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# PRELIMINARY LIMNOLOGICAL CHARACTERISTICS OF RESERVOIRS ON THE RECLAIMED WASTE HEAP OF SULPHUR MINE „MACHÓW" (SE POLAND)

WOJCIECH PĘCZUŁA[1], RADOSŁAW MENCFEL[2], KAMILA BARYŁA[3]

[1]University of Agriculture in Lublin, Department of Hydrobiology and Ichthyobiology
ul. Akademicka 13, 20-950 Lublin, Poland
[2]Catholic University of Lublin, Department of Botany and Hydrobiology
ul. Norwida 4, 20-061 Lublin, Poland
[3]ul. Staffa 68, 20-454 Lublin, Poland

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## WSTĘPNA LIMNOLOGICZNA CHARAKTERYSTYKA ZBIORNIKÓW WODNYCH NA ZREKULTYWOWANYM ZWAŁOWISKU KOPALNI SIARKI „MACHÓW" (PD-WSCH. POLSKA)

W czerwcu i listopadzie 2003 r. dokonano wstępnych badań limnologicznych czterech małych (powierzchnia: 0,4–2,3 ha), lecz stosunkowo głębokich (głębokość maksymalna: 6,5–7,8 m) antropogenicznych zbiorników wodnych, utworzonych w latach 1979–1988 na zrekultywowanym zwałowisku zewnętrznym kopalni siarki „Machów" (N 50°31'35"; E 21°37'51"). Jesienią w jednym z jezior (Kacze) stwierdzono stratyfikację termiczno-tlenową, co może sugerować występowanie meromiksji. Pozostałe jeziora uznano za dimiktyczne. We wszystkich zbiornikach stwierdzono wysokie wartości twardości ogólnej, przewodnictwa elektrolitycznego, chlorków i siarczanów oraz niską zawartość azotu i fosforu ogólnego. Zbiorowiska fitoplanktonu oraz makrofitów były słabo rozwinięte. W planktonie zbiorników zanotowano także duże ilości zielono-żółtych bakterii. Zarówno skład chemiczny wody jak i jakość i ilość zbiorowisk roślinnych jest odzwierciedleniem składu chemicznego gleb zwałowiska, zbudowanego głównie z iłów krakowieckich pochodzących z nadkładu kopalni siarki.

### Summary

Four small (surface area: 0.4–2.3 ha), but relatively deep (max. depth: 6.5–7.8 m) man made reservoirs, created between 1979 and 1988 on recultivated waste heap of former sulphur mine in Machów (N 50°31'35"; E 21°37'51"), were studied in summer and autumn 2003. In autumn one lake – Kacze was not mixed down to the bottom, which could point to its meromixis. The other lakes were found to be dimictic. In all the lakes high values of total hardness, conductivity, chlorides, sulphides and low amounts of total phosphorus and nitrogen were found. Both phytoplankton and hydromacrophyte communities were poorly developed. Considerable amounts of green-yellow bacteria were also noted in plankton. The water chemistry as well as quantity and quality of plant communities reflect the chemical composition of loam soils which constitute the waste heap.

## INTRODUCTION

Mining produces dumps and waste heaps which need to be remediate. Dump recultivation is performed both to make it stable and safe as well as because of environmental concern. Lakes established on dumps, like other mining reservoirs, are interesting objects for limnological research [15]. Coal mine lakes, for example, are often very acidic and constitute a special limnological type of water bodies [8], but not all pit lakes are determined to be acidic, especially when bottom rocks have high neutralizing capacity [5]. Habitat conditions in mining lakes are often extreme, and can serve as refuges for rare species [20].

Very little is known about reservoirs connected with sulphur mining areas. Some studies were made in sunken open-pit mines [2, 24] but the limnology of reservoirs established on sulphur mine waste heaps is still unknown.

This paper gives the preliminary limnological characteristics of four water bodies created on reclaimed waste heap of former, open-pit sulphur mine in Machów, east-southern Poland. We report for the first time on the morphometry, physico-chemical water properties and composition of plant communities of these water bodies.

## SITE DESCRIPTION

The lakes were created on the waste heap of sulphur mine Machów (N 50°31'35"; E 21°37'51"; Sandomierska Valley, east-southern Poland) (Fig. 1). The heap was built between 1966 and 1988, reclaimed from 1976 to 1998, now occupies the area of 8.8 km$^2$ and has prominence of 65 m [6]. The structure of waste heap consists mainly of over-layer loams, which compose up to 90% of dump's upper surface level. The soil is slightly alkaline, rich in calcium, magnesium and sulphur but contains small amounts of phosphorus and nitrogen [12, 14]. During waste heap reclamation, hilltop was transformed to arable fields and slopes were planted by sea buckthorn *Hippophaë rhamnoides* L. (> 50% of planted area), black locust *Robinia pseudoacacia* L., grey alder *Alnus incana* (L.) Moench. Some depressions created during dumping were left and now they are filled with precipitation water. Four of them have been studied (Wąsik, Bliźniaki, Suchorzów, Kacze). All of them are surrounded by very close shrubs and forests consisting of species listed above. Only one (Bliźniaki) borders with arable field. Hydrology of lakes is unknown, but on the basis of authors' observations one can suppose that reservoirs are supplied mainly with precipitation and surface runoff. Average yearly precipitation in the Sandomierska Valley (in the period 1971–2000) amounted to 550 mm [16]. In 2003–2004 monthly sum of precipitation in June and October was about 40–50 mm and 60 mm, respectively [11].

## METHODS

Lake area parameters were calculated using a map of the heap [18]. Calculation of Lake Basin parameters were based on bathymetric plans, which were drawn following the methods by Wetzel and Likens [23]. Mean depth was calculated as volume [m$^3$]: area [m$^2$] ratio, relative depth ($h_w$) was calculated using Halbfass formula:

$$h_w = \frac{h_{max}}{\sqrt{A_j}}$$

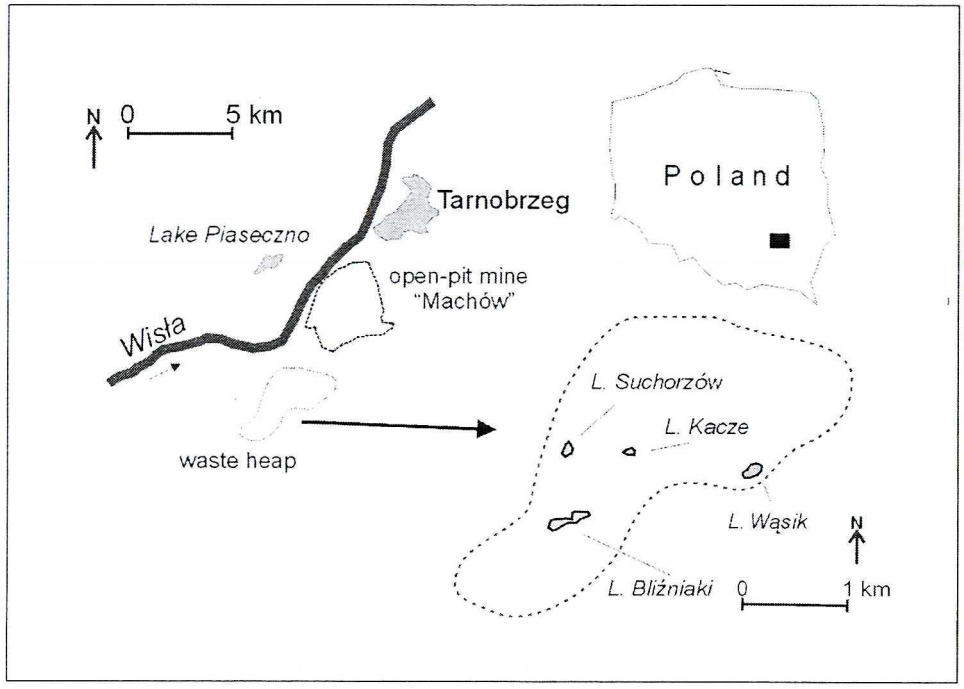


Fig. 1. Situation of studied lakes

where: $h_{maks}$ – maximal depth [m],
$A_l$ – lake area [m$^2$].

Biological and hydro-chemical samples were taken twice: in June and November 2003, except for Lake Kacze in which the chemical parameters were measured only in autumn. Sampling was done in the deepest point of the lakes, from two levels (ca. 0–3 m and 4–6 m), which correspond to summer epilimnion and hypolimnion. Water temperature, oxygen concentration, pH, and conductivity were measured *in situ* using electronic device (WTW OXI 96 oxymeter, Elmetron CP-401 pH-meter, Elmetron CC-401 conductometer). Water transparency was determined using Sechci disc. Concentrations of total phosphorus and nitrogen, sulphides, chlorides and chlorophyll-*a* were analyzed in laboratory following the methods by Hermanowicz et al. [10] and Nusch [17]. Phytoplankton numbers were counted by Utermőhl method [21] and classification of macrophyte communities were based on the paper by Brzeg and Wojterska [1].

## RESULTS

The lakes had small surface areas (0.4–2.3 ha) but were relatively deep (max depth: 6.5–7.8 m) which resulted in high relative depths (Tab. 1). The lake basins configurations are diversified but shorelines are rather not much developed – excluding Lake Wąsik (Fig. 2).

Table 1. Morphometrical parameters of studied lakes

| | Bliźniaki | Wąsik | Suchorzów | Kacze |
|---|---|---|---|---|
| Surface area [ha] | 2.3 | 1.4 | 0.8 | 0.4 |
| Volume [$10^3 \cdot m^3$] | 74.4 | 29.8 | 23.2 | 9.1 |
| Length [m] | 440 | 180 | 155 | 95 |
| Max. width [m] | 95 | 110 | 75 | 50 |
| Max. depth [m] | 7.5 | 6.5 | 7.8 | 7.0 |
| Mean depth [m] | 3.2 | 2.1 | 2.9 | 2.3 |
| Relative depth | 0.0495 | 0.0549 | 0.0872 | 0.1107 |

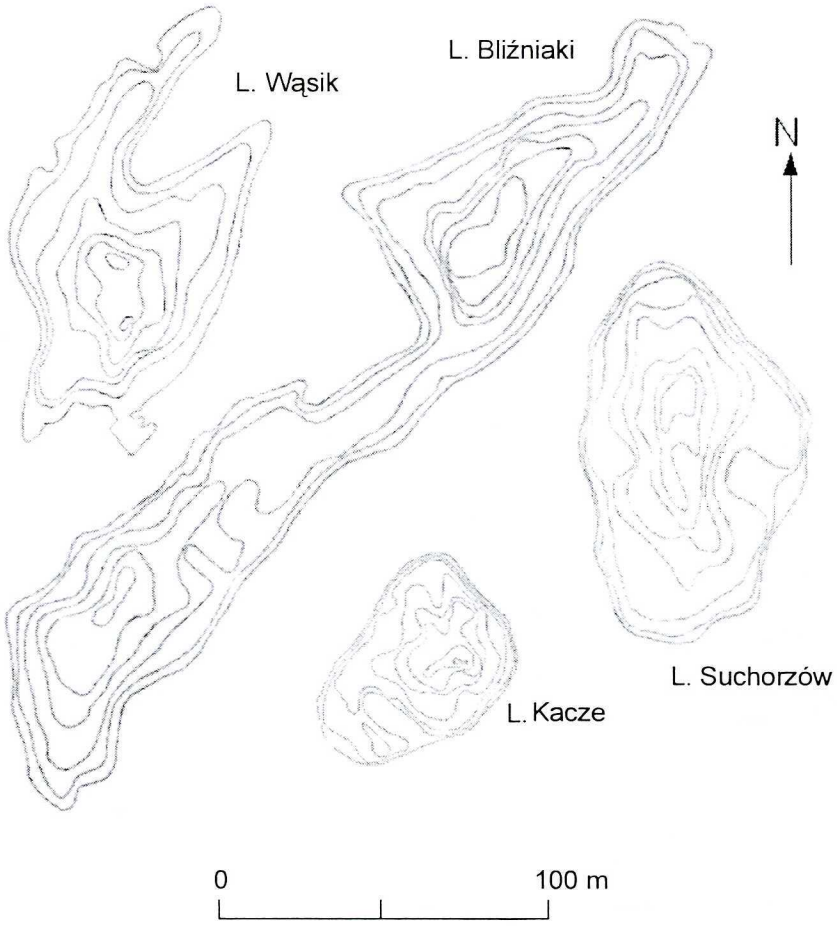


Fig. 2. Bathymetric maps of studied lakes (isobaths every 1 m)

In June water transparency was low – the euphotic zone reached 2–2.5 m. Thermal and oxygen stratification occurred: deeper layers (below 4 m) were cold and anoxic (Fig. 3). In November the whole water column had homogenous temperature and oxygenation, except for Lake Kacze. In this lake the water below 4 m was deprived of oxygen although the temperature profile resembled homothermy (Fig. 3).

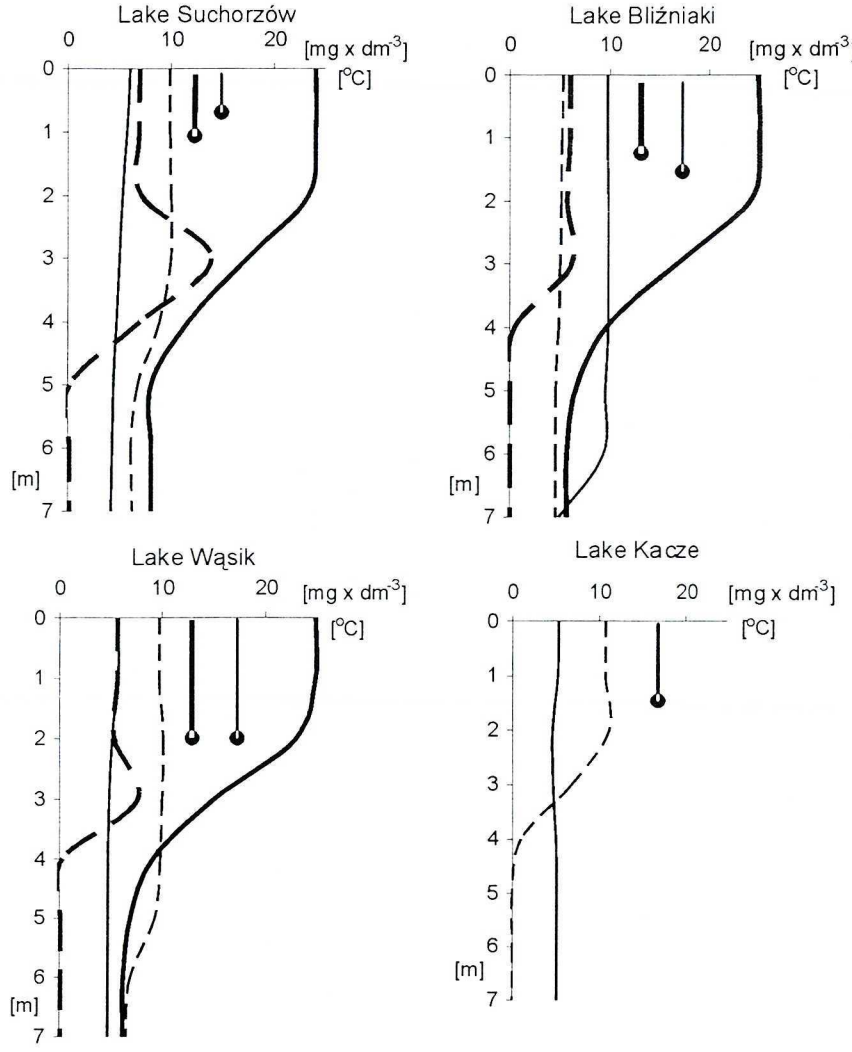


Fig. 3. Temperature, oxygen concentration and water transparency in the lakes studied in June (VI) and November (XI) 2003

Table 2. Values of pH, conductivity, total hardness, carbonate hardness, concentrations of chlorides ($Cl^-$), sulfates ($SO_4^{2-}$), total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* and total abundance of phytoplankton of the lakes studied in June (VI) and November (XI), 2003 (s – surface layer, b – bottom layer)

| | Bliźniaki | | | | Wąsik | | | | Suchorzów | | | | Kacze | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VI | | XI | | VI | | XI | | VI | | XI | | XI | |
| | s | b | s | b | s | b | s | b | s | b | s | b | s | b |
| pH | 7.6 | 7.4 | 8.4 | 8.3 | 7.9 | 7.5 | 8.4 | 8.4 | 7.9 | 4.8 | 8.9 | 8.6 | 8.2 | 7.3 |
| Conductivity (mS/cm) | 5.23 | 5.71 | 5.88 | 5.83 | 3.40 | 4.19 | 4.27 | 4.15 | 3.13 | 4.02 | 3.72 | 3.68 | 3.24 | 4.28 |
| Total hardness (mval/$dm^3$) | 90.0 | 104 | 55.0 | 53.5 | 59.7 | 61.5 | 81.5 | 83.7 | 57.0 | 73.5 | 59.9 | 60.1 | 48.8 | 68.5 |
| Carbonate hard. (mval/$dm^3$) | 18.2 | 21.8 | 15.1 | 15.3 | 14.1 | 14.3 | 14.7 | 14.6 | 7.8 | 13.0 | 9.6 | 9.3 | 11.2 | 45.6 |
| $Cl^-$ (mg/$dm^3$) | 26.1 | 45.6 | 25.4 | 26.3 | 5.4 | 7.7 | 32.2 | 33.2 | 18.4 | 47.9 | 8.3 | 7.9 | 9.1 | 5 |
| $SO_4^{2-}$ (mg/$dm^3$) | 878 | 831 | 1205 | 1251 | 875 | 930 | 1199 | 1181 | 640 | 822 | 1201 | 1195 | 1201 | 1446 |
| TP (mg/$dm^3$) | 0.10 | 0.06 | 0.09 | 0.09 | 0.07 | 0.11 | 0.06 | 0.08 | 0.10 | 0.14 | 0.11 | 0.07 | 0.05 | 0.72 |
| TN (mg/$dm^3$) | 0.09 | 0.22 | 0.50 | 0.61 | 0.09 | 0.22 | 0.54 | 0.41 | 0.38 | 0.18 | 0.08 | 0.08 | 0.85 | 5.11 |
| Chlorophyll-*a* (μg/$dm^3$) | 5.3 | 11.7 | – | – | 6.8 | 17.2 | – | – | 7.9 | 15.9 | – | – | 20.2 | 241 |
| Phytoplankton abundance (ind. x $10^3$/$dm^3$) | 945 | 311 | – | – | 1905 | 413 | – | – | 546 | 130 | – | – | 979 | 0 |

Water pH in the lakes was slightly alkaline and had very high (> 3 mS/cm) conductivity (Tab. 2) as well as total hardness (20–35 mval/dm$^3$), which mainly consists of non-carbonate fraction. It was confirmed by very high concentrations of chlorides (5.0–47.9 mg/dm$^3$) and sulphides (640.1–1446.8 mg/dm$^3$) (Tab. 2.). Nutrient concentrations were low (TP: 0.06–0.14 mg/dm$^3$; TN: 0.09–0.85 mg/dm$^3$) except in the bottom layers of Lake Kacze in November, when they reached very high values (0.72 and 5.11 mg/dm$^3$, respectively) (Tab. 2).

Chlorophyll-*a* concentrations were rather low (5.3–17.2 ug/dm$^3$), except for Lake Kacze in which the values were very high (Tab. 2). Values of this parameter were usually higher in deeper layers of lakes but it was not reflected by the total abundances of phytoplankton (Tab. 2). The phytoplankton was poorly qualitatively diversified. In lakes Bliźniaki and Kacze it was predominated by diatoms and in particular by *Synedra acus* Kütz (Fig. 4). In Lake Wąsik the most numerous were euglenas, with *Trachelomonas* sp. as a dominant. The most diversified phytoplankton was found in Lake Suchorzów. In its epilimnion the highest densities were achieved by dinoflagellates (35%) and chrysophytes (24%) and in the hypolimnion by cryptophytes (46%) and greens (46%) (Fig. 5).

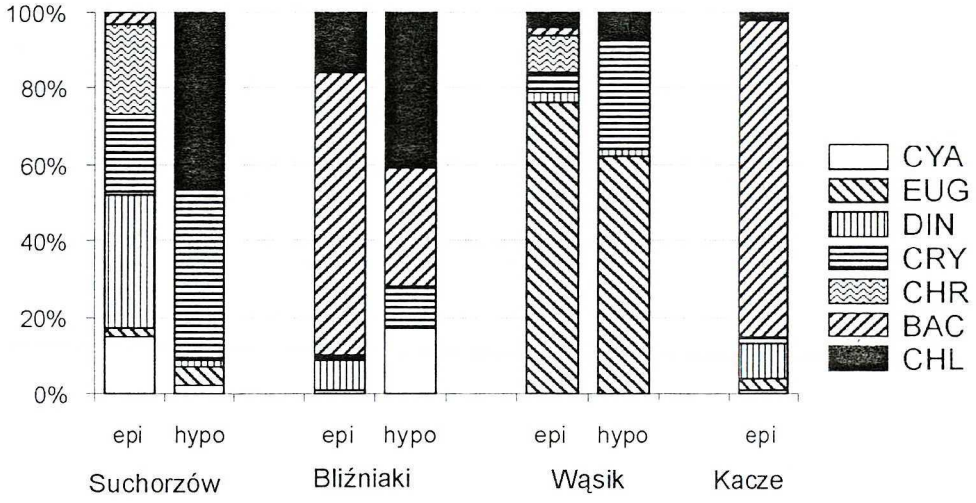


Fig. 4. Dominance structure of the total numbers of phytoplankton in epilimnion (epi) and hypolimnion (hypo) of the lakes studied. June, 2003 (CYA – *Cyanoprocaryota*, EUG – *Euglenophyta*, DIN – *Dinophyta*, CRY – *Cryptophyta*, CHR – *Chrysophyceae*, BAC – *Bacillariophyceae*, CHL – *Chlorophyta*)

It is worth mentioning that in hypolimnion of all the lakes, the green-yellow bacteria were found in large numbers, but they were not counted. Their most numerous communities seem to occur in Lake Kacze.

In majority of the reservoirs the narrow rush *Phragmitetea australis*, predominated by common reed was formed. In Lake Kacze, however, only single patches of that association occurred. In addition, the stands of *Scirpetum lacutris, Elocharietum palustris* and *Lemno-Utricularietum* with bladderwort (*Utricularia vulgaris* L.) were found in Lake Wąsik. Nympheid and elodeid patches composed mainly of *Potamogeton natans* L., *P. pectinatus* L. and *P. crispus* L. were numerous only in Lake Suchorzów.

## DISCUSSION

The water dynamics suggest dimictic character of the lakes, except for Lake Kacze, where water column was not mixed until November and water samples from the bottom layers were anoxic with sulphuretted hydrogen smell and had dark grey color. The lake, like all researched, is relatively deep (relative depth – 0.1107) but as the only one is surrounded by hills covered by dense shrubs and forests. These features, together with strongly mineralized water can support meromictic (maybe facultative) character of the lake [22]. Meromixis was observed also in situated nearby lake Piaseczno, the sunken open-pit sulphur mine [24] and in many other man-made reservoirs in Poland [7, 9, 20]. Because sampling in Lake Kacze was done only once, further detailed researches are needed to determine the mixing character of the lake.

All the lakes, despite their ombrogenic supply with water and location on watershed divide were alkaline and had strongly mineralized water. The lakes' water well reflects the chemical composition of the dump: loams are rich in sulphur (up to 1.5 %), magnesium and calcium [12]. On the other hand, the dump soil is poor in nitrogen and phosphorus [13], which results in low nutrient concentrations in reservoir waters. Higher concentrations of phosphorus and nitrogen in bottom layers of Lake Kacze could be connected with its specific mixing conditions.

Hydrochemistry of reservoir water was reflected in quality and quantity of phytoplankton and macrophyte communities. Nutrient content was low, so phytoplanktonic chlorophyll-*a* concentrations were typical of mesotrophic lakes. Poor development of the phytoplankton community could be also connected with high total hardness of the water. Similar relationships were found, e.g. in excavation lake Zakrzówek in southern Poland [7]. Also phytoplankton structure in studied lakes was typical of hard water lakes, both natural and man made [3, 4]. In the plankton communities of lakes studied also phototrophic bacteria could play a significant role – particularly in hypolimnion where higher concentrations of chlorophyll-*a* were found [23]. Some species of sulphur phototrophic bacteria can thrive in extremely low light intensity [19]. Except for phototrophic also some other sulphur bacteria, e.g. *Beggiatoa* sp. can be important in these kinds of lakes [2]. Macrophyte community was additionally restricted by specific morphometry of the lakes: high relative depth affected in narrow littoral zone developed in the lakes.

Lakes created during waste heap reclamation in Machów are certainly interesting from the limnological point of view. But the question also is: what role do studied lakes play in reclaimed post-mining landscape? The answer is complex. They certainly enrich biological diversity of the landscape, but on the other hand they are poorly diversified. These lakes (except Kacze) could be good places for recreational use, especially that this area lacks natural water bodies.

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