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# Peat mine as a threat to the diversity of aquatic beetles (Coleoptera: Dytiscidae) in the protected area Nature 2000 in Poland

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## Abstract

Peatlands, shaped by centuries of human activities, now face a primary threat from mining activities. Vulnerable to drainage and hydrological instability, peatland areas encounter challenges that compromise their ecological integrity. This study hypothesised that permanent water reservoirs within mines could serve as refugia for water beetles from adjacent areas prone to drying in the summer. Employing standard methods, including entomological scraping and water traps, samples were collected. Results revealed that, in most cases, water beetles exhibited a preference for the Nature 2000 area untouched by mining. Despite unfavourable conditions, the Nature 2000 area showcased a more diverse water beetle fauna. Remarkably, the selected Nature 2000 area, despite its identified degradation based on flora, remained a biodiversity hotspot for peatland water beetle fauna. The study underscores the significance of assessing insects, particularly beetles, as rapid responders to environmental changes. This evaluation holds crucial implications for peatland restoration planning and decision-making regarding mining investments in proximity to peatland areas.

## Introduction

Nowadays many peatlands are degraded due to human activities (Global Environment Centre and Wetlands International, 2008; Joosten *et al.*, 2017). This makes it challenging to protect these ecosystems today.

Peatlands are primarily evaluated for successful restoration through the development of dominant Sphagnum vegetation and the presence of characteristic Sphagnum plant species, focusing on the protection of local flora. In contrast, monitoring the success of restoration is rarely or not at all done by considering the diversity of aquatic insects (Irmler and Faunistisch-Ökologische Arbeitsgemeinschaft, 1998).

It should be remembered that peatlands are ecosystems encompassing variety of hugely important environmental functions. These functions play a key role in protecting the natural environment today. Peatlands are responsible for water retention in the landscape, functioning as the so-called 'kidneys' of ecosystems. They absorb nutrient compounds that would otherwise run off into rivers surrounded by peatlands (Manton *et al.*, 2021). They are a particularly essential element in global climate change. They can accelerate negative climate change if they are degraded, but peatlands preserved in good condition will inhibit these climate warming processes (Maltby and Acreman, 2011; Bonn *et al.*, 2016). The mentioned functions are hot topics of research in the 21st century, but the fact that peatlands are spots of invertebrate biodiversity should not be ignored.

Therefore, peatlands should be protected in several ways and consider more factors that can positively affect the potential protection of these ecosystems. In consideration of the environmental functions of peatlands, these ecosystems should be protected in every viable way, and research on peatlands should be guided towards their restoration. Following the Hannigan *et al.* (2011), to protect the ecosystems and restore habitat, invertebrates should be used as a measure of success. Water beetles are among the group of invertebrates that are ideally suited for this purpose (Nilsson and Svensson, 1995; Downie *et al.*, 1998; Spitzer *et al.*, 1999; Drinan *et al.*, 2013).

Water beetles are an integral part of any wetland and some species may be associated with specific types of water bodies or substrate conditions, providing insights into the local environment (Ramin and Ghazal, 2022). Aquatic beetles serve as essential indicators of ecological diversity and habitat characteristics (Sánchez-Fernández *et al.*, 2004), playing a crucial role in assessing water quality holistically. Their utilisation as bio monitors offers valuable insights into shifts in both water and habitat quality, shedding light on the impacts of human activities on aquatic ecosystems (Rosenberg and Resh, 1993). Among the diverse taxa of aquatic insects, beetles stand out as particularly suited for this purpose due to their extensive diversity, wide range of adaptations (including tolerance and sensitivity), long lifespan and utilisation of various habitat types. These qualities make them ideal candidates for serving as biological indicators (Sharma and Pandey, 2013).

Even during periods of drought in a peatland, it is still possible to study the water beetle fauna, as they are able to function for a very long time due to the moisture retained in the mosses (Burakowski, 1976). Conversely, certain insect groups, like dragonflies, though intriguing as biodiversity indicators, may differ in their response to habitat degradation. Dragonflies, while serving as indicators, tend to relocate to more suitable habitats when faced with deteriorating conditions. In contrast, water beetles, being a diverse group, stand out as excellent indicators reflecting habitat quality, age and the degree of degradation (Nilsson and Svensson, 1995).

It is anticipated that the responses of water beetles will yield more precise insights into the general health and condition of peatlands. The potential role of peat mines as refugia for water beetles from neighbouring areas is posited, with an expectation that the peat mine locale will harbour a diverse water beetle fauna, potentially functioning as a reservoir for species confronting challenges. Notably, the effectiveness of peat mines as refugia is contingent upon extreme drought conditions in a protected area. In addition, we evaluated the diversity of the water beetle fauna in the protected peatland and the peat mine area. During such conditions, water reservoirs in the Nature 2000 area dry up, while in the peat mine area, water availability persists throughout the year. In light of these considerations, our study aims to explore the potential of peat mines as refugia for water beetles during extreme drought conditions and to assess the diversity of water beetle fauna in both a protected peatland area and a peat mine locale, thereby shedding light on the broader ecological dynamics within these habitats

## Material and methods

### Study areas

The Reptowo peat bog is located in north-western Poland, Pomeranian region (GPS: 53.38670472064037, 14.838152185240 203). The area is fragmented into a part under nature protection and a part exploited by peat mine.

The area to be mined is flat, and the water level in the deposit is about 20 cm below the surface and is maintained due to hydrotechnical structures such as ditch levees. The overall condition of the ecosystem, formed at the mine site, qualifies as poor, as indicated by the cardinal indicators for this type of habitat. The area of the mine is 149.43 ha, of which 74.88 ha are intended for mining (Wigurska *et al.*, 2015). Peat mine is located along the northern border of the Nature 2000 area.

Nature 2000 area was established in 2012, and currently 605.55 ha of peatland are protected. The objects of protection in this area are degraded raised bogs, but capable of natural or stimulated regeneration and also species of Odonata group, *Leucorrhinia pectoralis*. The habitat has undergone significant degradation due to human activity, primarily stemming from peat extraction dating back to the late 19th century. Human influence is evident in the habitat's transformation, marked by drainage, deforestation of surrounding areas and exploitation of peat in a nearby mine. The area is dominated by heavily degraded bog forests, and peat plants are found mainly in ditches and post-mining furrows. Despite the changes in vegetation and structure, the peat bog is considered a 'geological document' and a local stabiliser of water conditions. It is possible to stop its further degradation as a result of active protection, although at the moment it does not seem possible to restore a living peat bog. In the Nature 2000 area, conservation measures were taken in 2005–2007 to improve water conditions in the peatland. In 2007, exploitation of peat at a neighbouring mine was discontinued due to the loss of the concession. Until around 2015, a gradual improvement of conditions in the peat bog continued, which involved a return to the habitat with plant species characteristic for type of peatlands. In 2015, peat mining resumed at a nearby mine. In 2016, there was a very strong drop in the level of the groundwater, causing the habitat to dry out and newly colonised patches of vegetation to die.

### Sampling procedures

Sampling took place early spring in April 2022 and during the summer: September 2022. In both areas, three sites each were selected (table 1).

The physico-chemical variables of the water were evaluated using a HYDROLAB DS5. Measurements of water and samples of organisms were collected at each site during both spring and summer seasons. Sampling techniques included the use of entomological scrapper and traps.

The sampling period lasted about three days, as organisms were caught according to two separate methodologies to obtain more reliable research results. Samples were collected by catching them with an entomological scrapper and by trapping the organisms in water traps placed at the sites. The traps were set in the spring in the period 13–15 April 2022, and in the summer 07–09 September 2022. Then the organisms that were successfully captured were transferred to test tubes with already prepared 70% alcohol.

Water beetles were caught using an entomological scrapper, trying to scrape from both the surface and the bottom. If vegetation was present at the site, a sample was also taken with the scoop at their location. Sampling always took 15 min at each site. Some of the acquired material was disguised in the field as far as possible. Protected species were identified in the field and released.

**Table 1.** Characteristic of the selected sites

| Site number | Nature 2000 | Peat mine |
|---|---|---|
| 1 | Post-mining ditch. Partially covered with vegetation | Mine ditch. Partially covered with vegetation, due to the temporary pause in mining this site |
| 2 | Post-mining peat lake | Mine ditch. Partially covered with vegetation, due to the temporary pause in mining this site |
| 3 | Post-mining, small peat lake. Closest to the mine area | Band ditch. Located on the border between the mine and a local blueberry plantation |

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In the Nature 2000 area, there was an extreme drought during the summer season, which caused sites 1 and 3 to dry out. Only site 2 in the protected area did not dry out. Hence, in the protected area in this season only at site 2 samples of organisms were collected, and physico-chemical parameters of water were measured.

To identify the beetles collected in the process of samplings, keys developed by Galewski (1971), Lohse and Lucht (1989), Valladares (2018), Biesiadka and Kazimierska (2004) were used.

### *Statistical analysis*

The redundancy analysis (RDA) is associated with regressions involving multivariate explanatory variables (representing environmental parameters) and response variables (representing species). Subsequently, we illustrated the RDA results using a 2D correlation triplot (fig. 1). The distances of vectors from the centre point were considered for additional insights during interpretation.

Changes in species composition were analysed using Jaccard's index of species similarity. In order to reveal the taxonomic similarity between the communities in the peat mine and the communities in the Nature 2000 area, the numbers of organisms from all months and locations in these two groups were summed and the Jaccard quantitative and binary similarity index was calculated. The Jaccard index values varied between 0 and 1, with 0 meaning the species compositions are the same, and 1 meaning the species compositions are totally different.

Quantitative and binary similarity and RDA analyses were conducted using package 'Vegan', version 2.6-4 (Oksanen *et al.*, 2022) in R: R version 4.2.2 (2022-10-31 ucrt) (R Core Team 2022).

## Results

### *The physico-chemical parameters of the water*

In the mining area, the pH of the water of the sites was more alkaline than in the protected area (table 2). Also, the water

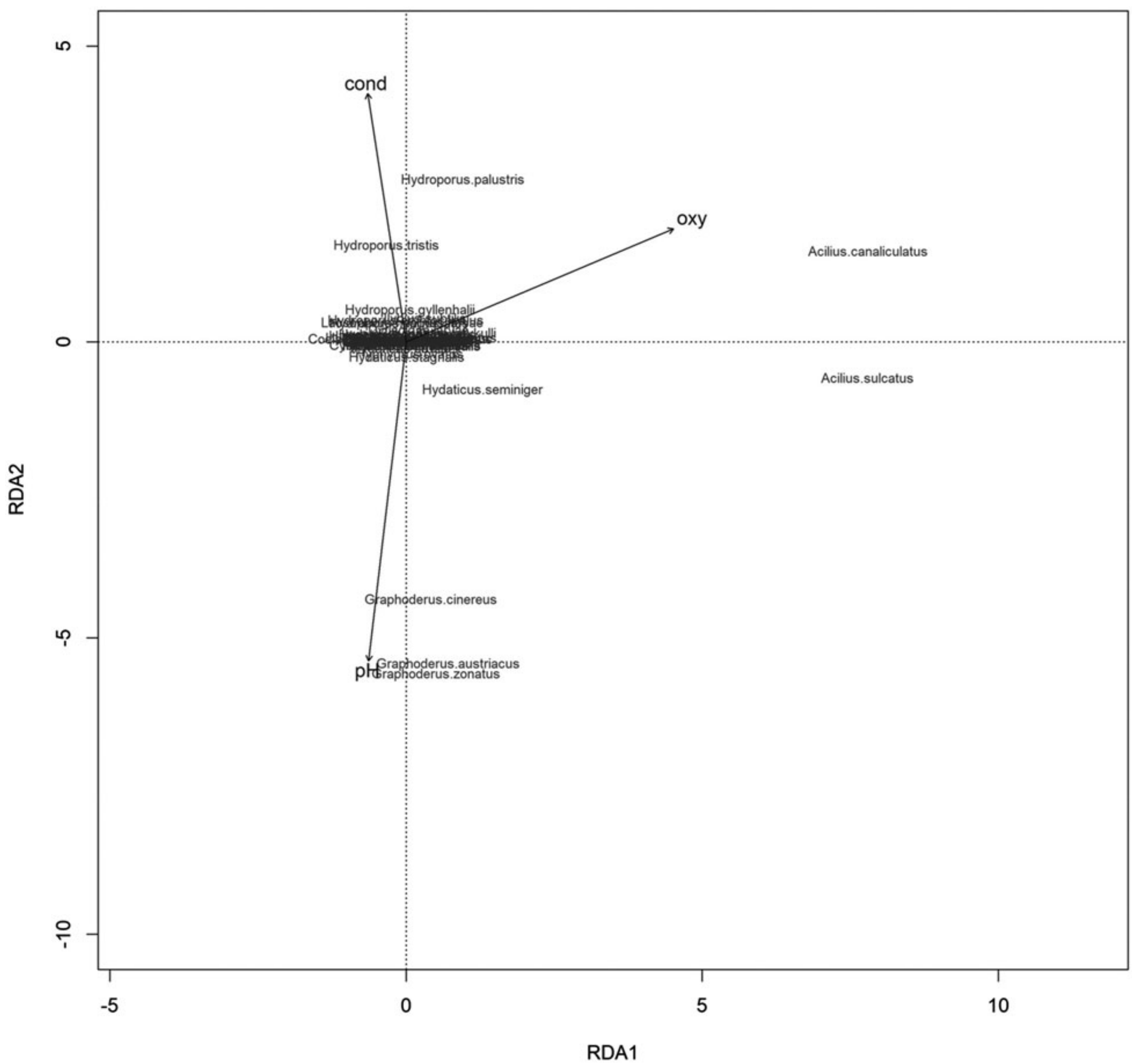


**Figure 1.** Correlation triplot from the redundancy analysis (RDA) showing the relationship between water beetles and environmental parameters.

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**Table 2.** The physico-chemical parameters of the water

| Site | Season | Temperature (°C) | pH | Conductivity (µS $cm^{-1}$) | $O_2$ ($O_2$ $litre^{-1}$) |
|---|---|---|---|---|---|
| K1 | Spring | 15.9 | 4.22 | 106.6 | 6.11 |
| K2 | Spring | 15.8 | 4.23 | 105 | 6.18 |
| K3 | Spring | 15.5 | 6.32 | 157 | 5.48 |
| K1 | Summer | 22.58 | 6.74 | 76.1 | 5.54 |
| K2 | Summer | 22.58 | 6.75 | 77 | 5.5 |
| K3 | Summer | 17 | 6.36 | 324 | 0.77 |
| N1 | Spring | 10.7 | 3.39 | 171 | 10.25 |
| N2 | Spring | 11.09 | 3.52 | 126 | 9.19 |
| N3 | Spring | 9 | 3.16 | 263 | 6.37 |
| N2 | Summer | 24.5 | 4.19 | 178 | 10.34 |

K, mine area; N, Nature 2000 area; 12, 3, site numbers.

temperature at the mine area was higher than at the Nature 2000 site. In contrast, the amount of dissolved oxygen in the water and conductivity were higher at the protected area.

The average values of water parameters at the mine site were 5.7 pH, 4.93 $O_2$ (mg $O_2$ $litre^{-1}$), 140.95 conductivity (µS $cm^{-1}$), 18.23 temperature (°C).

At the Nature 2000 site, the average values of water parameters were 3.56 pH, 9.03 $O_2$ (mg $O_2$ $litre^{-1}$), 184.5 conductivity (µS $cm^{-1}$), 13.82 temperature (°C).

### *Statistical analysis*

The analysis encompassed the examination of eight distinct species spanning four genera, elucidating their interrelations (fig. 1). The choice to focus on these eight species was dictated by the results of the RDA analysis, which highlighted their significance compared to other recorded species. Other species did not exhibit statistically significant correlations with the selected parameters analysed alongside the aquatic beetle species.

Notably, some species of the genus *Hydroporus* showed a tendency to occur at sites depending on the conductivity recorded at the study site. The heightened conductivity of the site correlated positively with an increased likelihood of the presence of some selected *Hydroporus* species, as indicated by the analysis. The results of the analysis suggest that Graphoderus species are indeed more likely to inhabit more acidic waters. In contrast, the genus *Acilius* demonstrated an association with elevated levels of water oxygenation.

As for Jaccard's index, two comparisons were made for taxa between the mine and the Nature 2000 area: the 'binary similarity' of Jaccard's method takes into account only the presence or absence of a taxon when comparing similarity: 0.48 (48% of the sites are similar, less than half of the taxa). Jaccard's similarity, which takes into account not only the presence but also the abundance of taxa, and this is where the two communities differ greatly: 0.16 (only 16% are similar to each other, if we also take into account abundance).

### *Fauna*

A total of 2181 individuals gathered in 27 genera and 43 species were recorded throughout the samplings (table 3).

The Nature 2000 area of samplings provided habitat for 1209 individuals. In total, 56% were species typical of peatland habitats (table 3).

The most common genera in the protected area were *Acilius*, *Hydroporus*, *Hydaticus*, *Heliophorus*, *Dytiscus* and *Graphoderus*. The genus *Acilius* was most frequently caught, represented by the species *Acilius sulcatus* and *Acilius canaliculatus*. The genus *Hydroporus* was also very numerous; also, *Hydroporus angustatus*, *Hydroporus eryhtocepalus*, *Hydroporus gyllenhalii*, *Hydroporus tristis* and *Hydroporus palustris*. *Hydroporus palustris* was found to be the most common. The genus *Hydaticus* was recorded during the study. This genus in the protected area was represented by species such as: *Hydaticus continentalis*, *Hydaticus transversalis* and *Hydaticus seminiger*. The most numerous was *H. seminiger*. The genus *Dytiscus* was quite abundant in the Nature 2000 area. It was represented by species: *Dytiscus circumcinctus*, *Dytiscus circumflexus*, *Dytiscus dimidiatus*, *Dytiscus semisulcatus* and *Dytiscus marginalis*. A similar number of individuals was recorded for the genus *Graphoderus*. They were represented by *Graphoderus austriacus*, *Graphoderus cinereus*, *Graphoderus bilineatus* and *Graphoderus zonatus*. *Graphoderus austriacus* was the most numerous.

The samplings area, which included the peat mine site in Reptowo, provided habitat for 972 individuals. In total, 48% represented species typical of peatland habitats. Three genera were recorded most frequently at the mine site over the entire study period: *Graphoderus*, *Acilius* and *Hydaticus*. *Graphoderus* was the most abundant. It was represented by the species *G. austriacus*, *G. cinereus*, *G. bilineatus* and *G. zonatus*. The genus *Hydaticus* were recorded. The area was inhabited by species such as *H. aruspex*, *Hydaticus stagnalis*, *H. transversalis* and *H. seminiger*. Most recorded was *Hydaticus seminigier*. Also recorded during the research were the genus *Acilius* – *A. sulcatus* and *A. canaliculatus*.

The only species not recorded in the Nature 2000 area was *Hydaticus aruspex*. This species was recorded only at the mine site. Species that occurred in both areas were *D. semisulcatus*, *G. bilineatus* and *G. zonatus*.

In the Reptowo Nature 2000 area, valuable species such as *D. semisulcatus*, *D. circumflexus*, *G. bilineatus*, *G. zonatus* and *H. gyllenhalii* were recorded throughout the study period.

In the peat mining area in Reptowo, the following valuable species were recorded throughout the study period: *D. semisulcatus*, *G. bilineatus*, *G. zonatus* and *H. aruspex*.

**Table 3.** Detailed list of species – number of collected specimens

| Site | K1 A | K1 J | K2 A | K2 J | K3 A | K3 J | N1 A | N2 A | N2 J | N3 A |
|---|---|---|---|---|---|---|---|---|---|---|
| • *Acilius canaliculatus* | 2 | 22 | | 13 | | | 2 | 47 | 256 | 5 |
| • *Acilius sulcatus* | | 82 | 4 | 32 | 3 | | | 38 | 253 | 2 |
| • *Agabus bipustulatus* | | 1 | | | | | | | | 1 |
| *Agabus didimus* | | | | | | | | | | 1 |
| • *Agabus labiatus* | 3 | | | | | | | | | |
| *Coelambus impressopunctatus* | | | | | | 6 | | | | |
| *Colymbetes fuscus* | | 1 | 13 | | | | | | 14 | |
| • *Colymbetes paykulli* | | | | | | | | | 18 | |
| • *Copelatus ruficollis* | | | | | 1 | | | | | |
| *Cybister lateralimarginalis* | | 3 | 1 | | | | | | | |
| *Dytiscus circumcinctus* | | | | | 1 | | | 3 | 3 | |
| *Dytiscus circumflexus* | | | | | | | | | 2 | |
| • *Dytiscus dimidiatus* | | 1 | | 1 | | | | | 4 | |
| • *Dytiscus semisulcatus* | | | 1 | | 2 | | | | 9 | |
| • *Dytiscus marginalis* | 1 | 2 | | | 3 | | | | 2 | |
| *Laccophilus hyalinus* | | 1 | | 1 | | 1 | | 2 | | 5 |
| *Larvae dytiscidae* | 5 | | 4 | | | | | 2 | | |
| *Laccophilus hyalinus larvae* | | | | | | | 2 | | | 11 |
| *Dytiscidae larvae* | | | | | | | 12 | | | 1 |
| *Graphoderus austriacus* | | 122 | | 106 | | | | | 11 | |
| • *Graphoderus cinereus* | | 60 | | 121 | | | | | 4 | |
| *Graphoderus bilineatus* | | | | 2 | | | | | 3 | |
| • *Graphoderus zonatus* | | 111 | | 122 | | | | | 4 | |
| • *Hydroglyphus geminus* | | | | | | 9 | | 1 | | 1 |
| • *Hydroporus palustris* | 2 | | | | 3 | 1 | 85 | | | 63 |
| *Hygrotus impressopunctatus* | | 2 | | | | | 5 | 1 | | 1 |
| *Hyphydrus ovatus* | | 5 | | | 8 | | | | | |
| *Hydaticus continentalis* | | | | | | | 1 | 6 | | 2 |
| • *Hydaticus aruspex* | | 5 | | | | | | | | |
| *Hydaticus stagnalis* | | 4 | | 7 | | | | | | |
| • *Hydaticus transversalis* | | 5 | | 1 | | | | 6 | 2 | |
| • *Hydaticus seminiger* | 3 | 48 | | 6 | 1 | | | 20 | 40 | 2 |
| *Ilybius fenestratus* | | 1 | | | | | | | | |
| • *Ilybius subtilis* | | | | | 1 | | 20 | | | 5 |
| • *Ilybius quadriguttatus* | | 2 | | 1 | | | | | | |
| *Rhantus bistriatus* | 1 | | | | | | | | | |
| *Rhantus suturalis* | | | | | | 2 | | | | 2 |
| • *Hydroporus angustatus* | | | | | | | | | | 12 |
| • *Hydroporus eryhtocepalus* | | | | | | | 5 | | | 11 |
| • *Hydroporus gyllenhalii* | | | | | | | 11 | | | 15 |
| • *Hydroporus tristis* | | | | | | | 9 | | 1 | 58 |
| *Hydroporus sp. Larvae* | | | | | | | 1 | | | |
| *Hygrotus decoratus* | | | | | | | | | | 3 |

(*Continued*)

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**Table 3.** (*Continued.*)

| Site | K1 A | K1 J | K2 A | K2 J | K3 A | K3 J | N1 A | N2 A | N2 J | N3 A |
|---|---|---|---|---|---|---|---|---|---|---|
| *Porhydrus lineatus* | | | | | | | | 2 | | |
| Total | 17 | 478 | 23 | 413 | 23 | I8 | 170 | 156 | 652 | 231 |
| Tax. | 7 | 19 | 5 | 12 | 9 | 5 | 18 | 18 | 17 | 32 |

K, mine area; N, Nature 2000 area; 1–3, site numbering; J, summer samples; A, spring samples. Marked with a black dot – peatland species.

Description of the indicated species:

– *Dytiscus semisulcatus* – in Poland it is one of the less frequently reported species of the genus *Dytiscus*. Archival data show that in the 1970s it was a species so rare that it was only shown on the Baltic Coast (Kornobis, 1979). It was also recorded in later years, but still with the caveat that it belongs to species that are rarely caught in waters in the Polish area. It is a stenotopic, acidophilous species (Koch, 1989).
– *Graphoderus bilineatus* – the species is caught throughout Poland except in the mountains. After 2000 it was recorded within 14 published sites (Zych and Wolender, 2004). Currently, it is a protected species. In Poland, it is under strict species protection and is on the IUCN Red List with a VU category assigned to it. The species is a Eurotypical acidophilous (Koch, 1989).
– *Hydroporus gyllenhalii* – is a species typical of peatland ecosystems (Burakowski, 1976). It was mainly demonstrated in the north of the country and in mountainous areas (Burakowski, 1976). It has a narrow habitat spectrum. It is currently listed on the Polish Red List, and has been assigned a VU (Vulnerable to Extinction) category (Pawlowski *et al*., 2002).
– *Graphoderus zonatus* – a species in Poland found in lowland areas and in the mountains to the lower regale. Officially, it is not a protected species or considered rare. However, it is the rarer representative of the genus *Graphoderus* and is caught locally rather than commonly throughout the country (Buczynski *et al*., 2022). An acidophilous species, it is caught in bogs and water bodies overgrown with aquatic and mud vegetation (Burakowski, 1976).
– *Hydaticus aruspex* – is a species quite rarely recorded in Poland. It is mainly reported from northern and northeastern areas in the country.
– *Dytiscus circumflexus* – although the species is widespread in almost all of Poland, it is caught sporadically (Przewoźny *et al*., 2012).

## Discussion

It is noticeable that the fauna of Coleoptera that develops in the Nature 2000 area is definitely more diverse and consists of more stenotopic species and rare or protected species. Jaccard's index showed that the similarity between the mine and the protected area is only 16% considering not only the presence but also the abundance of taxa. Although species that are eager to inhabit the bogs were also recorded at the mine site, their number was definitely lower than at the nearby protected area. Moreover, the results indicate that despite the drought, rarer and endangered species only migrated towards the mine at a very low or no rate at all. The peat mine does not provide a refugium in the drought season for peat bog beetles.

Our research of Coleoptera indicates that some aquatic beetle individuals rely exclusively on open, large reservoirs, while others rely on shallow post-mining ditches. Large, medium-sized aquatic beetle species, such as those from the *Dytiscus* genera or *Graphoderus* genera, were recorded mainly or exclusively in peat pools, while small species belonging to generas like *Hydaticus*, and *Hydroporus* preferred overgrown, shallow water bodies. Moreover, the literature indicates that some species need a combination of different types of microhabitats to reach different stages in their life cycles (Van Duinen *et al*., 2003). In order to protect the peatland at all levels of organisation, it is necessary to know the requirements of water beetle species so that renaturalisation is complete. So far, the most crucial factor in carrying out restoration activities has been the presence of Sphagnum vegetation, and the goal of these activities has been to improve hydrological conditions. Degraded peatlands often have a mosaic character. In his research, Verberk *et al*. (2001) emphasises that endangered, rare species of water beetles prefer habitats with a variety of water assemblages. The mine is too homogenous a habitat. A greater diversity of microhabitats offers opportunities for the development of species diversity. This is essential information from the point of view of peatland restoration.

It seems that to improve the success of revegetation in peatlands, we must also focus on preserving already existing conditions that can act as a refugium for rare, characteristic species of water beetles of peatlands. Unfortunately, the topic of water beetles of peatlands is still insufficiently studied, there are still many gaps in knowledge – the main problem may be gaps in understanding the ecology, biology or behaviour of these insects. Therefore, future ongoing research needs to check what species are present in different types of habitats. Consequently, learn about the environmental conditions that the species rely on, as well as the local hydrological processes that cause these conditions. Such knowledge is extremely important in choosing a restoration strategy for degraded peatlands, not only to preserve or restore characteristic vegetation, but also to preserve local hotspots of water beetle biodiversity in the long-term effect (van Duinen, 2013).

Peat pools help to maintain a balance of hydrological conditions and can provide a possible refugium for insect species, including water beetles, since there is less chance of their periodic disappearance during dry periods. The Nature 2000 area was so extreme in terms of conditions that during the drought some of the sites dried up in the summer season. This should also not necessarily be considered a negative feature of degraded peatlands, which could determine the future viability of protecting such an area. Due to the fact that this type of peatland has a diversity of microhabitats, the presence of both various types of permanent and periodically drying waters offers a chance for many species to survive and remain in the habitat in the event of extreme drought (Moller Pillot, 2003).

Rare tyrphophilous species prefer to remain in the Nature 2000 area despite the drought, and this may be due to the fact that some water beetles are able to survive for a very long time under peat moss tussocks in dried-up peatlands (Galewski, 1971) or from the presence of a peat pools. In Reptowo at Nature 2000 area, it was noted during the study that at a site with a peat pool character, the water temperature cools down with depth, and often temperature-dependent individuals prefer waters of 4–11°C (Buczyńska and Buczyński, 2019) Nilsson and Svensson (1994) showed that temperature dependence is linked to the requirements of the beetle during the larval stage. Therefore, this type of water body can be a refugium during hot weather for species that prefer low temperatures. In contrast, the mine area, although it did not dry out in summer, the shallow, exposed water bodies warmed up strongly during the summer. Although the RDA analysis showed that the genus *Graphoderus* is pH-dependent (the more acidic the pH, the higher the abundance of the genus (Kolar and Boukal, 2020)), it should be taken into account that all the sites where it occurred were not characterised by a very acidic pH, but rather the highest water temperatures were recorded at these sites during the time of the highest abundance of species of the genus *Graphoderus*. It has been reported in the literature that, in general, species of the genus *Graphoderus* were the most thermophilic species, and their abundance increased with water temperature (Buczyńska and Buczyński, 2019). In addition, species of the genus *Graphoderus* may tend to inhabit poorly overgrown sites, such as mine area (Buczyńska and Buczyński, 2019). In the study conducted in Reptowo, this tendency is confirmed by the highest abundance of the genus Graphoderus at poorly overgrown sites on peat mine area.

As a result of conducted studies, it appears that beetles of the genus *Hydroporus* would be suitable as a possible environmental indicator. Although RDA analysis indicates that species of the genus *Hydroporus* show a correlation with conductivity, it should be noted that the sites where they occurred also recorded the most acidic pH among the sites studied (average pH level of 3.58). *Hydroporus* species are tyrphophiles, preferring acidic water pH (Drost, 1992). Their presence may indicate that there are conditions in the ecosystem that will potentially be suitable for Sphagnum vegetation, which is strongly associated with acidic pH level. Sphagnum vegetation is a vegetation typical of raised bogs (Verberk *et al.*, 2001). This leads to the conclusion that species of the genus *Hydroporus* can be indicators of the conservation status of the habitat, since their occurrence is correlated with the presence of characteristic peatland vegetation, the presence of which is taken into account when assessing the condition of the habitat. Successful restoration efforts in peatlands, focusing on the development of dominant Sphagnum vegetation, will positively correlate with increased water beetle diversity. We expect restored peatlands to harbour a more diverse water beetle fauna compared to degraded counterparts.

An important indicator for evaluating the condition of peatland habitat is the proportion of tyrphophilous species in relation to ubiquitous species. Both common tyrphophilous beetles and ubiquitous water beetle species were recorded in the mine area. Degraded bogs such as in the area of the mine can eventually become a refugium but for species originally not at all associated with bog ecosystems (Akkermann, 1982; Schouten, 2002). As environmental conditions change at the mine as a result of human activity, exemplified by shifts towards alkaline pH levels or the depletion of peatland vegetation, this exploited peatland loses the unique characteristics that define it as a peatland ecosystem, which is reflected in a higher proportion of ubiquitous species in the fauna of the area and the loss of acidophilous species, which are often rare, protected species. Examples include the presence of species such as *Hyphydrus ovatus* or *Hydroglyphus geminus*. *Hyphydrus ovatus* was abundant in mine area. It is a common species; it does not prefer to inhabit peat bogs. This species is found mainly in aquatic vegetation that overgrows lakes, ponds or riverbanks (Galewski, 1971). *Hydroglyphus geminus* was also recorded in large numbers in the mine area. This species is not a representative of the bog beetle fauna, as it has mainly been shown from free-flowing or standing waters with sandy, gravelly or clay bottoms. The presence of ubiquitous species and their predominance in the share of the aquatic beetle fauna of an area may indicate negative processes. The higher the diversity and number of opportunistic species, the more we are dealing with the disappearance of the characteristics of peatlands that define their uniqueness. Ubiquitous species in peatland fauna can indicate pollution, deforestation of drainage basin, inflow of nutrients, increase in trophy, lowering groundwater table and drying out (Bernard *et al.*, 2002).

Studies in Europe and North America have suggested that peat pools are often dominated by an insect group such as Coleoptera, and in the UK they are typically the second most abundant group of macroinvertebrates in peat pools (Brown *et al.*, 2016). They can be an example of umbrella species, whereby protecting water beetles we will protect the peatland from the impact human activities. What is more, water beetles can serve as umbrella species for other aquatic macroinvertebrates that populate bogs. A great example is the species *G. bilineatus*, which was found at localities with higher species richness of large-sized aquatic beetles (both protected and common), thus supporting the species status as an umbrella species for other aquatic macroinvertebrates (Kolar and Boukal, 2020). If aquatic beetles were considered as another factor conditioning the establishment of protected areas or the approval of mining permits, there would be a better chance of protecting this type of ecosystems. Currently, we still know little about the environmental preferences of water beetles in peatlands. Far more research is being conducted on terrestrial fauna. Therefore, it is important to continue research on the water beetles of peatlands. Water beetles are a great research aspect, as they are a precursor to undertaking restoration efforts to preserve local hot spots of peatland biodiversity around the world.

## Conclusion

The consideration of water beetle fauna is crucial when assessing the condition of peatland habitats. The homogenisation of the aquatic environment in mining areas poses a potential threat to valuable and often protected aquatic beetles, especially those typical of acid environments. Implementing sustainable peatland management practices positively contributes to the conservation of water beetle species. We predict that well-managed peatlands will support higher water beetle diversity compared to poorly managed or degraded peatlands. Alternatively, the peat mine could be a possible refugium for thermophilic species that are ubiquitous rather than tyrphophilic.

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