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RESEARCH ARTICLE

Role of bottom sediments in ecological assessment of oil-polluted waterbodies

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Bottom sediments are one of the most objective indicators of the ecological state of water body as a whole. Of particular importance is the assessment of bottom sediments quality in the regions subject to intensive anthropogenic load. In the Middle Ob basin, an intensive long-lasting oil production resulting in oil-pollution of bottom sediments takes place. One of the major water bodies used for oil production is Lake Samotlor. In September 2007, the macroinvertebrates were sampled from the Samotlor sediments, which differed in granulometric composition. It is shown that benthos communities of different sediments (sand, silt, mixed sediments) differed significantly in taxonomic composition, abundance and structure of dominant macroinvertebrates. To choose a method for assessing the ecological state of the water body, the correlation of biotic indices with oil concentration in the bottom sediments was determined. It is noted that the Goodnight-Whitley index significantly correlated with oil concentration in all types of bottom sediments except for sands. Indices of diversity correlated with oil only on mixed sediments, the Woodiwiss biotic index - only on sands and silts with detritus. The level of pollution of bottom sediments corresponded to the 3rd class, i.e. "moderately polluted". The decrease in environmental quality (class 4-5) was observed only in the western part of the lake, as well as in some parts of the central sectors. Recommendations on the choice of indices for environmental monitoring of water bodies in the region are given.

Keywords: oil pollution; macroinvertebrates; middle Ob; bottom sediments

Introduction

Bottom sediments reflect long-term processes of accumulation and transformation of substances in a water body and, therefore, they are one of the most objective and reliable indicators of ecological state of a water body and the total anthropogenic load (Brekhovskikh, 2006; Schweizeret al., 2018). Along with hydrochemical analysis in evaluating the quality of bottom sediments, the analysis of hydrobiological indices is of particular importance since they total up all biologically significant loads and reflect the state of water body as a whole. In bioindication of the ecological state of bottom sediments, macroinvertebrate communities are most widely used, since benthic invertebrates are commonly found, confined to a certain biotope, show high abundance, relatively large size and long enough life to accumulate pollutants for extended period of time (Bakanov, 2000).

However, the response of communities to environmental changes is different; the biological effect of external influence depends not only on impact, but also on the structural-functional and spatio-temporal characteristics of biotic systems (Protasov, 2002). It is widely acknowledged that one of the main factors of spatial distribution of benthic invertebrates is the nature of bottom sediments, primarily, its granulometric composition (Litvinov et al., 2004; Vinogradov et al., 2002).

One of the most common factors of bottom sediments pollution in water bodies is the occurrence of oil. This is due to the widespread use of oil by various industries and transport. Oil-producing areas are at the greatest risk of oil pollution. Nevertheless, studies of petroleum impacts on freshwater invertebrates are limited (Vinson et al., 2008). Samotlor oil and gas field is one of the largest in Russia. It was discovered in 1965. A significant period of field operation (more than 50 years) results in the wear of pipelines, which is the main reason for high accident rate, accompanied by oil spills. Every year, about 750 accidents are recorded at the Samotlor field (Timofeev, Klepikov, 2015). It is known that heavy fractions of oil, entering the water body, are deposited, causing the restructuring of benthos communities. To identify the role of the type of bottom sediments in the choice of a method for assessing the environmental quality, we analyzed the data on the composition and structure of macroinvertebrate communities from the Samotlor sediments, which differed in granulometric composition and the level of oil pollution.

Methods

Lake Samotlor is located in the eastern part of Khanty and Mansi Autonomous District, near the city of Nizhnevartovsk. The water area is divided by dams into 13 different-sized sectors, each of which has technological facilities for oil production ("bushes"). The dams are covered by roads and pipelines. Such technogenic transformations, the lake area decreased by almost 1.5 times (from 63 to 46 km^2), and the depth – by half (Tolkacheva, 2004). The modern length of the lake is about 11 km, width - up to 7 km, depth - up to 1.5 m, water-surface area - 46.07 km^2.

The zoobenthos of Lake Samotlor was studied during September 8-21, 2007. In each sector, we took from 2 to 14 samples of zoobenthos depending on its size. Bottom sediments were taken with a GR-91 bar dredge with a mouth area of 0.007 m^2 (two replications in each site). The samples were washed through a nylon gauze (350 x 350 μm mesh size). The invertebrates then were collected and preserved in 70% ethanol. When the invertebrates reached the constant weight, they were divided into systematic groups, counted and weighed on a torsion balance BT-500. A total of 72 quantitative samples of zoobenthos were collected, of which 20 were taken from silt, 23 – from sand, 17 – from mixed sediments (silt with sand, peat with clay, silt with peat, silt with clay), 10 – from silt with detritus, 1 – from clay, and 1 – from peat.

Simultaneously with the benthic invertebrates sampling, the samples of bottom sediments were taken to determine the oil concentration. The analysis of oil content in bottom sediments was performed by STS "Priborservice".

To assess the ecological state, the following indices were determined: the Goodnight-Whitley oligochaetal index (Ko); the Woodiwiss biotic index (W); the Balushkina chironomidae index (Kch) (Guidelines..., 1992), as well as other indices of species diversity (Pesenko, 1982; Shitikov et al., 2003): the Shannon index (H), the Margalef index (d), polydominance index (Sλ), the Sheldon index (SH), the Pielu evenness index (H'); the probability of interspecific encounters (PIE).

The Pearson correlation coefficient was used to quantify the relationship between the structural parameters of zoobenthos and the oil concentration in the bottom sediments. To calculate the correlation coefficient, the normalized data were used. Statistical data processing was performed with Statistica 6.0.

Results and discussion

Structure of benthos communities of Lake Samotlor. A total of 118 species of invertebrates from 17 taxonomic groups were found in the lake, of which 16 species were observed only in macrophyte thickets. The lake zoobenthos was dominated mainly by mollusks and chironomids. In some parts of the lake, oligochaetes were among the dominant species in abundance and biomass. The productivity of the bottom zoocenoses in most parts of the lake is estimated by biomass (Kitaev, 1986) as "average" that corresponds to the beta-mesotrophic type of water body. "Low" productivity (beta-oligotrophic type) was observed only in the western and northern parts of the lake. The zoobenthos is also characterized by high Shannon index (except for the western parts).

A total of 41 species of zoobenthos were found in the lake silt (on average 8.7±0.7 species in each sample) (fig. 1). The highest occurrence was observed in chironomids Procladius choreus (60% of samples) and nematodes (75% of samples). The species diversity of zoobenthos in silt was relatively low (Shannon index 2.2±0.1), which is associated with a relatively small number of species in each sample. The number and biomass of zoobenthos in silt in different parts of the lake changed slightly (3.3±0.5 thousand specimens/m^2, 5.9±1.6 g/m^2, respectively). Oligochaetes and nematodes prevailed in number, and larvae of chironomids of the genus Chironomus and oligochaetes were dominant in biomass. Silts of the central part of the lake were the most productive. The lowest number and biomass were observed in the south-western part of the lake.

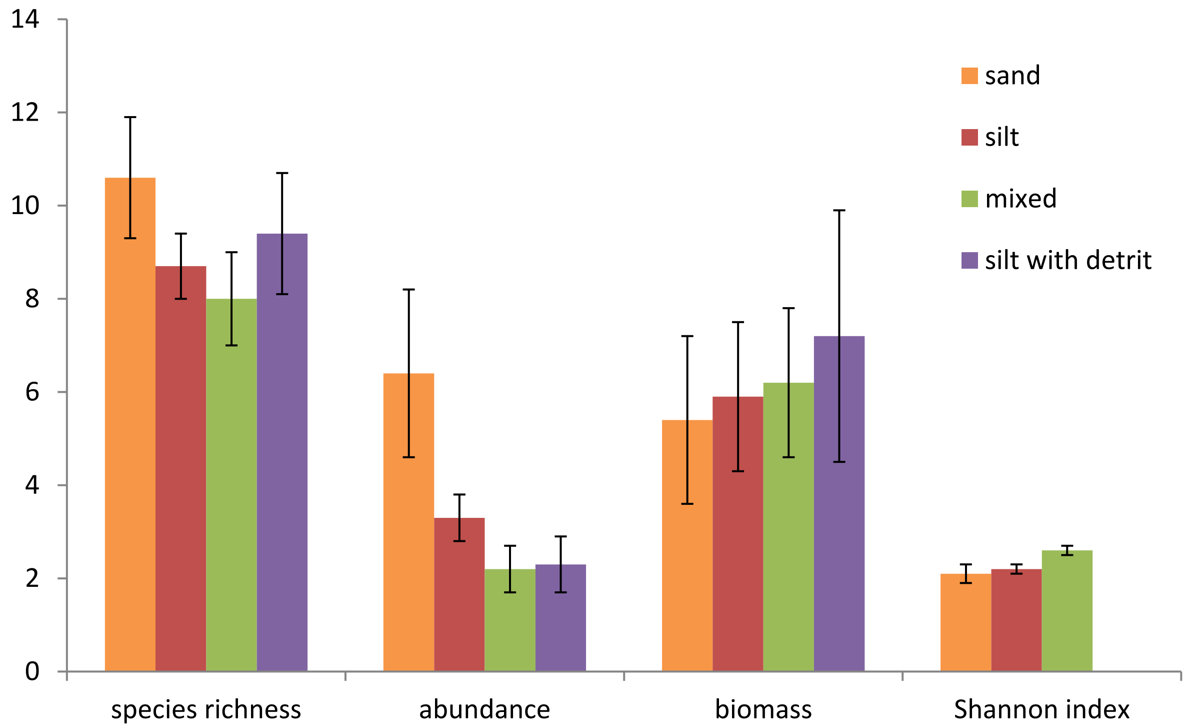

Figure 1. Species richness, abundance, biomass and Shannon index in different sediments of Lake Samotlor.

The maximum species richness was observed in sand sediments of the lake: 67 species of zoobenthos were found during the study period (on average 10.6±1.3 species in each sample). The highest occurrence was observed in psammophilic hydrobionts Cryptochironomus gr.defectus (65 % of samples), Psectrocladius fabricus (57%) and Polypedilum bicrenatum (57 %). Despite the relatively large number of species in each sample, the species diversity was small (Shannon index 2.1 ±0.2) due to a pronounced dominance of particular species. The number of zoobenthos in sand sediments varied significantly in different parts of the lake and was much higher than in the silt (6.4±1.8 thousand specimens/m^2). The biomass of benthic invertebrates from sand sediments (5.4±1.8 g/m2) corresponded to the same index of silt. Chironomids Cladotanytarsus gr. mancus and nematodes prevailed in number, and biomass was dominated by chironomid larvae from different taxonomic groups, and leeches. The sand sediments of artificial embanks in the central part of the lake were the most productive, the lowest number and biomass were observed in the south-western part of the lake.

The taxonomic composition of zoobenthos in mixed sediments of the lake was much poorer: 51 species of invertebrates (on average 8.0±1.0 species in each sample) were found. However, the Shannon index (2.6±0.1) for this type of sediments was significantly higher than in other biotopes that was primarily due to a high evenness of the number of particular species. The most common were Microtendipes gr. pedellus (59% of samples) and Euglesa sp. (53% of samples). The number zoobenthos in mixed sediments (2.2±0.5 thousand specimens/m^2) was lower as compared with other types of bottom sediments; the biomass was slightly higher than that in sand and silt (6.2±1.6 g/m^2). Chironomids dominated in number, and chironomids and mollusks were dominant in biomass.

The taxonomic richness of zoobenthos in silt with detritus (47 species, on average 9.4±1.3 species in the sample) was low and slightly exceeded the one in silt. The highest occurrence was observed in Euglesa sp. (70% of samples) and Microtendipes gr. pedellus (70%). The number of zoobenthos in silt with detritus (2.3±0.6 thousand specimens/m^2) was relatively small and corresponded to the same index of mixed sediments. Chironomids prevailed in number. The silt with a high content of detritus showed the maximum biomass (7.2±2.7 g/m^2) that is most likely due to the high content of nutrients in this biotope. Chironomids and mollusks were dominant in biomass.

Thus, the studied biotopes differed significantly in taxonomic composition of bottom zoocenoses, abundance and structure of dominant macroinvertebrates. Unusually high abundance and biomass were observed in sand sediments. This may be associated with the stimulating effect of low oil concentration on the invertebrates.

Evaluation of the ecological status. To assess the possibility of using zoobenthos structure in the indication of oil pollution, as well as the choice of indices that can be used for environmental biomonitoring, the correlation between the biotic indices and oil concentration in bottom sediments was determined. Because of the great influence of sediment type on the distribution of benthic invertebrates, the correlation analysis used both the pooled data and the data on a particular type of sediment (silt, sand, silt with detritus and mixed sediments).

The calculation of the considered biotic indices is based on the taxonomic composition, structure and density of benthos communities. All the indices largely depend on the type of biotope. For instance, oligochaetes, the number of which is used to calculate the Goodnight-Whitley index, are less common in the sand; stoneflies, caddisflies and mayflies, the number of species of which forms the basis for calculating the Woodiwiss index, avoid the silt sediments.

The concentration of oil in the sand negatively correlated only with the Woodiwiss index (table 1). Silt sediments showed a positive statistically significant moderate correlation between oil concentration and the Goodnight-Whitley oligochaetal index. Oil concentration in the silt with detritus showed strong positive correlation with the Goodnight-Whitley index; negative moderate correlation was noted between the Pielu index and the Woodiwiss index, as well as the zoobenthos biomass. The mixed sediments revealed a good correlation of oil with almost all indices of diversity, as well as with the abundance, biomass, number of zoobenthos species, and the Goodnight-Whitley index. The best correlation was observed with the Shannon and Goodnight-Whitley indices. The analysis of all the data indicated only a weak negative correlation between the oil concentration and the Woodiwiss index and the number of species. Besides, a moderate positive correlation with the Goodnight-Whitley index was found. It is evidence that consideration of the sediment type is necessary in the choice of bioindication method. It should be noted that the abundance and biomass of zoobenthos strongly correlated with oil concentration in the bottom sediments. However, this correlation was positive in the silt, and negative in other types of sediments. Most likely, the correlation depended on the tolerance of invertebrate species dominant in abundance and biomass. For example, silt sediments were dominated by oligochaetes, the abundance of which increased with increasing oil concentration that was confirmed by a positive correlation of oligochaetal index with oil concentration.

Thus, the Goodnight-Whitley index can be used to estimate oil pollution of all types of bottom sediments except for sand. The diversity indices can only be applied to evaluate the contamination of mixed sediments (the strongest correlation was noted with the Shannon index). The Woodiwiss index should be used carefully and only for sands and silt with detritus. Despite the strong correlation between the abundance and biomass of zoobenthos and the concentration of oil, these indices cannot be used for evaluation of bottom sediments contamination since they are determined by the structure of the dominant complex. The change of the Balushkina chironomidae index was not associated with oil concentration in bottom sediments. The lack of reliable correlation of the Balushkina index with the level of bottom sediments pollution was also noted in other studies (Litvinov, 2004; Vinogradov, 2002).

The assessment of ecological state of Lake Samotlor bottom zoocenoses indicates quite favorable conditions for the habitat of aquatic organisms in most of the lake. The level of pollution of lake bottom sediments corresponds to the 3rd class, i.e. "moderately polluted". The decrease in environmental quality (class 4-5) was observed only in the western part of the lake, as well as in some sites of the central sectors.

Table 1. Coefficients of linear correlation of biotic indices with oil concentration in lake Samotlor bottom sediments

Type of sediment	N	B	d	H’	SH	H	PIE	Sλ	S	Ko	Kch	W
sand	-0.18	-0.15	-0.26	-0.18	-0.23	-0.14	-0.05	-0.19	-0.29	-0.07	0.00	**-0.42**
silt	0.23	0.38	-0.23	0.46	-0.41	-0.36	-0.36	-0.38	-0.16	**0.52**	-0.38	-0.38
silt with detritus	-0.22	**-0.53**	-0.35	**-0.63**	-0.13	-0.21	-0.04	0.09	-0.36	**0.73**	-0.18	**-0.52**
mixed	**-0.56**	**-0.56**	**-0.65**	-0.49	**-0.58**	**-0.68**	**-0.54**	**-0.51**	**-0.64**	**0.68**	-0.14	-0.49
pooled sample	-0.21	-0.08	-0.23	-0.24	-0.16	-0.07	0.02	-0.09	**-0.27**	**0.32**	-0.11	**-0.27**

Note: N is the number of zoobenthos; B is the biomass of zoobenthos; S is the number of species; other conventions in the text; in bold are statistically significant relationships ($p < 0.05$).

Conclusion

Despite the long-term operation of the oil-producing complex, the benthos communities of Lake Samotlor showed a significant species richness, great diversity and high density. The taxonomic composition of the bottom zoocenoses, abundance, biomass and dominant macroinvertebrates varied widely in different types of sediments. Maximum species richness and abundance were observed in sands, biomass – in silts with detritus. The biotic indices and structures of benthos communities strongly correlated with oil concentration in bottom sediments. When choosing methods for assessing the ecological state of the lake, it is necessary to take into account the peculiarities of the species composition and structural characteristics of benthos communities in different types of sediments. It is recommended to include the Goodnight index for all types of sediments (except sands) into environmental monitoring of Lake Samotlor. Besides, the assessment of benthos communities in sand sediments is recommended to perform with diversity indices and the Woodiwiss index. The pollution of lake bottom sediments corresponded to the 3rd class, i.e. "moderately polluted". The decrease in environmental quality (class 4-5) was observed only in the western part of the lake, as well as in some sites of the central sectors.
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