Assessment of anthropogenic salinisation impact on the benthic invertebrates and fish in a small river – a tributary of the Kama Reservoir

M A Baklanov¹, I V Pozdeev¹ ², V S Kotelnikova¹ ², S P Ogorodov² and V V Bezmaternykh²
¹ Perm State University, 15, Bukireva str., 614990, Perm, Russia
² Russian Federal Research Institute of Fisheries and Oceanography, Perm Branch, 3, Chernyshevskogo str., 614002, Perm, Russia
mabakl@yandex.ru

Abstract. The characteristic of changes in communities of benthic invertebrates and fish in a small watercourse as its salinisation is given. It is shown the Shannon diversity index and Balushkina chironomid index play the greatest value in assessing the effect of salinity on river communities. There was a violation of the structure of the fish population of the river, expressed in the complete disappearance of fish in the area of intensive receipt of highly mineralized waters.

1. Introduction

It is a large amount of wastes generated and accumulated into salt and sludge dumps during Verkhnekamskoye potassic-magnesian field management. Salt dumps composed of solid halite wastes that contains over 90–95% of sodium chloride. Excess brines and clay-salt sludge enter the sludge depository. Salts are washed out into surface and ground waters by atmospheric precipitation.

Usually, intensive salt contamination leads to drastic rearrangements in the aquatic communities of watercourses under highly mineralized water inflow. Volim river, the right tributary of the Yayva river, which is left inflow of Kama reservoir, is such watercourse.

The goal of this investigation is to determine the nature of changes in the benthic macroinvertebrates and fish communities in small watercourses under conditions of salt contamination.

The greatest salinisation of Volim River waters occurs at its right tributary Chyornaya confluence. Large sludge depository is located at its watershed. However, the inflow of strongly mineralized groundwater occurs higher, upstream the Sibir village.

Volim river is somewhere strongly modified by zoogenic activity. Beaver dams are built in both not salinised and intensively polluted areas. Beavers managed a dam in the Volim river right down the Chyornaya mouth, which is in the zone of maximum saltwater inflow, for several years.

This work continues a series of publications on the assessment of the various components of the biocenoses of the Yayva River exposed to salinisation or their background parameters [1–4].

Effects of anthropogenic salinisation on the aquatic fauna, especially macroinvertebrate assemblages, were shown on Germany and Czech rivers Werra, Weser and Bilina, which has been
affected by salinisation caused by potash fertilizer industries and heavy industrial pollution [5–9]. Other inland water ecosystems in different regions such as Asia, Australia and North America also suffer from salinisation effects [10–12].

2. Materials and methods

2.1. Stations
Stations in seven Volim river sections and Chyornaya stream were set up to assess the effect of water salinisation degrees. “V–1” station is background of the Volim river with natural water salinity. “V–2” and “V–3” stations are in the Volim river where it has minimal salinisation getting in with surface runoff through intermittent and temporary streams (“Site I”, 32 samples). “C” station is at the mouth of the Chyornaya, the tributary of Volim, having ore sludge storage in its watershed (“Site II”, 10 samples). “V–5”, “V–6” and “V–7” samples in the Volim located at 30, 5 500 and 7 500 m distance, respectively, downstream the mouth of Chyornaya (“Site III”, 34 samples).

2.2. Benthic invertebrates’ collection
The samples of zoobenthos collected in 2008, 2011–2018 are the material for the study. Sampling was carried out usually in September, from July to October in 2013, and from May to September in 2014. Zoobenthos samples were collected using box dredge with a capture area of 0.0025 m² and having 4 portions in each. The samples were washed through a 200–220 μm meshed sieve and fixed with 8 % formalin. Benthic macroinvertebrates were species identified if possible. Immature individuals of amphibirotic insects (mayflies, stoneflies, biting and non-biting midges) were raised to adults in order to clarify the species composition.

2.3. Fish collection
Fish were sampled using electrical backpack fishing machine in shallow watercourses. A set of gillnets 16 to 30 mm meshed and 1 m high was used in the mouth part of Volim river.

2.4. Pollution assessment metrics
Species composition, abundance and biomass of benthic communities, abundance-based Shannon and Simpson diversity indices, Pielou index, Balushkina chironomid index, Goodnight-Whitley oligochaetes index, Trent biotic index, Saprobity index, BMWP’ and ASPT’ were calculated to assess the degree of pollution [13–18].

2.5. Statistical analysis
The calculation of biotic indices, statistical criteria and their analysis was performed in the R version 3.5.2 [19]. Anova and Tukey’s HSD were used to clarify significance of differences.

3. Results
Analysis of physical, chemical and hydrobiological parameters of the Volim and Chyornaya waters allowed to distinguish three large sections. The total mineralization and conductivity are the key parameters in assessing the water salinisation degree. Their values in the Volim river increases from Site I (background) to Site III by an order, and in Chyornaya stream (Site II compared to background) by two orders in average. It exceeds there the level of “average salinity of sea water”, taken as 35 ‰ (tables 1, 2).

A pairwise comparison showed the total water mineralization differed highly significantly on Sites I–III of watercourses. The conductivity in all Sites of the Volim differs significantly from that in Chyornaya. Sites I and III are not significantly different due to the large conductivity variance: absolute values could differ by three orders. The value of conductivity as a contamination indicator is reduced because of it’s depending on the surface runoff of low-mineralized waters and its spreading over the surface of highly mineralized water masses.
Table 1. The main parameters of the registration of water salinisation and the structural parameters of the benthic communities on Sites I–III of the Volim river and Chyornaya stream (M ± SE) and the results of their comparison by F-test.

| Parameter                        | Site       | ANOVA       |
|----------------------------------|------------|-------------|
|                                  | I          | II          | III         | F (73;2)  | p            |
| Total mineralization (mg l⁻²)    | 0.57±0.07  | 41.99±5.43  | 8.68±0.60   | 135.70    | <<0.001      |
| Conductivity (mS cm⁻²)           | 1215±134   | 110811±68768| 17763±7076  | 6.10      | 0.004        |
| Abundance (ind. m⁻²)             | 1856±383   | 30663±11018 | 12541±3794  | 8.84      | <<0.001      |
| Biomass (g m⁻³)                  | 7.73±1.94  | 44.15±15.21 | 15.34±4.62  | 7.63      | 0.001        |
| Shannon index                    | 1.21±0.12  | 0.31±0.08   | 0.53±0.09   | 16.17     | <<0.001      |
| Simpson index                    | 0.69±0.04  | 0.18±0.05   | 0.29±0.04   | 31.80     | <<0.001      |
| Balushkina index                 | 1.19±0.49  | 6.50±0.00   | 3.56±0.87   | 11.72     | <<0.001      |

There are 30 families are registered in the benthic communities of the Volim and Chyornaya, 90 species and 10 taxa, defined to the genus or family. The greatest species richness was provided by chironomid family, which is presented with 52 taxa. There are 8 species of oligochaetes, 5 species of each bivalve mollusks and caddisflies, 3 species of each leeches, mayflies and short-palped crane flies were also noted. Other groups of benthic invertebrates are gastropods, spiders, crustaceans, stoneflies, bugs, beetles, aquatic snipe flies, biting midges, long-legged flies, dance flies, shore flies, fanniidae, hairy-eyed crane-flies, moth flies, black flies, horse flies, craneflies were presented with 1 to 2 taxa.

None of the taxa was found at all stations. The most widely presented species are hairy-eyed crane-flies Dicranota bimaculata (Schummel), non-biting midges – Prodiamesa olivacea (Meigen) and horse flies Chrysops flavipes Meigen. Most of taxa (65) are registered at only station, and the maximum number of unique taxa is found at the background station “B–I”.

Abundance and biomass of zoobenthos increase from the Volim river background section (Site I) to the site below the Chyornaya stream mouth (Site II). Their maximums are noted in conditions of the highest water salinity (Site II). Quantitative values of benthic invertebrates’ communities in Sites I and III not differ significantly (under 95% threshold) (Table 2). Thus, it is not clear to assess pollution degree of small watercourse using zoobenthos quantitative values only. That is because, high abundances and biomasses can be provided with semi-aquatic forms such as few large larvae of Tipulidae and Tabanidae or numerous but tiny Ceratopogonidae.

Table 2. The p-levels of Tukey HSD test in pairwise comparison of the main parameters recording of water salinisation and structural parameters of benthic communities in selected stations of the Volim river and Chyornaya stream.

| Parameter                        | Sites comparison       |
|----------------------------------|------------------------|
|                                  | I – II                 | I – III                | II – III               |
| Total mineralization (mg l⁻²)    | <<0.0001               | 0.0002                 | <<0.0001               |
| Conductivity (mS cm⁻²)           | 0.0031                 | 0.7599                 | 0.0142                 |
| Abundance (ind. m⁻²)             | 0.0002                 | 0.0702                 | 0.0293                 |
| Biomass (g m⁻³)                  | 0.0006                 | 0.4577                 | 0.0075                 |
| Shannon index                    | <<0.0001               | <<0.0001               | 0.5106                 |
| Simpson index                    | <<0.0001               | <<0.0001               | 0.3863                 |
| Balushkina index                 | <<0.0001               | 0.0235                 | 0.0461                 |

74 taxa were registered on the Site I. Oligochaetes Limnodrilus hoffmeisteri Claparedes, Tubifex tubifex (Muller), chironomids Prodiamesa olivacea, Pseudodiamesa nivosa (Goetghhebuer), hairy-eyed crane-flies Dicranota bimaculata and long-legged flies Tipula lateralis Meigen had most value in
benthic communities. Stoneflies *Nemoura cinerea* (Retzius) and *Isoperla difformis* (Klapalek) were only registered in benthic fauna in this section.

The benthoфаuna of Chyornaya (Site II) contains only 6 taxa, and 2 of them are unique for this section. Biting midge *Culicoides riethi* Kieffer with chironomids *Chironomus melanotus* Keyl and *Chironomus salinarius* Kieffer form the basis of benthic communities here. These species are euryhaline and reach maximum abundance at increased salinity conditions. Another group of taxa inhabiting this watercourse such as coastal flies *Setacera aurata* (Stenhammer), famniid *Fannia canicularis* (Linnaeus) and moth flies (not identified) are synanthropic forms able to develop in degrading organics.

46 taxa compose benthoфаuna of Site III in Volim river downstream the Chyornaya stream mouth. Oligochaetes *Lumbricillus lineatus* (Muller), biting midges *Culicoides riethi* and the chironomid *Chironomus salinarius* are dominant species here. That is, euryhaline and halophilic species are massively developing at this section. Some species of benthic invertebrates with a high indication significance in the traditional assessment of anthropogenic impact (black flies, aquatic snipe flies) are rare on the section. However, oligochaete *Nais elinguis* Muller which is also important indicator species enters dominant complex here.

Shannon and Simpson species diversity indices decrease from the Sites I to II and are minimal on Site III. However, Sites II and III do not differ significantly. The best results of water quality assessment were shown by Balushkina chironomid index. It is the only parameter showed significant differences between all three sites (Tables 1, 2).

Ichthyological studies have shown fish composition violation caused by watercourse salinisation. The common minnow *Phoxinus phoxinus* (Linnaeus) inhabits the headwaters of Volim river. Common minnow disappears after substantial salinisation of the Volim by Chyornaya. There are also no fish typical for this type of watercourses on Site III despite of water masses significant increase. Few transits of eurybiont fish species from Yayva River were registered on the lower site of the Volim near and above its mouth. Abundant food could be the reason of that. These are common riverine species pike *Esox lucius* Linnaeus, perch *Perca fluviatilis* Linnaeus, roach *Rutilus rutilus* (Linnaeus), ide *Leuciscus idus* (Linnaeus).

4. Conclusion
Generally, the species richness and diversity of Volim benthoфаuna are relatively large. Taxonomic composition of Volim and especially wide presence of dipteran larvae are typical for streams and small watercourses. The benthoфаuna of the Volim and Chyornaya in the zone of strong anthropogenic salinisation includes halobionts and euryhaline species. These species become dominant and determine the course of the dynamics of the abundance and biomass of benthic communities.

Statistical analysis of water physical, chemical and hydrobiological traits indicates that certain parameters for assessing anthropogenic salt-load do not give an unambiguous result. The Shannon diversity index, the Balushkina chironomid index, and the position of halophilic and euryhaline species in the dominant structure of the benthic invertebrates’ communities are the most important in salinisation impact assessing.

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