# Initial succession of zooplankton and zoobenthos assemblages in newly formed quarry Lake Medard (Sokolov, Czech Republic)

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**Abstract** This paper gives the results of the initial observation period of the development of zooplankton and zoobenthos during flooding of the residual brown coal mine pit Medard. Changes in the quantity and quality of water, flowing from different sources, and development of stratification in the lake water affect the composition of zooplankton and zoobenthos. Original sources of zooplankton inoculum, which are the reservoirs in the Lake Medard own catchment area, are monitored too. Another important source, that will significantly affect the formation of the newly formed lake, is the river Ohře (Eger), which will contribute with the greatest volume of water. At the same time, the hydrochemical water quality parameters and their influence on the formation of zooplankton and zoobentos communities are monitored.

**Key Words** brown coal mine pit lake, zoobenthos, zooplankton, crustaceans, conductivity

## Introduction

The quarry Lake Medard near town Sokolov in west Bohemia is supposed to be the largest residual pit flooded in the Czech Republic. Coal mining was stopped in 2000 and the lake filling began in 2008, when pumping the mine water from the pit ceased. By the end of 2010, only indigenous drainage basin water (plus mine waters) and relatively small volumes of river water were coming to the lake. Since the 2011, the filling from the river Ohře will be much more important and in 2013 the total area of the lake will be 493 ha, $120 \times 10^6$ $m^3$, mean depth 24 m, maximum depth 57 m.

During the filling of the lake, its morphological characteristics, water quality, the vertical stratification and ultimately fish stock are gradually changing. We expect important changes in the composition of zooplankton and zoobenthos following the development of the lake. We expect development which can not be observed in stabilized water reservoirs.

## Methods

Zooplankton has been observed from the beginning of 2009, when the original 3 separate retentions at the bottom of the quarry merged into a common lake. Sampling is done in the three deepest sites of the former retentions, during ice-free period of the year, in 2 to 3 week intervals, by vertical stroke from the bottom to the surface, using plankton net with mesh diameter of 80 µm. In these samples, fresh biomass of zooplankton is estimated. Since 2010, monitoring of the vertical distribution of zooplankton has started. For this purpose, sampling with closing net - SEDA (mesh diameter of 80 µm) from epilimnion, metalimnion, hypolimnion, the layer below chemocline and possibly from other clearly physically and chemically defined layers (see Vrzal *et al.* 2011) was used. This closing net was successfully used in the study of depth distribution of Daphnia species in other Czech reservoirs (Seďa *et al.* 2007). From these samples zooplankton size fractions of >710 µm, 420—710 µm and <420 µm are separately quantified as dry weight (sorted by sieves). In places, where water sampling for chemical analysis takes place (depth of 0, 5, 10, 15, 20 m and bottom, four times a year), there is also sampled zooplankton to determine its density using collectors of 3 l (Van Dorn) or 5 l (Friedinger) volume. Samples for analysis of phytoplankton and cyanobacteria, which are not the subject of this contribution, are collected in the same places. Since 2011, samples are taken from various depths only in the central profile. Since 2010, during the warm half of the year, zooplankton in lake littoral band has been monitored too, but it is only qualitative sampling using net with mesh diameter of 80 µm.

As a source of zooplankton inoculum, 21 reservoirs in the own catchment area of the lake in the range of quarry Medard are also monitored using semiquantitative method. With one exception (the existing reservoir from the 50s of the 20th century), the reservoirs were built in the reclamation after 2000. These reservoirs have low flow rate, so the zooplankton inoculum can get into the lake only during the spring melting of snow and after heavier rains.

Another monitored source of zooplankton inoculum is the river Ohře, which will provide about 70% of water for the lake. The river Ohře catchment area above the inlet to the lake includes eutrophic and oligotrophic dams, a series of fish farming ponds and riverain pools. Ohře is therefore a source of potentially very wide variety of species of aquatic organisms from a number of systematic groups. Zooplankton of the river is monitored by semiquantitative method using plankton net with mesh diameter of 80 µm.

Zooplankton samples are preserved with formaldehyde at a concentration of 2—4%. In the case of crustacean Daphnia species part of the material is kept in frozen state for later genetic analysis.

Monitoring of zoobenthic assemblages was started in 2010. Samples were taken once a month (from June to September 2010) at predefined locations in the west, middle and east part of water body (deepest points and littoral areas) in accordance with routine limnological methods (Bejček *et al.* 2001). An Ekman-Birge dredge (15cm x 15cm) was used for quantitative sampling from benthic communities in the deepest part of the lake (c. 20 m), as well as in shallow waters near the banks. Three separate withdrawals were performed at each point forming one mixed sample. A D-frame limnological hand-net with a mesh aperture of 1 mm and a modified plankton net were used for qualitative sampling in littoral areas with aquatic and flooded plants. Occasionally, a hand collection of aquatic invertebrates was practiced from the submerged subject matters. Since 2011, three elongated profiles situated from the deepest places to relevant littoral area have been monitored. Particular samples have now been taken in depths corresponding to physical/chemical stratification of the lake. Retained zoobentic organisms were sorted from bottom substrate with entomological forceps in a white photo plate. All biological material was preserved immediately with a 4% formaldehyde solution and stored in laboratory conditions for later determination. Whenever possible, macroinvertebrates were identified at the lowest taxonomical level through the use of standard field guides (except order Diptera). The exact determination of water beetles (Coleoptera), water bugs (Heteroptera) and caddyisfly (Trichoptera) will be done in collaboration with particular specialists, therefore only the names of taxonomic orders are used in these cases. This contribution presents only results from season 2010.

## Results

The lake chemistry in 2008 was characterized by high conductivity (cca 2500 µS/cm) with dominance of $Ca^{2+}$, $Na^{+}$, and $SO_4^{2-}$ ions and pH between 5.4 and 7.6. In the following period, the lowest pH levels in the water column gradually increased and in 2011 did not fall below 6.4. Some metals initially exceeded the limit for surface water. Their concentration in the water column during the period gradually declined. In 2 deepest places (3 in 2009) of the lake a chemocline occurs, below which water temperature and the concentration of range of substances increases and, on the contrary, no dissolved oxygen is found. Based on the physical and chemical analysis (see Vrzal *et al.* 2011), at least since 2009, the occurrence of toxicity in the lake can not be assumed and the composition of zooplankton is influenced only by gradual spread of species into the lake, the decrease of lake trophy, water temperature, oxygen concentration and fish stock. Only in few cases it is possible to correlate the occurrence of some species with lake chemistry specifics.

In the lake catchment area, small reservoirs are largely overgrown with water plants. Therefore it is not always possible to make a correct sampling of zooplankton from the open water and part of the samples is only qualitative. Among the dominant species (a frequent occurrence, a higher frequency) are rotifers Filinia longiseta, Hexarthra fennica, Keratella cochlearis, Keratella quadrata, Polyarthra dolichoptera, Polyarthra luminosa and Synchaeta pectinata, developmental stages of copepods, calanoid Eudiaptomus vulgaris, cyclops Tropocyclops prasinus and daphnids Ceriodaphnia pulchella, Daphnia longispina and Chydorus sphaericus. Fresh biomass of zooplankton is low. It ranges between 0.1 to 3 g/m$^3$ with a mean value of about 1 g/m$^3$.

Zooplankton biomass in the river Ohře is very low and it ranges between 0.001 to 0.2 g/m$^3$ with a mean of 0.02 g/m$^3$. The proportion of zooplankton biomass is below 1% of floating seston. By contrast, phytoplankton and surface-growing algae account for tens of % of seston. Among the dominant species of zooplankton are rotifers Asplanchna priodonta, Bdelloidea g.sp., Brachionus angularis, Brachionus calyciflorus, Conochilus unicornis, Kellicottia bostoniensis (new species for the republic, in many samples of zooplankton in the majority), Keratella cochlearis, Keratella quadrata, Polyarthra dolichoptera, Polyarthra maior, Synchaeta pectinata and Synchaeta sp.div. From copepods, the developmental stages of Cyclopidae, Diaptomidae and Harpacticoida are relatively abundant. Only 4 types of Cyclopidae have been found: Acanthocyclops trajani, Eucyclops serrulatus, Mesocyclops leuckartii, Thermocyclops oithonoides. From cladocerans, Chydorus sphaericus and Bosmina longirostris are relatively abundant. Bosmina coregoni and Daphnia sp. were also repeatedly found.

Several stages and influences can be traced in the development of the lake that are reflected in the incidence of some types of zooplankton. In the initial stage (2008 – 2009) without fish stock, the occurrence of low pH faded away. The finding of acidofilic rotifer Brachionus sericus and occasionally a high proportion of the Bdelloidea group rotifers can be related to this fact. Other species typical for water with high salt concentrations and high alkalinity (Hexarthra fennica, Tropocyclops prasinus) also occured. Other identified species have no special requirements on the chemical properties of water. Cyclops Acanthocyclops trajani, which is common in eutrophic waters with dense fish stock and is considerably more tolerant to increased concentrations of dissolved salts, was relatively abundant in this period. Since 2010, it has been found in the open water only sporadically, more often in the littoral. A large proportion of biomass accounted for calanoid Eudiaptomus vulgaris. This species is rare in waters with fish stock but relatively common in mining pits without fish. The last major zooplankton species is cladoceran Daphnia longispina, which is the most tolerant species to low trophy level from the Central European members of the genus Daphnia.

In 2010, the gradually rising water level accentuated the lacustrine character of Lake Medard and composition of the zooplankton had no longer a random character conditioned by inoculum from small reservoirs in lake catchment area. The low presence of rotifers (few species, a tiny percentage) is striking. Only in July rotifer Hexarthra fennica occurred, forming up over 50% of individuals in the samples. The samplings from September almost completely lacked rotifers (1 individual recorded in a 1.5 $m^3$). This is probably the result of food particles being off-filtered by daphnia Daphnia longispina and predation by calanoid Eudiaptomus vulgaris. However, Daphnia longispina concentration was very low, only about 2 per liter. In early June, the functionality of the inlet device was briefly tested. Approximately for half an hour water flowed into the lake from the river Ohře, in total less than 5000 cubic meters of water. It had only negligible influence on the chemical composition of water, because the water level in the lake has increased by less than 3 mm by the inflow, but it could bring zooplankton inoculum and affect the species composition. According to the analysis of zooplankton samples, this influence accounted for probably no more than 1—2 species. The first one was an isolated finding of copepod Thermocyclops oithonoides in 2 samples,which was not previously recorded in the own lake basin. The larger effect was observed on cladoceran Ceriodaphnia affinis, which was in one month found in several samples from pelagial in littoral, and its proportion reached up to tens of percent.

In the first half of 2011, the composition of zooplankton was substantially affected by the water filling from the river Ohře, which was taking place from 21.12.2010 to 12.01.2011, with resulting increase in water level of 4 meters. It was also reflected by a significant change in the chemical composition of water in the upper layer, because water in river Ohře has a conductivity only of about 300 µS/cm and approximately ten times higher concentration of total phosphorus. In early February, there was conductivity of only 800 µS/cm found at the surface. However, it was followed by mixing of surface water layers and conductivity levels gradually increased to 1200 µS/cm in late March and to 1450 µS/cm at the beginning of June. Another possible influence on zooplankton composition was the whitefish (Coregonus maraena) fry stocking in early March in the amount of 2 million individuals. The high proportion of rotifers in zooplankton was a significant change with the appearance of several new species: Brachionus angularis, Filinia terminalis, Kellicottia longispina, Keratella hiemalis, Keratella valga, Polyarthra remata and Synchaeta lakowitziana. It can be assumed that most of them will become a permanent part of the Lake Medard. There should be species of Filinia terminalis, Keratella hiemalis and Synchaeta lakowitziana present year round in the deeper layers of cold water. Interestingly, rotifer Kellicottia bostoniensis, which was very significantly represented in samples of zooplankton from the river Ohře, was not detected. Synchaeta lakowitziana were very numerous in March, while its proportion in zooplankton exceeded 80%. Other abundant species of rotifers included Keratella quadrata, Keratella testudo and Polyarthra dolichoptera. Another significant change occurred in calanoids, because a new species Eudiaptomus gracilis was found in Lake Medard. In June, the frequency of adults exceeded 10 % in the western part of the lake, but there was a significant reduction in their body size (length of both sexes about 1.3 mm). The bigger species Eudiaptomus vulgaris was even not found in 2011. This change in species composition of diaptomidae is probably caused by two factors. The first is a supply of large amounts of nauplii stages of Eudiaptomus gracilis from the river Ohře that subsequently matured in the lake. Another influence is the fish stocking. Whitefish fry prefer greater zooplankton individuals and maybe were able to completely consume older adults and copepodits of Eudiaptomus vulgaris. This change is also likely to become a permanent feature of the zooplankton of Lake Medard. In summer a greater incidence of copepod Thermocyclops oithonoides can be expected (only sporadically in first half of 2011), as well as the occurrence of cladocera genus Diaphanosoma, Bosmina longirostris and Bosmina coregoni. Trophy should rise in the lake during the filling from the river Ohře. Therefore an increase in zooplankton biomass and a wider range of species can be expected. Comparison between the number of species found in the lake

| | lake watershed | river Ohře | Medard | total |
|---|---|---|---|---|
| **Rotifera** | 28 | 38 | 25 | 53 |
| **Copepoda** | 12 | 5 | 15 | 22 |
| **Cladocera** | 8 | 7 | 4 | 14 |
| **total** | 48 | 50 | 44 | 89 |

***Table 1*** *Number of species from different taxonomical groups*

and at the source localities is shown in Table 1.

Zooplankton density in the Lake Medard is very low. The average value for the period from 2009 to 2011 is 7.7 pc/L, median 1.5 pc/L. Density decreases from the surface to the bottom: in the depths of 0 m approximately 23 pc/L, at 5 m 9 pc/L and a depth of 10 m 2 pc/L. Increased concentrations were found again in some samples from the top of the chemocline, which corresponded to an average depth of 15 m with a density of 13 pc/L. Zooplankton density was only 0.67 pc/L in the layers with oxygen concentrations below 1 % of saturation. Increased density of zooplankton (nauplii Cyclopidae 34 to 44 pc/L) was found in oxygen saturation of only about 3 %. Time course of zooplankton density is shown in Figure 1. It is obvious that higher density occurred in the summer and there was a decline in the cold season.

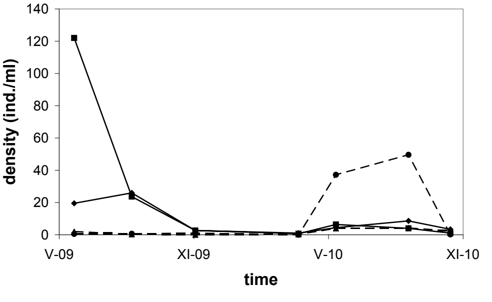


***Figure 1*** *Density of zooplankton in different depth (squares – 0 m, diamonds – 5m, triangles – 10 m, circles – 15 m)*

Number of zooplankton species in the littoral is far poorer than in pelagial. This is partly due to the smaller number of samples from this part of the lake and partly still due to undeveloped littoral area without aquatic plants. The environment for the littoral zooplankton is still formed by submerged terrestrial vegetation. Compared to pelagial some phytophil and benthic species are more numerous here: Bdelloidea g.sp., Lecane sp. div., Eucyclops serrulatus, Macrocyclops albidus, Ceriodaphnia affinis, Chydorus sphaericus. Species originally present in pelagial (that subsequently disappeared), however, occur in the littoral in relatively large quantity: Acanthocyclops trajani and Tropocyclops prasinus. An increased number of littoral species compared to pelagial can be expected after lake filling and littoral stabilization.

From May to September 2010, forty samples of aquatic macro invertebrates were taken – 12 in the littoral zone using a limnological sieve and 28 from the deeper bottom substrate using an Eckman-Birge dredge. By quantitative sampling, 477 organisms were collected representing groups Diptera, Odonata, Ephemeroptera, Heteroptera, Coleoptera, Trichoptera, and Oligochaeta. Detailed information about species diversity in particular sampling localities is listed in Table 2. During qualitative sampling, 14 species were found representing the groups cited above with the exception of Oligochaeta. For additional information see Table 3. The greatest species diversity was recognized in the littoral zone in the middle of the lake (at least 10 species).

***Table 2*** *Results of qualitative sampling (phytophil aquatic invertebrates)*

| Group | West | Middle | East |
|---|---|---|---|
| **Diptera** | Chironomidae | Chironomidae | Chironomidae |
| **Odonata** | *Enallangma cyathigerum* | *Anax imperator* | *Anax imperator* |
| | *Ischnura elegans* | *Ischnura pumilio* | *Lestes viridis* |
| | *Lestes sponsa* | | |
| **Ephemeroptera** | *Cloeon dipterum* | *Cloeon dipterum* | *Cloeon dipterum* |
| | | *Cloeon simile* | *Cloeon simile* |
| **Heteroptera** | *Notonecta lutea* | *Notonecta lutea* | |
| | *Cymatia rogenhoferi* | *Cymatia rogenhoferi* | |
| | | *Ilyocoris cimicoides* | |
| **Coleoptera** | Dytiscidae | Dytiscidae | |
| **Trichoptera** | | Hydropsyche | |

***Table 3*** *Results of quantitative sampling (zoobenthos)*

| Group | West | Middle | East |
|---|---|---|---|
| **Diptera** | Chironomidae | Chironomidae | Chironomidae<br>Dolichopodidae |
| **Odonata** | *Pyrrhosoma nymphula* | *Cordulia aenea*<br>*Enalangma cyathigerum* | *Enalangma cyathigerum*<br>*Anax imperator*<br>*Ischnura elegans* |
| **Ephemeroptera** | *Cloeon dipterum* | | *Cloeon dipterum* |
| **Heteroptera** | Corixidae | | |
| **Coleoptera** | Gyrinidae | | Dytiscidae |
| **Trichoptera** | | Trichoptera | |
| **Oligochaeta** | | | Oligochaeta |

***Table 4*** *Chironomidae /m² in littoral zone*

| Locality | May | June | July | August | September | Aritmethic mean |
|---|---|---|---|---|---|---|
| **West** | 1667 | 800 | 44 | 667 | 1111 | 858 |
| **Middle** | - | - | 44 | 200 | 1578 | 607 |
| **East** | 67 | 822 | 67 | 1067 | 556 | 516 |

The most numerous samples from the quantitative observation came from the west littoral area of the lake containing approximately 858 Chironomus sp. per m$^2$. Numbers of individuals can be found in Table 4. The deepest part of lake (20 m) seems to be very poor in zoobentic assemblages, as only one organism was found there in August. All identified creatures represent common zoobenthic organisms and the majority of them belong to pioneer species.

## Conclusions

During the 3 years of monitoring, the zooplankton species composition of flooded residual mine pit has gradually changed from a random species assemblage typical for waters in areas affected by coal mining to the typical lake zooplankton community. In total, 44 species of zooplankton were found in the lake: Rotifera 25, Copepoda 15 and Cladocera 4.

There was not found any negative influence of the chemical water properties on water zooplankton species composition, although some indicators exceeded the limits for surface water.

Factors that influenced the occurrence of at least some species of zooplankton are a temporary occurrence of acidic water, high salt concentrations and high alkalinity, the initial absence of fish, formation of lake stratification with a decrease in oxygen concentration and temperature of water to the bottom, the oxygen deficit at the bottom and especially under chemocline, low trophy and changing water trophy, massive inoculum of zooplankton from the river Ohře and artificial fish stocking of the lake.

Hydrobiological monitoring provides important information about the aquatic component of the environment. Abundance of diversified zoobenthos assemblages in monitored water reservoirs reflects the satisfactory living conditions in this lake. Fourteen phytophilic aquatic macroinvertebrates and thirteen zoobentic organisms were detected in the locality during the first season of our monitoring period (second year of lake filling). All of the identified creatures represent common zoobentic organism, and the majority of them belong to the pioneer species. Therefore we can assume that Lake Medard is colonized by numerous aquatic invertebrates, supports suitable conditions for sequential succession of aquatic ecosystems and increases the biodiversity and ecological stability of the reclaimed Medard post-mining area.

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## References

Bejček, V., Šťastný, K., *et al.* (2001): Metody studia ekosystémů. Lesnická práce. Praha, 110 pp.

Přikryl I (2010): Kvalita vody jezera Chabařovice na konci napouštění, Tagungsband aus Magdeburger Gewässerschutzseminar in Teplice 4. bis 6. Oktober 2010: 97 - 100

Přikryl I, Špaček J, Koza V (2011): First large mine lake successfully filled up in Czech Republic, IMWA 2011 proceedings

Seda J, Kolarova K, Petrusek A, Machacek J, (2007): Daphnia galeata in the deep hypolimnion: spatial differentiation of a "typical epilimnetic" species, Hydrobiologia 594:47—57

Vrzal D, Přikryl I, Fafílková V, Truszyk A: (2011): Complicated water quality and stratification at post mining-pit lake Medard near by Sokolov city, Czech Republic, IMWA 2011 proceedings