	UO_3	0.000898

identification is an application of biodiversity indices such as Simpson index (D), Margalef index (R_1 lub d) and Shannon diversity index (H') [Sienkiewicz 2010].

- Simpson index:

$$D = 1 - \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)}$$

where: S – number of all species,
N – number of all individuals,
n_i – number of individuals of i-species.

- Margalef index:

$$R1 = \frac{S-1}{\log N}$$

where: S – number of all species,
N – number of all individuals.

- Shannon diversity index:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where: S – number of all species.

$$p_i = \frac{n_i}{N}$$

N – number of individuals,
n_i – number of individuals of i- species.

For the calculation of biodiversity indices the taxonomic identification to the family level was done (with the exception of Acari, where even identification to the family level was not possible).

SITES DESCRIPTION

Macroinvertebrates collection (diameter >2 mm) was done in 5 sites (Fig. 2). Two of them were located on a "crown" of pond - they were regarded as reference sites because of soil enriched with humus layer what highly supports the flora development, in contrast with the pond surface, where humus layer was not present or was minimal.

Detailed descriptions of sites:

- **Reference site 1** – situated in the north part of the tailings pond, on the crown (banking) of settler, abundant grass layer and trees such as *Betula* sp. and *Salix* sp. are present.
- **Reference site 2** – west of site 1, also at the top of the settler. Similar flora, like in site 1. Situated in the vicinity of path surrounding the settler, where the frequent presence of people, as well as different waste left by them, were observed.
- **Site 3** – located in the distance of about 50 m from the north banking. Flora reduced to single mosses, the small amount of grass and poorly developed bushes.
- **Site 4** – in a distance of about 200 m from the basin of sludge and about 300 m from site 3.

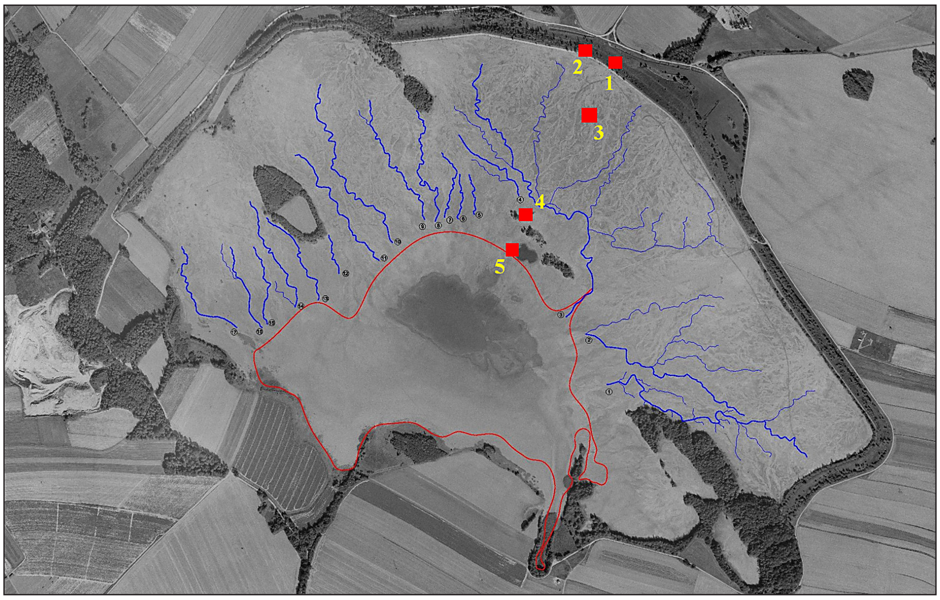

Fig. 2. Map of research sites: 1 – site 1, 2 – site 2, 3 – site 3, 4 – site 4, 5 – site 5, blue colour – watercourses of rain water (Author Łukasz Buczkowski on the base of Spiak et al. [2010])

Flora similar like in site 3, but more scarce.

- **Site 5** – situated on a natural island. It is surrounded from three sides with basin of water. More developed flora was observed compared with site 4: low birches, grass, bushes, mosses and lichens.

Sampling was done with the use of pitfall traps (filled with glycol), exhauster, and by simply catching all spotted macroinvertebrates. The research was carried out in the summer of 2012. Each site was equipped with 5 pitfall traps (plastics containers of 120 ml capacity). Each site had the area of about 10 m^2. Pitfall traps were emptied three times, in week's intervals, in July and August. Caught individuals were drained off glycol as well as they were sorted in the laboratory and then conserved in ethanol (60%). Samples were stored in 4ºC until their identification with the use of stereoscopic microscope and appropriate keys. The obtained results were statistically analyzed (t-test, $p = 0.05$). We analyzed also Pearson r-correlation coefficients between plant richness and Shannon diversity index using Statistica 9 (StatSoft).

RESULTS

The composition of macroinvertebrates assemblages was presented in Table 2. All sites apart from reference sites were characterized by the certain influence of post-flotation sludge. We identified 928 macroinvertebrates in total, the majority belongs to insects (41%). Family Formicidae, Hymenoptera (77,8%), then protected Carabidae, Coleoptera (18,6%) were the most dominant families. Less numerous were Homoptera, Aphididae family (1.3%) and Coleoptera, Staphylinidae family (1.2%). Occasionally beetles from Curculionidae (0.23%), Elateridae (0.1%), Rhynchitidae (0.1%), Buprestidae (0.1%) families, Reduviidae (0.1%) and Miridae (0.1%) belonging to Heteroptera as well as Ichneumonidae belonging to Hymenoptera (0.1%) were recorded.

Arachnids constituted 37% of the collected material. The most numerous was Lycosidae family (37% of samples belonging to arachnids), then Linyphiidae (13%). Families of Phalangiidae belonging to Opiliones (15.2%) and Acari order (8.7%) were found less frequently. Representatives of pseudoscorpions (Chthonidae) (2.2%) and Opiliones (Nemastomatidae) (2.2%) as well as other families of spiders (Pisauridae: 2.2%, Theriididae: 10.9%, Salticidae: 4.4% and Araneidae: 4.4%) were collected rarely. Diplopoda were represented by three families: Glomeriade (73.7%), Polydesmidae (21%) and Julidae (5.3%). Entognatha were represented by two families: Tomoceridae (96.2%) and Poduridae (3.8%). Only one individual belonging to Chilopoda was identified from the Lithobiidae family (Fig. 3, 4 and 5). The most individuals were collected in site 3 while the least in site 4.

Table 2. Contribution of different families of macroinvertebrates in all sites, green colour – the highest score, red – the lowest score

Taxa	Family	Site 1	Site 2	Site 3	Site 4	Site 5	Sum
Insecta	Curculionidae	1	1	0	0	0	2
	Staphylinidae	7	1	0	0	2	10
	Formicidae	107	82	202	21	239	651
	Reduviidae	1	0	0	0	0	1
	Aphididae	1	10	0	0	0	11
	Carabidae	0	0	153	2	0	155
	Elateriade	0	0	1	0	0	1
	Rhynchitidae	0	0	0	0	1	1
	Buprestidae	0	0	0	0	1	1
	Ichneumonidae	0	1	0	0	0	1
	Miridae	0	2	0	0	0	2
Arachnida	Acari	2	2	0	0	0	4
	Lycosidae	8	9	0	0	0	17
	Pisauridae	1	0	0	0	0	1
	Linyphiidae	4	0	0	0	2	6
	Phalangiidae	5	2	0	0	0	7
	Theriididae	4	1	0	0	0	5
	Nemastomatidae	1	0	0	0	0	1
	Salticidae	0	0	0	1	1	2
	Chthonidae	0	1	0	0	0	1
	Araneidae	0	2	0	0	0	2
Diplopoda	Polydesmidae	4	0	0	0	0	4
	Glomeridae	13	1	0	0	0	14
	Julidae	0	1	0	0	0	1
Entognatha	Tomoceridae	20	3	0	0	2	25
	Poduridae	0	0	0	0	1	1
Chilopoda	Lithobiidae	0	0	0	0	1	1
Sum		179	119	356	24	250	928

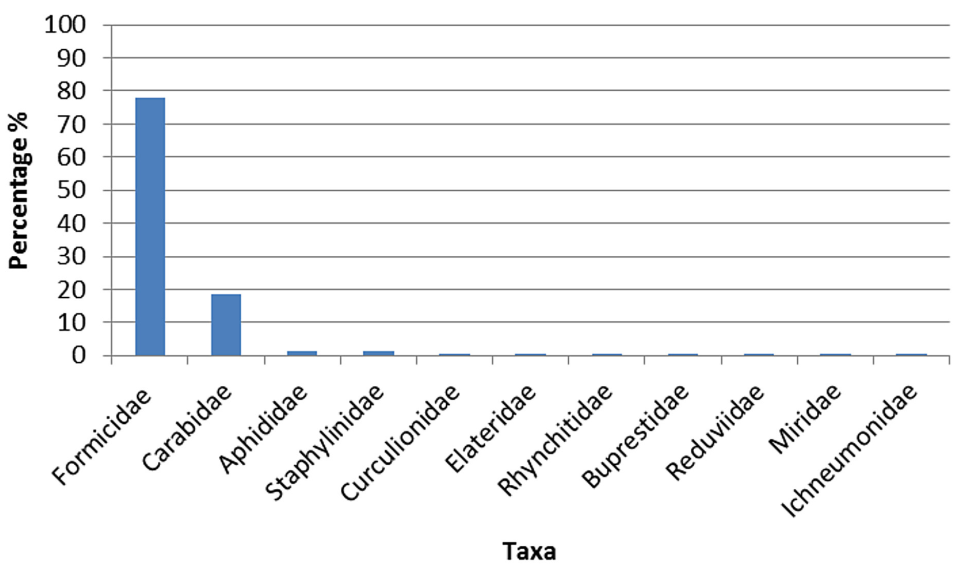

Fig. 3. Family participation of Insecta

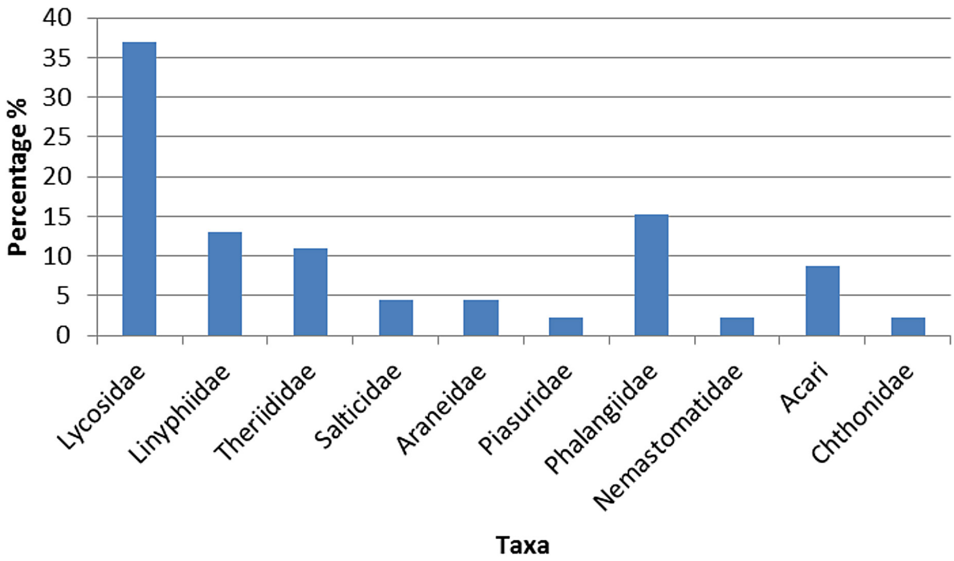

Fig. 4. Taxons participation of Arachnida

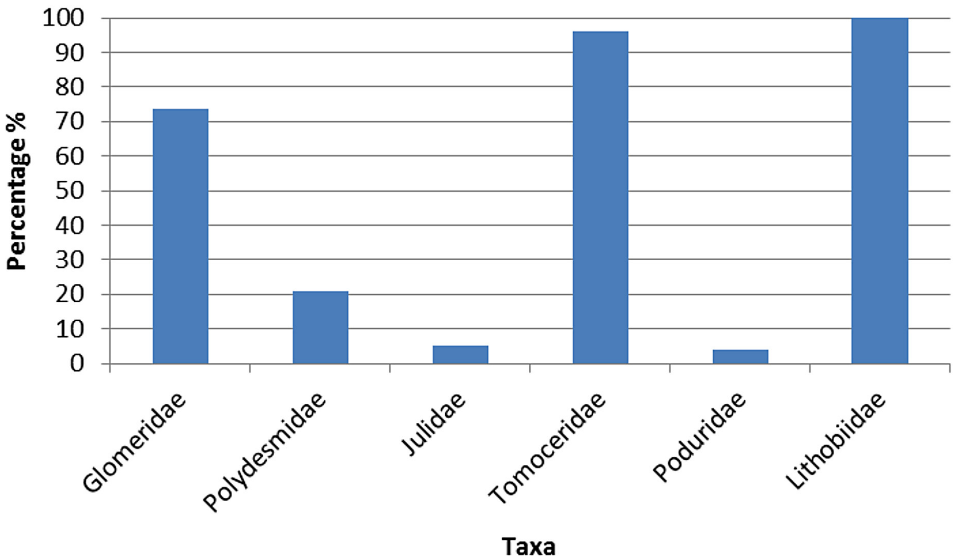

Fig. 5. Family participation of Diplopoda, Chilopoda and Entognatha

Morphopecies merthod

The organisms were grouped by the parataxonomist according to their morphological features. They were classified to the taxonomical groups from "and" to "r". Table 3 shows the number of species and individuals in each site, assigned according to the subjective evaluation based on their morphology.

Biodiversity indices

The obtained values of Shannon diversity index (H'), Simpson (D) and Margalef (d) indices for all sites and both methods are shown in Table 4. According to the first method (identification to family level), the highest value of Margalef, Shannon diversity and Simpson indices were recorded in site 1, 2 and surprisingly in site 3, whereas the lowest in site 4 and 5. According to morphospecies method site 1 achieved the highest value of Margalef and Shannon diversity indices, however, the lowest value was calculated for site 4 for all three indices, site 3 also achieved the highest value of Simpson index.

The obtained values of average plant richness for all studied sites are shown in Table 5. We also analyzed the correlation coefficient among Shannon diversity index for morphospecies method and average plant richness (Pearson r-correlation coefficient = 0.74, p = 0.01). Species diversity

Table 3. Grouping organisms according to morphospecies method

Site 1	Site 2	Site 3	Site 4	Site 5	Sum
20 species	16 species	6 species	3 species	10 species	53 species
179 individuals	119 individuals	356 individuals	24 individuals	250 individuals	928 individuals

Table 4. Comparison of all biodiversity indices calculated for both methods

Site no.	Biodiversity indices calculated for identified taxons			Biodiversity indices calculated for morphospecies method		
	Margalef (d)	Simpson (D)	Shannon-Wiener (H')	Margalef (d)	Simpson (D)	Shannon-Wiener (H')
1	**2.69**	0.63	1.55	**3.66**	0.64	**1.73**
2	1.309	0.52	**2.92**	3.13	0.76	1.35
3	0.34	**0.95**	0.71	0.85	**0.98**	1.56
4	0.45	**0.24**	**0.62**	**0.45**	**0.24**	**0.62**
5	**0.269**	0.91	1.44	0.69	0.54	1.63

Table 5. Average plant richness of all study sites

Site no.	Average plant richness/m^2
1	8.9
2	7.8
3	5.8
4	1.9
5	4.5

tended to increase with increasing average plant species richness. Figure 6 shows the above discussed dependence. The species diversity between reference sites (sites 1, 2) and contaminated sites (3, 4 and 5) was significantly different for the first method ($t = 3.32$, $p = 0.0208$) and morphospecies method ($t = 3.51$, $p = 0.024$).

DISCUSSION

The Shannon diversity index is characterized by a higher values in assemblages of good structure, at least not very numerous. Next, the Margalef index value, apart from taxonomical composition takes also into account, the number of sites. It assigns the greater rank to rarer taxons. Thus, both indices get the highest score for reference sites. Site 1 was often the best in terms of biodiversity which is probably connected with human absence in the area. Site 2 was visited more frequently by humans (presence of path and garbage). Simpson's Index gives more weight to more abundant species in a sample. Rare species cause only small changes in the value of this in-

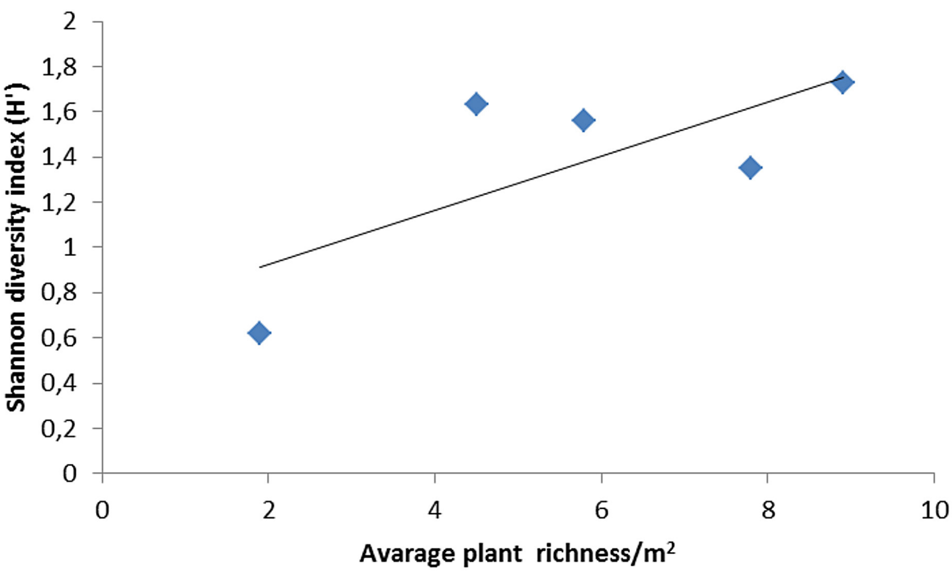

Fig. 6. The distribution of the values of Shannon diversity index as average plant richness

dex, therefore, its value was the highest in both methods in site 3 (356 individuals caught belonging to 3 or 6 taxons depending on methods).

The arrangement of taxons is strictly connected with the naturalness of the examined macroinvertebrates assemblage. The arrangement when over half of the collected individuals belong to a few species or one family and the rest consists of not very numerous species is considered as natural in favourable environmental conditions. Such a model was not observed in our studies. Abundant individuals from Carabidae family (Coleoptera) – 155 specimens were collected in site 3 as well as numerous Formicids which were observed in all sites suggesting environment disturbance which strongly affect macroinvertebrates community structure.

Species diversity tended to increase only with increasing average plant species richness (Fig. 6). We found lower diversity in the most transformed sites (Table 4 and Table 5) suggesting that the habitat type could be a key factor when considering the macroinvertebrates diversity. We found significant positive correlation in our research is the dependence between invertebrates diversity and plant richness (Fig. 6). Considering the influence of the vegetation structure on macroinvertebrates assemblages [Perner and Malt 2003] it is unsurprising that the fauna differed among all studied sites.

The application of biodiversity indices showed that sites 1 and 2 are characterized by the highest diversity, what is correct with the assumptions of the work that the reference sites should be characterized by the highest biodiversity. A minimum or low values of the Margalef index were observed for site 5, in spite of relatively high floristic diversity, what can be caused by peculiar localization of this site. It is an island surrounded from three sides with a basin of rain water what can constitute the natural barrier for the colonization of this area by some invertebrates. A great retention of water (great humidity of soil) can also create unfavorable conditions for living organisms. What is more, the dominance of Formicidae representatives in all sites (especially in site 5 where 239 individuals were collected), also affects the decrease of the number of other taxons. Ants are eurybiontic - they are very tolerant to environmental conditions, as well as they can dominate the environment and displace other species. Site 4 was recognized according to all indices as an area with the lowest biodiversity what corresponds with the observations of high influence of post-flotation sludge in this area (poor flora, high retention of water). At the family level some families have real indicator values (Coleopteran, Diplopods, Hymenoptera), among them Formicidae and Curculionidae were found as a significant indicators of metalophyte grasslands, Staphilinidae, Elateridae and zoophagous Coleopterans such as Carabidae are a significant indicator of unpolluted forest. Diplopods, a family Polydesmidae was an indicator of polluted poplar plantations, Chilopods, Lithobiidae was an indicator of litter-rich sites. For Arachnids Agelenidae appeared to be significantly associated with unpolluted forests, but Arachnida as a whole are good indicators of litter-rich sites [Nahmani et al. 2006]. In general, invertebrates can be divided into two groups by habitat type they prefer: habitat generalists present in all habitats, probably not sensitive to contamination and sensitive species, recorded rarely or in great number in unpolluted sites. Nahmani et al. [2006] found that the proportion of specialist (generalist) groups decreases (increases) while species are aggregated to form families and families to form ecological groups. The author showed that the increase of the proportion of generalists, which is the case when we consider family level, are likely to yield either non-significant indicator values or to create generalist groups which are non-informative. For conservation purposes species level is needed [Nahmani et al. 2006]. On the other hand, Nahmani et al. [2006] found that family level is sufficient in order to indicate the site disturbance. Higher levels are convenient when we look for indicators of sustainable land use [Bùchs 2003] or in terms of biodiversity indices in order to know the structure of macroinvertebrates assemblages.

Comparing the values of two biodiversity indices (Margalef and Shannon) at the family level (the highest value for site 1 or 2, the lowest for site 4 or 5) with morphospecies method where the same indices scored different results (the highest value for site 1, the lowest for site 4) it can be assumed that they are quite similar. What is more, the values received for the Simpson index are exactly the same for both methods, the highest value was registered for site 3, whereas the lowest, as usual, for site 4. Derraik et al. [2002] found that the overall difference between the morphospecies and taxonomic species was only 3.3%. The authors [Derraik et al. 2002] obtained the most accurate results for Lepidoptera – 91% of correct separation, whereas Coleopteran and

Araneae yielded poor results (63% and 50% respectively), but they suggest that it depends on different levels of separation accuracy obtained by parataxonomists. They also claim the better accuracy if parataxonomists were to receive one day of taxonomic training from a recognized expert. This method has a potential use mainly for environmental impact assessment and for comparing species richness between similar sites at a local level [Derraik et al. 2002].

CONCLUSION

To summarize, we found a correlation between low biodiversity of macroinvertebrates and flora abundance in the most transformed sites, thus habitat type, not metal content alone, could be a key factor when considering biodiversity.

According to the received values of all indices for both method the lowest biodiversity was observed in site 4 (the only exception was Margalef index for the family level identification with the lowest value for site 5). It is probably connected with a scarce plant diversity in this area. The highest diversity of macroinvertebrates was recorded in sites 1 and 2 which are reference sites, with the exception of Simpson index which indicated site 3.

Morphospecies method, as well as the taxonomic identification to the family level are not very accurate when evaluating the biodiversity, the obtained discrepancies in values of three analyzed indices can be an evidence. However, both methods are suitable for the assessment of the impact of pollution on macroinvertebrates assemblages.

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