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Post-mining ponds in the Sandomierz Forest (SE Poland) as an important site for the conservation of a species-rich odonate assemblage

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Abstract. In this study, the species composition and diversity of dragonfly and damselfly assemblages of six post-mining ponds differing in habitat conditions, located within a single sand pit in the central part of the Sandomierz Forest (SE Poland) were assessed. In total, 42 species were recorded in 2019, including 35 species considered resident to the site. In the six studied ponds, a range of 8 to 30 species were recorded, including 5 to 26 resident species. In each pond, at least one unique species was found, and one-third of all species were confined to single ponds only. As a result, the qualitative (Jaccard) and quantitative (Bray-Curtis) similarity indices between the pairs of ponds were low, reaching 12-61% and 19-53%, respectively. Thus, despite a lack of distinct barriers and negligible distances between the ponds (max. 350 m), the structure of assemblages in adjacent water bodies differed considerably. This is probably largely due to the habitat selectivity of species. A redundancy analysis (RDA) showed, that factors such as area and plant diversity of the pond were shaping odonate assemblages, explaining 49.1% of the total variance in the dataset. Due to the high species richness and the identification of several species of special concern, the studied sand pit should be considered a valuable secondary habitat for odonates, which – after termination of exploitation – should be regarded as a good candidate for a site designated for the conservation of biodiversity.

Key words: Odonata, dragonflies, damselflies, assemblage, sand pit, sand mine, excavation site, ordination analysis.

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I. INTRODUCTION

Man-made surface excavations of loose mineral materials, i.e. sand pits and gravel pits, after being filled with water, can become a valuable secondary habitat for many taxa of terrestrial and freshwater fauna (WILDERMUTH & KREBS 1983a, SCHIEL & RADEMACHER 2008; HENEBERG et al. 2012; PAKULNICKA et al. 2015). These include odonates (Insecta: Odonata) – dragonflies and damselflies (BUCZYŃSKI 1999; BERNARD et al. 2002). Such habitats, although artificial, can support a high species diversity of this group of insects (WILDERMUTH & KREBS 1983b; INULA 2011), including a wide variety of rare and endangered species (BUCZYŃSKI & DARAŻ 2006, SCHIEL & RADEMACHER 2008; BUCZYŃSKI & BUCZYŃSKA 2014), playing an important role in their conservation on both local (SCHIEL 2008; GWARDJAN et al. 2015) and regional scales (WILDERMUTH & KREBS 1983a, b; DARAŻ 2009). Although the importance of post-mining mineral excavations for odonates of high conservation value has been studied quite well, much less attention was paid to the differences in the assemblage structure of individual water bodies located within a single site (BUCHWALD 1985), as well as factors shaping the assemblages of insects which inhabit them (BUCZYŃSKI 1999; RADEMACHER 1999).

The objective of this study was to assess the species composition and diversity of the dragonflies and damselflies of post-mining sand ponds located in the central part of the Sandomierz Forest (SE Poland). Subjected to intensive sampling, the similarities and differences of odonate assemblages in post-mining ponds located within a single sand pit were assessed and described. Also, the relationships between the area and the plant diversity of the ponds and the structure of odonate assemblage were investigated by means of ordination analysis methods.

II. MATERIAL AND METHODS

Study area

The research was carried out in south-eastern Poland (Fig. 1), in the region of the Sandomierz Forest, which covers the central part of the Sandomierz Basin, bounded to the east and north-east by the valley of the San River, to the west and north-west by the valleys of the Wisła and Wisłoka, and to the south by the Sub-Carpathian Ice Marginal Valley (KONDRACKI 2013). The studied site was an active open-cast sand and gravel mine (50^{o}23′42′′N; 21^{o}46′57′′E), located north of the village of Brzostowa Góra. According to the physico-geographical regionalization, this site is located in the northern part of the Kolbuszowa Plateau mesoregion, close to the border with the neighboring Tarnobrzeg Plain (KONDRACKI 2013). It is an agricultural and forest land. The altitudes of the plateau reach 200-265 m above sea level. The geological substrate is made of miocene clays, covered with preglacial gravels and a 2-20 m layer of sand (KONDRACKI 2013). The annual precipitation is in the range of 600-800 mm, and the average annual air temperature is 7-8°C. The vegetation season is long and lasts 220-225 days (GŁOWACIŃSKI & MICHALIK 1979).

The mining site in Brzostowa Góra covers an area of 23.3 hectares, of which about 7.7 hectares are occupied by water bodies (hereafter: ponds), which were created in the excavations after sand and gravel extraction. Out of about 20 ponds existing in the area, 6 were selected for research (A-F; Fig. 1), covering a total area of 7.0 ha. The ponds studied, which are no longer used for extraction, are separated by no more than 350 m. They are surrounded by a mosaic of patches of bare sand and gravel, low initial grasslands, dry herbaceous vegetation, reedbeds, sparsely scattered bushes, and shrubby thickets. Along the southern and south-western border of the study area, there is a completely channelized watercourse/drainage ditch about 1 m wide. A description of each pond covered by the research is presented below.

Pond A. The largest and deepest pond within the mine, with an area of 6.30 ha and a shoreline of 1400 m (Fig. 1, 4). The shores are mostly high, there are no wide, flat sandy shores, shallows occupying more significant areas present only in the northern part of the pond. The central part of the reservoir is exposed and thus subject to waves caused by the wind. The water is clear. Along the shores there are stripes of reeds (*Phragmites australis* (Cav.) Trin. ex Steud., Typha spp.) of varying width, covering over 30% of the water surface of the pond. In some fragments, lower rush

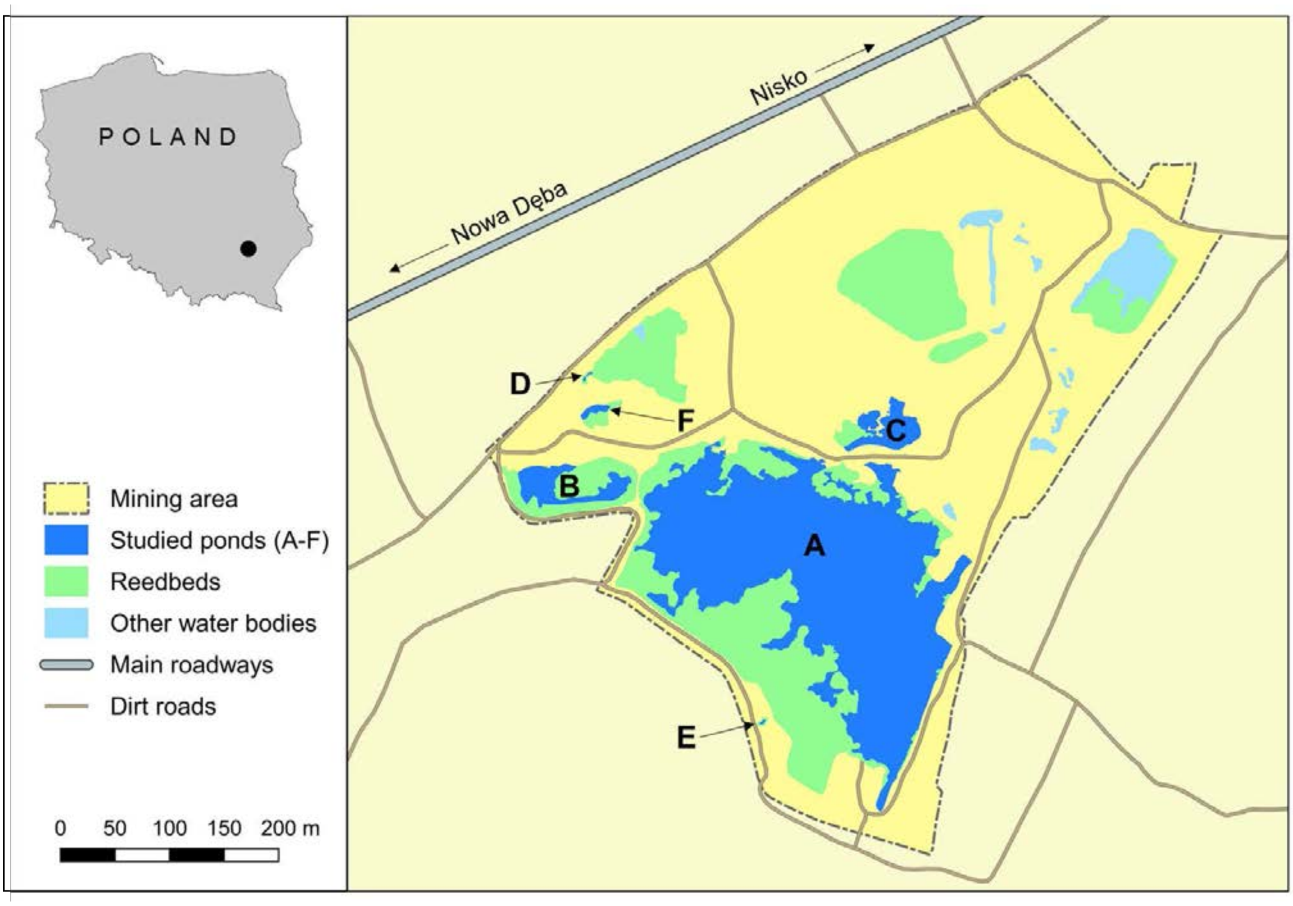

Fig. 1. Map of the study area.

communities, formed by *Eleocharis* spp., *Juncus* spp., *Scirpus* spp., and *Carex* spp., are also present. Floating and submerged vegetation is poorly developed, represented by *Potamogeton* spp., *Myriophyllum* spp., *Nymphaea* spp., *Sparganium* spp., and *Utricularia* spp. The pond is stocked with fish and it was the only one among the surveyed that was used by anglers.

Pond B. A medium sized pond, with an area of ca. 0.50 ha, max. depth exceeding 1 m and a shoreline of 315 m (Fig. 1). The water is clear. The shores are mostly high, with the exception of the northern part, where there are flat shores and wide areas of shallow water. The coastal zone is surrounded by reedbeds, formed by *Phragmites australis* with an admixture of *Typha* spp., covering ca. 60% of the water's surface. The north and north-west shores are accompanied by low rush communities, formed by *Eleocharis* spp., *Juncus* spp., and *Carex* spp. There is rich floating and submerged vegetation, mainly represented by *Potamogeton* spp. and *Ranunculus* spp. Pond B is basically a shallow bay of pond A, separated from it by a wide strip of shallow water covered by reeds. Due to its different morphology (shallow depth, sheltered from wind and waves, rich submerged vegetation), it was treated as a separate reservoir.

Pond C. A medium sized pond, with an area of *ca.* 0.17 ha, max. depth exceeding 1 m and a shoreline of 340 m (Fig. 1, 5). The water is clear. The shores are mostly high, with the exception of the northern part, where there are fragments covered with clumps of *Juncus* spp., *Carex* spp., and *Typha* spp. The marginal zone in this part of the pond is covered by *Eleocharis* spp., and the deeper parts are heavily overgrown by *Potamogeton* spp., *Utricularia* spp., and *Polygonum amphibium* L. In the rest of the pond, both water and riparian vegetation are poorly developed. A patch of reedbed formed by *Phragmites australis* adjoins the pond from the west, covering only a marginal surface of the water table. Moreover, the northern shores are largely covered with *Salix* spp. bushes.

Pond D. A small pond, with an area of ca. 0.007 ha, max. depth not exceeding 1 m and a shoreline of 50 m (Fig. 1). The water is clear. The shores are low, surrounded by a narrow belt of rush communities (*Juncus* spp., *Scirpus* spp., *Typha* spp., *Eleocharis* spp., *Carex* spp., *Phragmites australis*), covering *ca.* 70% of the pond area. From the east, a vast patch of reedbed formed by *Phragmites australis* adjoins the pond. Floating and submerged vegetation are rich, dominated by *Potamogeton* spp. Several *Salix* spp. bushes present along the shores.

Pond E. A small pond, with an area of ca. 0.005 ha, max. depth not exceeding 1 m and a shoreline of *ca.* 25 m (Fig. 1). The water is clear. The shores are low, surrounded by a belt of rush communities (*Typha* spp., *Juncus* spp., *Carex* spp.), covering ca. 70% of the pond area. Rich floating and submerged vegetation (*Potamogeton* spp., *Ranunculus* spp.). In the surroundings of the pond there are *Phragmites australis* reedbeds and willow *Salix* spp. thickets.

Pond F. A medium sized pond, with an area of *ca.* 0.05 ha and a shoreline of 110 m (Fig. 1). The water is clear and shallow, max. depth not exceeding 0.5 m, and the shores are low. The pond is astatic and as the only one among the surveyed, in 2019 it was completely dry from about the beginning of July onwards. A significant part of the pond (about 60%) and its immediate surroundings are covered with marsh vegetation, both tall (*Typha* spp., *Scirpus* spp., *Phragmites australis*), and lower (*Juncus* spp., *Carex* spp., *Eleocharis* spp.). No typical aquatic vegetation (submerged or floating), which requires the constant presence of water. Several low *Salix* spp. bushes are present in the vicinity.

Sampling methods

The research was conducted in 2019. The study site was visited 12 times – field surveys were carried out on April 4 and 25, May 17 and 27, June 5, 14, and 24, July 9, 16, and 22, August 17, and September 22. Particular visits, conducted between 8:00 and 18:00 h, lasted from 1 h 40 min to 5 h 20 min (on average 3 h 39 min) and took a total of 43 h and 50 min. During a single field survey, all ponds (A-F) were inspected from the shore and/or by wading in shallow water. Adult odonates were observed (with the naked eye or with the use of binoculars), and identification was supported by catching selected individuals, with the use of a butterfly net. Many observations were also photographically documented. The material was supplemented by 6 exuvia collected during the field surveys. Except in one case (*Anax imperator* LEACH, 1815 recorded in pond E only as exuvium), this type of material never affected the results of the analyses. During a single field visit, data on reproductive behavior and relative abundance was collected for each of the recorded species. Dragonfly behavior was classified according to the probability that the examined pond is an area of reproduction for a given species. Reproduction was considered confirmed if oviposition, teneral individual or exuvia were recorded. Reproduction was classified as probable if a territorial or juvenile individual, tandem or mating wheel was observed. All other observations were considered indicative of unconfirmed reproduction. The species whose reproductive status was assessed as probable or confirmed were considered as resident species. To describe the quantitative relationships between species, the relative abundance index was used, defining the minimum number of odonates (including exuvia) observed during a single field visit, which were clearly different individuals. Five semi-quantitative abundance classes were used to calibrate the index (the number of individuals corresponding to each class is given in parentheses): 1 (1), 2 (2-10), 3 (11-20), 4 (21-50), 5 (>50). The highest abundance class recorded during a single visit was used as a single-species index, regardless of the abundance recorded on other survey days. The reproductive status and relative abundance of each species were determined both for individual ponds and globally – for the entire study area.

Data analysis

The analyses considered the aggregate picture of fauna of a given pond, obtained on the basis of all 12 field visits carried out during the season. Similarities in the structure of Odonata assemblages of particular ponds were evaluated qualitatively using the Jaccard index and quantitatively using the Bray-Curtis index (MAGURRAN 2004). The latter was calculated on the basis of semi-quantitative data (abundance classes) for each species. The obtained indices of similarity were then used in the hierarchical clustering of the studied ponds. To build a dendrogram, the group average linking method was used. Cluster analysis was performed in BioDiveristy Pro ver. 2 software (MCALEECE et al. 1997).

The relationships between the structure of odonate assemblages in individual ponds and the basic habitat variables were also explored. The sample included six ponds, and two explanatory variables were used, for which proper data were available, and which were not intercorrelated. These included the size of the pond (AREA) and the index of vegetation diversity (PLANTDIV). These two habitat features are among key factors influencing odonate assemblages in water bodies (CORBET 1999). The pond area was selected as a parameter easy to measure and strongly correlated with several other variables which may have direct influence on odonate occurrence, e.g. depth, shoreline length, intensity of wind-induced waves, or water temperature changes. Therefore, to avoid the use of correlated variables and to facilitate interpretation of the results, only pond area was used in the analyses. The pond area was measured on satellite imagery (Google Satellite) using QGIS 3.4.12 software, whereas the index describing the diversity of vegetation was created on the basis of the assessment of the share of various types of pond vegetation. Visually, using a three-point scale (1-3), the relative coverage of (i) helophytes, (ii) plants with floating leaves, (iii) submerged plants, and (iv) trees and shrubs growing on the banks, was assessed for each pond. This assessment was made on the basis of observations of the development of vegetation during the entire study period and it refers to the stage of maximum vegetation growth. The global value of the index was obtained by summing the scores for all four of the above parameters for a given pond (this approach yielded clearer results than a multi-factor analysis). The higher the value of the index, the greater the diversity of pond vegetation. To improve performance, both environmental variables were transformed ($\log_{10}$) prior to analysis. The influence of the pond size and vegetation diversity on the structure of odonate assemblages was investigated in two stages. First, the data distribution was analyzed using the detrended correspondence analysis (DCA) technique. Because the length of the gradient represented by the first ordinate axis was 2.54 SD, the redundancy analysis (RDA) was chosen as a method of direct gradient analysis (LEPŠ & ŠMILAUER 2003), with AREA and PLANTDIV as the explanatory variables. The DCA and RDA analyses were performed using the software R ver. 3.6.1 (R CORE TEAM 2019) and Past 4.03 (HAMMER et al. 2001), respectively.

III. RESULTS

In 2019, the presence of 42 dragonfly species was recorded at the studied site, including 17 species of Zygoptera and 25 of Anisoptera (Table 1). In the case of 22 species, the collected observations allowed their reproduction to be considered as confirmed, and for a further 13 species, probable. These two groups, with a total of 35 species, were considered to be resident for the site. The reproduction of 7 species remained unconfirmed. Two species dominated in the studied sand pit: *Lestes sponsa* (HANSEMANN, 1823) and *Ischnura elegans* (VANDER LINDEN, 1820), which were the only species included in the highest (5) abundance class, whereas 4, 6, 21, and 9 species placed in the lower classes (4 to 1), respectively.

A range of 8 to 30 species of odonates were recorded in individual ponds, including 5 to 26 resident species. At least one unique species, not found in any of the other ponds studied, was recorded in each of the six ponds. In total, out of 42 dragonfly species, the occurrence of 14 species (33%) was limited to single ponds. Similarly, from among 35 resident odonates, seven species (20%) were recorded within a single pond. The latter include *Aeshna isoceles* (MÜLLER, 1767) (pond A), *Aeshna grandis* (LINNAEUS, 1758), *Chalcolestes viridis* (VANDER LINDEN, 1825), *Leucorrhinia rubicunda* (LINNAEUS, 1758) and *Orthetrum coerulescens* (FABRICIUS, 1798) (pond B), *Anax parthenope* (SELYS, 1839) (pond C), and *Somatochlora flavomaculata* (VANDER LINDEN, 1825) (pond D). However, the non-resident species in this group include *Calopteryx splendens* (HARRIS, 1782) (pond A), *Leucorrhinia dubia* (VANDER LINDEN, 1825) (pond B), *Sympecma paedisca* (BRAUER, 1877) and *Sympetrum fonscolombii* (SELYS, 1840) (pond C), *Pyrrhosoma nymphula* (SULZER, 1776) (pond D), *Coenagrion pulchellum* (VANDER LINDEN, 1825) (pond E), and *Lestes dryas* KIRBY, 1890 (pond F).

The qualitative (Jaccard) and quantitative (Bray-Curtis) similarity indices between the pairs of ponds are presented in Table 2. The values of the former

Table 1

List of odonate species recorded during the study. The code of reproduction behavior and abundance class were given for the particular ponds (A-F), while the reproduction probability and abundance class were provided globally (for all ponds). Reproduction was considered unconfirmed (REC – adult recorded), probable (TER – territorial behavior, JUV – juvenile, TAN – tandem, COP – mating wheel), or confirmed (OVI – oviposition, EXU – exuvia, TEN – teneral imago). Probable or confirmed reproduction defined resident species. The number of all and resident species are given at the bottom of the table. Abundance classes were set as follows (the number of individuals defining each class is given in parentheses): 1 (1), 2 (2-10), 3 (11-20), 4 (21-50), 5 (>50)

No	Species	Species code	Pond A	Pond B	Pond C	Pond D	Pond E	Pond F	All ponds	
									Reproduction	Abundance Class
1.	*Lestes sponsa* (HANSEM.)	Les_spo	REC / 1	TEN / 4	TEN / 3	TAN / 2	REC / 2	TEN / 2	confirmed	5
2.	*Ischnura elegans* (VANDER L.)	Isc_ele	TEN / 4	TEN / 4	TEN / 5	REC / 1	COP / 2	COP / 2	confirmed	5
3.	*Lestes virens* (CHARP.)	Les_vir	REC / 1	TEN / 3	REC / 2	TEN / 3		JUV / 2	confirmed	4
4.	*Platycnemis pennipes* (PALL.)	Pla_pen	TEN / 2	REC / 1	REC / 1		REC / 1		confirmed	4
5.	*Coenagrion puella* (L.)	Coe_pue	OVI / 3	TEN / 4	OVI / 2	TEN / 4	OVI / 2	COP / 2	confirmed	4
6.	*Erythromma najas* (HANSEM.)	Ery_naj	TEN / 4	COP / 2	OVI / 2	REC / 1		TAN / 2	confirmed	4
7.	*Sympecma fusca* (VANDER L.)	Sym_fus	TEN / 1	TEN / 2	TEN / 2			OVI / 3	confirmed	3
8.	*Erythromma viridulum* (CHARP.)	Ery_vir	OVI / 3		TER / 2				confirmed	3
9.	*Libellula quadrimaculata* L.	Lib_qua	TER / 1	OVI / 2		TER / 2	TER / 2	TER / 2	confirmed	3
10.	*Orthetrum albistylum* (SEL.)	Ort_alb	TER / 2	OVI / 2	TER / 2	REC / 1		TEN / 2	confirmed	3
11.	*Sympetrum depressiusculum* (SEL.)	Sym_dep	REC / 1	TER / 2	TEN / 2			TER / 2	confirmed	3
12.	*Sympetrum sanguineum* (MÜLL.)	Sym_san	OVI / 2	TEN / 2	TEN / 1	OVI / 2		TEN / 1	confirmed	3
13.	*Chalcolestes viridis* (VANDER L.)	Cha_vir		OVI / 2					confirmed	2
14.	*Enallagma cyathigerum* (CHARP.)	Ena_cya		TEN / 2		REC / 2		TEN / 2	confirmed	2
15.	*Coenagrion hastulatum* (CHARP.)	Coe_has	TEN / 1	REC / 1			TEN / 2		confirmed	2
16.	*Anax imperator* LEACH	Ana_imp	OVI / 2	EXU / 2	OVI / 2		EXU / 1	TER / 1	confirmed	2
17.	*Cordulia aenea* (L.)	Cor_aen	OVI / 2	EXU / 2	TER / 1				confirmed	2
18.	*Orthetrum cancellatum* (L.)	Ort_can	COP / 2	COP / 2	COP / 2			TEN / 1	confirmed	2
19.	*Crocothemis erythraea* (BRULLÉ)	Cro_ery	TER / 1	OVI / 2	TER / 2			TER / 1	confirmed	2
20.	*Sympetrum striolatum* (CHARP.)	Sym_str	REC / 2	OVI / 2	TER / 1	TER / 1		TEN / 2	confirmed	2
21.	*Sympetrum vulgatum* (L.)	Sym_vul	JUV / 1	TEN / 2	TEN / 1			JUV / 1	confirmed	2
22.	*Aeshna grandis* (L.)	Aes_gra		OVI / 1					confirmed	1
23.	*Aeshna cyanea* (MÜLL.)	Aes_cya		TER / 1	TER / 1	TER / 2			probable	2
24.	*Aeshna isoceles* (MÜLL.)	Aes_iso	TER / 2						probable	2
25.	*Aeshna mixta* LATR.	Aes_mix	TER / 1	TER / 1	TER / 2				probable	2
26.	*Libellula depressa* L.	Lib_dep			TER / 1			COP / 2	probable	2
27.	*Orthetrum coerulescens* (FABR.)	Ort_coe		TER / 2					probable	2
28.	*Sympetrum danae* (SULZ.)	Sym_dan	REC / 1	TER / 2				TER / 1	probable	2
29.	*Leucorrhinia albifrons* (BURM.)	Leu_alb	TER / 1	COP / 2					probable	2
30.	*Leucorrhinia caudalis* (CHARP.)	Leu_cau	REC / 1	TER / 2					probable	2
31.	*Leucorrhinia pectoralis* (CHARP.)	Leu_pec	REC / 1	REC / 1		COP / 2			probable	2
32.	*Ischnura pumilio* (CHARP.)	Isc_pum	JUV / 1					JUV / 1	probable	1
33.	*Anax parthenope* (SEL.)	Ana_par			TER / 1				probable	1
34.	*Somatochlora flavomaculata* (VANDER L.)	Som_fla				TER / 1			probable	1
35.	*Leucorrhinia rubicunda* (L.)	Leu_rub		TER / 1					probable	1
36.	*Sympecma paedisca* (BRAU.)	Sym_pae			REC / 2				unconfirmed	2
37.	*Coenagrion pulchellum* (VANDER L.)	Coe_pul					REC / 2		unconfirmed	2
38.	*Pyrrhosoma nymphula* (SULZ.)	Pyr_nym				REC / 2			unconfirmed	2
39.	*Calopteryx splendens* (HARR.)	Cal_spl	REC / 1						unconfirmed	1
40.	*Lestes dryas* KIRBY	Les_dry						REC / 1	unconfirmed	1
41.	*Sympetrum fonscolombii* (SEL.)	Sym_fon			REC / 1				unconfirmed	1
42.	*Leucorrhinia dubia* (VANDER L.)	Leu_dub		REC / 1					unconfirmed	1
	Species		**27**	**30**	**23**	**14**	**8**	**20**	**42**	
	Resident species		**19**	**26**	**19**	**9**	**5**	**19**	**35**	

Table 2

Percentage values of the Jaccard (grey part of the table) and Bray-Curtis (white part of the table) similarity coefficients between each pair of studied ponds

	Pond A	Pond B	Pond C	Pond D	Pond E	Pond F
Pond A		42.0	43.2	19.2	25.8	22.4
Pond B	45.2		52.7	45.8	18.9	33.5
Pond C	52.0	55.2		20.4	19.2	32.7
Pond D	12.0	25.0	21.7		29.4	25.0
Pond E	26.3	14.8	14.3	16.7		21.9
Pond F	46.2	60.7	58.3	27.3	20.0	

ranged from 12-61%, while the range of the latter was narrower, reaching 19-53%. A cluster analysis showed a similar pattern of similarities between the resident odonate assemblages of the studied ponds, analyzed on the basis of both types of indices (Fig. 2a & b). Regarding all the ponds together, the similarity of species composition (17%; Fig. 2a) turned out to be slightly lower than the similarity also taking into account the abundance of individual species (28%; Fig. 2b), however, both dendrograms indicated the existence of a cluster of four ponds (A, B, C, and F), clearly different from the other two (D and E). Qualitative and quantitative similarity between ponds A, B, C, and F reached 48% (Fig. 2a) and 55% (Fig. 2b), respectively, while in both cases pond A differed the most from the others. In terms of the species composition, the most similar (about 61%) ponds turned out to be B and F (Fig. 2a), while quantitatively the most similar were ponds B and C (65%; Fig. 2b). Neither pair of ponds achieved higher values of the Jaccard or the Bray-Curtis similarity.

Differences in the composition of odonate assemblages were highlighted by the results of the RDA analysis (Fig. 3). First, two canonical ordination axes explained 49.1% of the total variance in the dataset, although the Monte Carlo permutation test showed that the results were not statistically significant (F=1.449, p=0.16). The first axis was associated principally with the gradient of area of the studied ponds (Area), whereas the second axis emphasized more the gradient of water and marsh plant diversity in the ponds (Plantdiv). The occurrence of several species was clearly related to the area of the water body. This relation was positive for *Ischnura elegans*, *Erythromma najas* (Hansemann, 1823), *E. viridulum* (Charpentier, 1840), *Orthetrum cancellatum* (Linnaeus, 1758), and *Cordulia aenea* (Linnaeus, 1758), while it was negative for *Libellula quadrimaculata* Linnaeus, 1758. The high diversity of plants positively influenced the presence and abundance of *Lestes sponsa*, *L. virens* (Charpentier, 1825), *Coenagrion puella* (Linnaeus, 1758), and *Aeshna cyanea* (Müller, 1764), while the reverse was true in the case of *Libellula depressa* Linnaeus, 1758, *Ischnura pumilio* (Charpentier, 1825), and *Coenagrion hastulatum* (Charpentier, 1825) (Fig. 3).

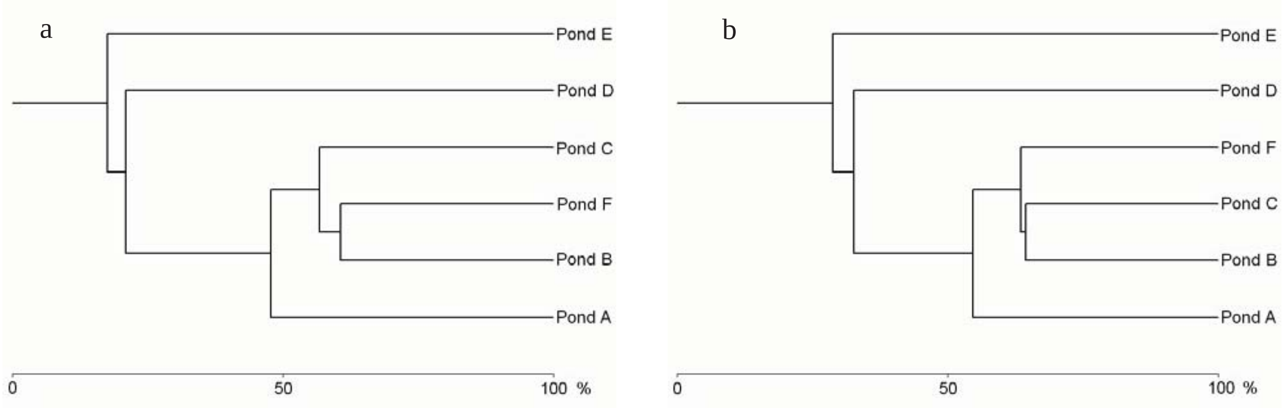

Fig. 2. Dendrograms illustrating the Jaccard (a) and Bray-Curtis (b) similarities between resident odonate assemblages of the studied ponds.

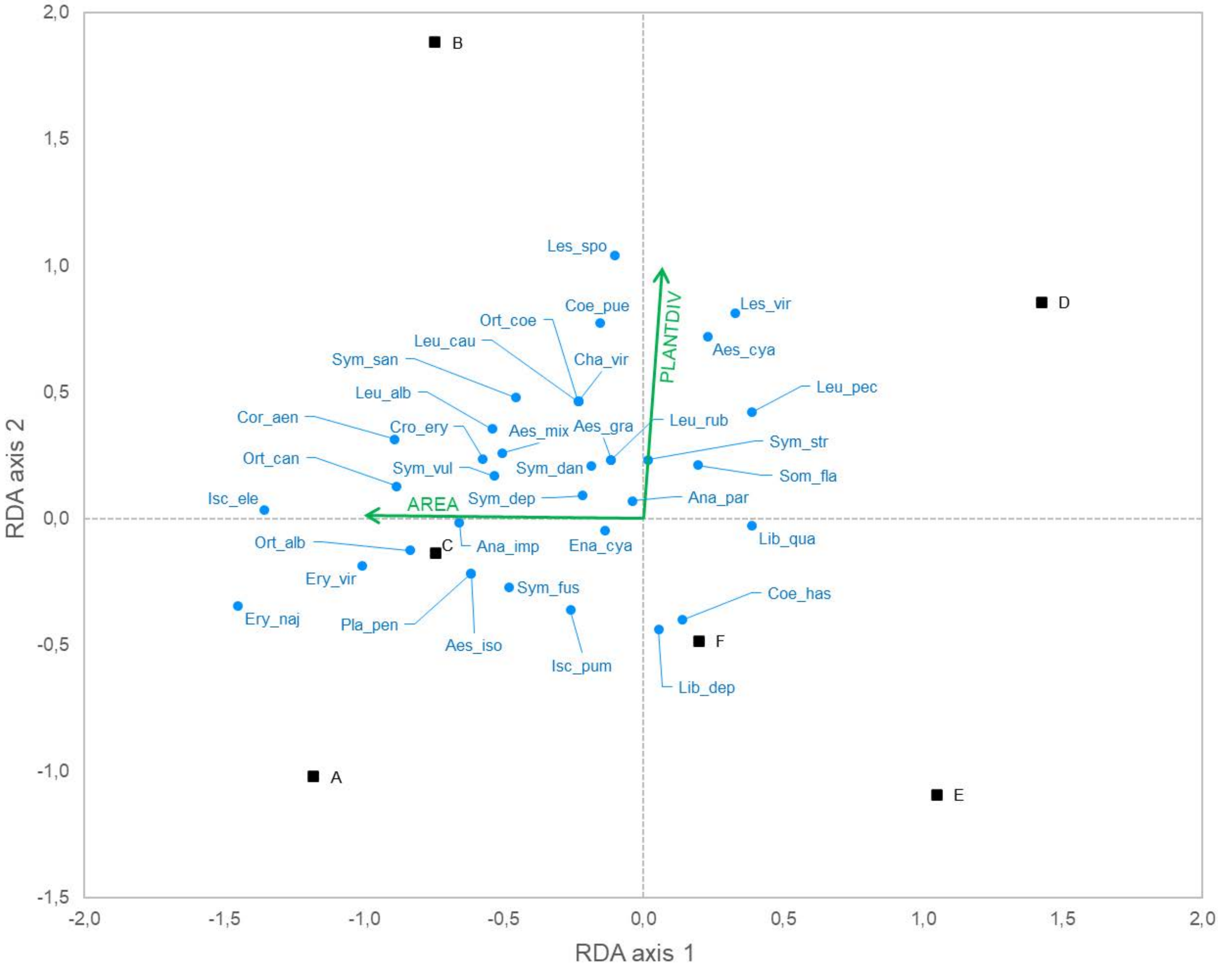

Fig. 3. Triplot of odonate species (blue), sampling ponds (black), and environmental variables (green: PLANTDIV – plant diversity in the pond, AREA – pond area) in the space of the first two ordination axes of redundancy analysis (RDA) (eigenvalues: axis 1 = 10.928, axis 2 = 5.386). Species codes are given in Table 1.

Fig. 4. Habitats of a small bay in the northern part of pond A.

Fig. 5. Habitats of pond C.

IV. DISCUSSION

The research carried out in the sand mine in Brzostowa Góra resulted in a number of interesting findings on dragonflies and damselflies. It is especially valuable to record here the presence of all five native *Leucorrhinia* BRITTINGER, 1850 species, including the probable reproduction of four of them – the relatively widespread *L. rubicunda* and *L. pectoralis* (CHARPENTIER, 1825), the rare in southern Poland *L. albifrons* (BURMEISTER, 1839), and, above all, *L. caudalis* (CHARPENTIER, 1840) (BERNARD et al. 2009). It is worth noting that the last three are species under legal protection in Poland, which also applies to the another odonate species recorded in the mine, *Sympecma paedisca*. The reproduction of the fifth *Leucorrhinia* species – *L. dubia* – was not confirmed, which is not surprising, taking into account that it is a tyrphobiontic and sphagnobiontic, raised bog specialist (BERNARD et al. 2009), and there is no such habitat in the area under study. A single observation of a female of this species most likely concerned a vagrant individual, who dispersed from the wetland area located 7 km NE of the study site. This nearby area includes a military training ground with mires and *Sphagnum* peat bogs, where this species was recorded in the past (BUCZYŃSKI 2003). Similarly, a territorial male of *Somatochlora flavomaculata*, which is a relatively rare dragonfly in southern Poland, may have come from the above-mentioned wetland area, as this species usually selects mire habitats (BERNARD et al. 2009), also absent in the studied mine. It is also worth noting that *Orthetrum coerulescens* – one of only a few species listed on the Red List of dragonflies (BERNARD et al. 2009) and considered to be near threatened (NT) in the country – is reproducing here. Interestingly, the territorial behavior of males of this dragonfly, ecologically associated with flowing water, was limited to a small stretch of the stagnant-water pond.

Despite the fact that the studied ponds were located close to each other, so that the distance between them certainly did not constitute a dispersion barrier for adult dragonflies, the resident assemblages of Odonata of individual ponds turned out to be quite different. Even within the cluster of the most similar and adjacent ponds A, B, C, and F, assemblages showed qualitative and quantitative similarity at a level of only 48-65%. And taking into account the significantly smaller and more distant ponds D and E, the similarity of the composition and abundance of the assemblages was even lower. Thus, despite a lack of distinct physical barriers in the studied mine, there was no homogenization in the structure of odonate assemblages in adjacent water bodies. It can be assumed that this is largely due to the habitat selectivity of species, which may operate in the field of different habitat conditions of individual ponds, even those located close to each other and completely not isolated.

Numerous studies show that among the most important factors shaping the species composition and abundance of odonates in water bodies are pond area (e.g. OERTLI et al. 2002, JOHANSSON et al. 2019) and the differentiation of the structure of the accompanying water and marsh vegetation (e.g. SAHLÉN & EKESTUBBE 2001, RAEBEL et al. 2011, GOERTZEN & SUHLING 2013; BUCZYŃSKI 2015; HARABIŠ 2016), which can potentially be used by adult odonates e.g. for oviposition and resting, or as a place where larvae can hide (CORBET 1999). The results of the redundancy analysis conducted on the data from the studied mine confirmed that these two factors also affect the diversity of odonate on a local scale (individual ponds located within one complex of post-excavation reservoirs), explaining about half of the variance in the structure of their assemblages. Moreover, the obtained results show a significant accordance with the knowledge about the ecological requirements of some species. Among others, the avoidance of ponds with rich, diverse vegetation by *Libellula depressa* and *Ischnura pumilio* coincides with the fact that they are pioneer species (BERNARD et al. 2002, 2009; GOERTZEN & SUHLING 2013), i.e. inhabiting newly created water bodies at an early stage of succession, with little or no vegetation. At the studied site, both species were clearly related to the single temporary, ephemeral pond. On the other hand, the colonization of water bodies with a high share and significant diversity of macrophytes is typical of species of the genus *Lestes* LEACH IN BREWSTER, 1815 (SCHINDLER et al. 2003; BUCZYŃSKI 2015), which was shown in this study in the case of *Lestes sponsa* and *L. virens*. The positive relationship between the occurrence of species such as *Cordulia aenea*, *Orthetrum cancellatum*, *Erythroma najas,* and *E. viridulum*, despite the fact that they are basically eurytopic odonates, is consistent with their preference for lakes (BUCZYŃSKI 2015), i.e. water bodies of a rather large area. It should be noted, that in the case of pond area, it does not have to be about the direct influence of this parameter. It is possible that the dependence on factors correlated with the area, such as depth, shoreline length, changes in water temperature, or the intensity of wind-induced waves is crucial. The latter factor may be important in the case of *P. pennipes* (PALLAS, 1771), which is a rheophilic species, fostered by the movement of water (BERNARD et al. 2009), e.g. waves, which is more intense in large, exposed bodies of water. Although it cannot be ruled out that the presence of some flowing water-related species (like *P. pennipes* and *O. coerulescens*) in post-mining ponds may also result from the outflow of cool groundwater, which was suggested in the case of rheophilic *Gomphus vulgatissimus* (LINNAEUS, 1758) in a gravel pit in Germany (WEIHRAUCH 1998). The remaining half of the variance in the dataset, not explained by the first two axes of the RDA, may be shaped by other environmental factors affecting odonate assemblages, not analyzed directly in this study. These include, for example, the physicochemical parameters of water (VANACKER et al. 2018), astatism of the pond (SCHINDLER et al. 2003), or insolation/shading of the water surface (REMSBURG et al. 2008). Obviously, this does not exclude the influence of biotic factors on the composition of odonate assemblages of individual ponds, including fish predation (JOHANSSON & BRODIN 2003) or the competition and predation of dragonflies themselves (WISSINGER 1989).

The species richness of odonates in the studied excavation site should be considered high. The number of 42 recorded species, including 35 resident ones, places the surveyed object among the most species-diverse sand and gravel pits described in Central European literature (e.g. BILEK 1952; WILDERMUTH & KREBS 1983b; OTT 1989; PIKSA et al. 2006; SCHIEL & RADEMACHER 2008; INULA 2011; BUCZYŃSKI 2015; GWARDJAN et al. 2015). However, it should be noted that sand and gravel ponds are among the habitats richest in odonate species, also compared to other anthropogenic water bodies formed in post-mining excavations (e.g. lignite mines: RYCHŁA et al. 2011; HARABIŠ et al. 2013; clay pits: BUCZYŃSKI & PAKULNICKA 2000; RYCHŁA 2017; limestone quarries: INULA 2011; BOBREK 2020). This indicates a significant role of such habitats in preserving the biodiversity of this group of insects in human-modified landscapes (WILDERMUTH & KREBS 1983a, b; BUCZYŃSKI 2015; HARABIŠ 2016).

Sand and gravel pits are valuable secondary habitats for odonates, therefore they are worth careful and appropriate management after termination of exploitation. This also applies to preventing standard reclamation, leading to the destruction of biodiversity (filling with water, creating a water reservoir for recreation, angling or fish production, afforestation, etc.; OSTRĘGA & UBERMAN 2010). After exploitation has ceased, these habitats should obligatorily be subject to faunistic and floristic studies, including dragonfly surveys, and depending on the results, should be directed to an appropriate reclamation path. One of these paths should be management for the purposes of biodiversity conservation.

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