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STRUCTURE AND FUNCTIONING OF AQUATIC ECOSYSTEMS

Criteria of Rehabilitation of Biotic Communities in Oil-Polluted Small Rivers (by Example of the Shava River, Nizhnii Novgorod Oblast)

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Abstract—An assessment of the ecological state of the small Shava River (Kstovskii raion, Nizhnii Novgorod oblast) subjected to oil pollution as a result of a pipeline accident in 2007 is presented. On the basis of physical and chemical characteristics of water quality and the results of a study of hydrobiont communities, the degree of the river pollution has been determined and a conclusion about the rehabilitation of communities as a result of the complex effect of recultivation measures and self-purification processes has been made. Criteria for recultivation activity completion have been defined according to hydrobiological indicators (phytoplankton, zooplankton, and zoobenthos).

Keywords: oil pollution, rehabilitation of communities, criteria of rehabilitation, phytoplankton, zooplankton, zoobenthos, small river

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INTRODUCTION

Eliminating the consequences of oil pollution of water objects is a matter of high economic and ecological importance because of frequent pipeline damages. Oil pollution reduces the species richness of hydrobiont communities, changes the ratio between species, and decreases primary production [1]. The impact of oil products on phytoplankton is ambiguous and depends on the crude oil concentration in water. It is demonstrated experimentally that a concentration of crude oil extracts of 12% had a stimulating effect on most diatom cultures, a concentration of 25% delayed their growth, and a concentration of 50% suppressed the growth of cultures [3]. An oil slick did not kill algae, but it disturbed their normal cell division. Under natural conditions, an intensive development of α-mesosaprobic forms, a sharp decrease in the number of species, and changes in abundance are observed at sites of oil-pollutant discharge [3]. While accumulating oil products in tissues, phytoplankton is subjected to the toxic impact of dispersed oil, loses viability, and can be a source of oil for phytoplankton-eating fish [3]. A toxic effect of diesel fuel on zooplankton is manifested in a decrease in species richness and changes in the ratio between species [4].

Experiments in natural zoocenoses have demonstrated their high sensitivity to even small concentrations of oil products [2]. Oil and oil products cause disturbances of gas and filtration processes in invertebrate hydrobionts and change their respiratory and heart rhythms and behavioral responses [2]. Under the effect of oil and high-molecular oil products, crustaceans adhered to the surface film [2]. Cladocerans and juvenile copepods are the most sensitive to the effect of oil products, and rotifers of the genus *Brachionus* are more resistant to their effect [2]. Mollusks and gammarids are less sensitive to the effect of oil products than cladocerans and copepods [2].

The Shava River is a second-order tributary of the Volga River; it flows through Kstovskii raion, Nizhnii Novgorod oblast. The length of the river is 31 km, the catchment area is 239 km^2, the width is from 1 to 5 m, and the depth (along the channel) is from 0.2 to 1.0 m. The river is a small plain river with mixed, primarily snow, feeding. A wetland at a distance of 18 km from the source of the Shava River is a regional natural monument (Shava Swamp). A pond was built downstream the river and is used as a feeding ground at the Borok fishery. Downstream from the pond, the Shava River enters the Kud'ma River. The water discharge in spring is 0.8–1.0 m^3/sec.

An accidental oil spill (diesel oil) with a total volume of 309.05 m^3 happened in the region of the village of Slobodskoye, Kstovskii raion, Nizhnii Novgorod oblast, in March 2007. Soil; underground waters; water in the Shava River; a feeding pond of the Borok fishery; and, partially, the Kud'ma River were subjected to pollution by oil products.

Urgent measures were undertaken to collect oil products and clean the soil at the site of the accidental

Table 1. Hydrological characteristics of the river part under study (July 28, 2011)

Number of station	Width of channel, m	@Глубина русла, м	Current velocity, m/sec	Water discharge, m^3/sec	Characteristic of banks
1	2.7	0.1	0.20	0.055	Swampy
2	1.2	0.4	0.15	0.063	Left – swampy, right, steep
3	0.6	0.2	1.00	0.060	То же@
4	6.0	0.4	0.04	0.010	Swampy
5	2.6	0.7	0.06	0.110	Steep

spill and waters and bottom sediments in the Shava River. Later, a complex of measures (the construction of barriers, dams, water pumping; use of booms, mats and sorbents; stirring-up of bottom sediments and their binding by sorbents; removal of bottom sediments; excavation and utilization of polluted ground; etc.) was taken to eliminate residual pollution [7].

An assessment of the degree of rehabilitation and the water safety (nontoxicity) of water and bottom sediments in the polluted part for hydrobionts and human health were of the utmost importance.

The aim of the study is to determine criteria for the rehabilitation of hydrobiont communities in small rivers (by the example of the Shava River) which can be used for an assessment of the degree of completion of rehabilitation activities when eliminating accidental spills of oil products in small plain watercourses.

MATERIALS AND METHODS

In the course of studies in the Shava River in 2007 and 2011, physical and chemical analyses of water and bottom sediments were made and the state of phytoplankton, zooplankton, and zoobenthos was studied. An assessment of the state of the river was made on the basis of data of organizations responsible for state (Nizhnii Novgorod Environmental Public Prosecutor's Office) and departmental (Borok fishery) monitoring, nature conservation control (Central Specialized Inspectorate for Analytical Control of the Ministry of Ecology and Natural Resources, Republic of Tatarstan), and archival materials of the Laboratory of Optimization of Aquatic Ecosystems, Kazan State University. Samples of water and hydrobionts were collected in May, August, and October 2007 at 2–5 stations and in May and July at 5 stations: 1000 m upstream from the site of the accidental oil spill (station 1), at the site of the oil spill (station 2), 1550 m downstream from the site of the accident (station 3), 2500 m downstream from the accident (at the outflow from the feeding pond, station 4), and 3000 m downstream from the accident (station 5).

Hydrological characteristics of the river portion under study are presented in Table 1.

The degree of water pollution was assessed according to hydrochemical parameters by a comparison with the maximum allowable concentrations (MACs) developed for fishery ponds. Sampling of hydrobionts and their cameral treatment were made according to common methods [5]. The assessment of water quality according to phytoplankton was made in accordance with the ecologo-sanitary classification of the quality of surface waters [8]; water quality according to zooplankton and zoobenthos was estimated using the Shannon index *H*) [13], Simpson index (*C*) (by abundance), and Woodiviss index (*W*). The Pantle–Buck index of saprobity modified by Sladček (*S*) was used to determine the degree of pollution of waterbodies [14]. The trophic state of the river portions according to phytoplankton was determined using the trophic index of Milius [10].

RESULTS

Physical and chemical parameters. After the accidental pipeline damage (March 15, 2007), the concentration of oil products in the water of the Shava River was 874.2 mg/L, which exceeded MACs 17484 times. Oil products entering the river were collected from the surface, extracted by sorbents; some of them were accumulated in bottom sediments or dispersed by currents. In June 2007 the concentration of oil products in water decreased to 0.09–0.12 mg/L (2.4 MAC). In August the concentration of oil products at stations 1 and 3 were within normal values, being 0.087 mg/L (1.7 MAC) only at the site of inflow into the pond. The concentration of oil products at the site of water outflow from the pond did not exceed the norm (0.044 mg/L). In October 2007 the concentration of oil products in all samples was <0.05 mg/L; i.e., it did not exceed MAC. In 2011 the concentrations did not exceed MAC except for one sample (station 2, 1.5 MAC).

Water in the Shava River is very hard (10.6–29.2 mg equivalent/L of calcium carbonate ($CaCO_3$)) and highly mineralized (from 789 to 1866 mg/L); sulfates and calcium prevailed among macrocomponents. The concentration of oxygen in water of the river was 65–77% in summer and autumn 2007. The concentration of ammonium ions was high in summer 2007 (station 5, 23 MAC); the concentration of nitrites was 8 times higher than the norm. In autumn the concentration of nitrogen-containing compounds was within the norm; only the concentration of phosphates exceeded the MAC (1–3 MAC). Biochemical oxygen demand (BOD_5) was 1.3–2.2 mg O/L in summer and 2.3–8.0 mg O/L in autumn. Oxidability to permanganate increased from 9.5 to 14.3 mg O/L at stations 1–4 in summer and was characterized as medium and high and in autumn it was low at station 2 and very high (43.9 mg O/L) at station 5. The concentrations of hydrogen sulfide and sulfides in the site of oil products spill (station 2) were 54 MAC, and they were within the norm downstream the river. Concentrations of copper, zinc, manganese, and iron in water exceeded MACs.

Studies in 2011 revealed high concentrations of ammonium at station 1 (1.2 Mac) and at station 5 (1.4 MAC). Concentrations of nitrites and nitrates in water were within the normal range; concentrations of phosphates were at the level of MACs in May and in July exceeded 1.8–5.0 MAC. High concentrations of phosphorus and nitrogen compounds and high values of chemical oxygen demand (COD), probably, because of agricultural activities (cattle grazing and the effect of water discharge from ponds of the fishery farm) and high concentrations of permanganate (27 MAC) and iron (5 MAC) were recorded near station 5. The current velocity in this portion of the river is low and promotes water stagnation. In whole, in 2011, water quality improved sufficiently according to chemical parameters compared to 2007.

Bottom sediments in the Shava River consisted of silty sand, sandy silt, and clayey silt (along the channel); in some areas they consisted of viscous silty–peaty grounds. In 2007 an oil slick appeared on the surface in different sites along the river channel after the bottom sediments were stirred up; in 2011 the concentration of oil products was within the normal range and the oil slick did not appear on the surface [7].

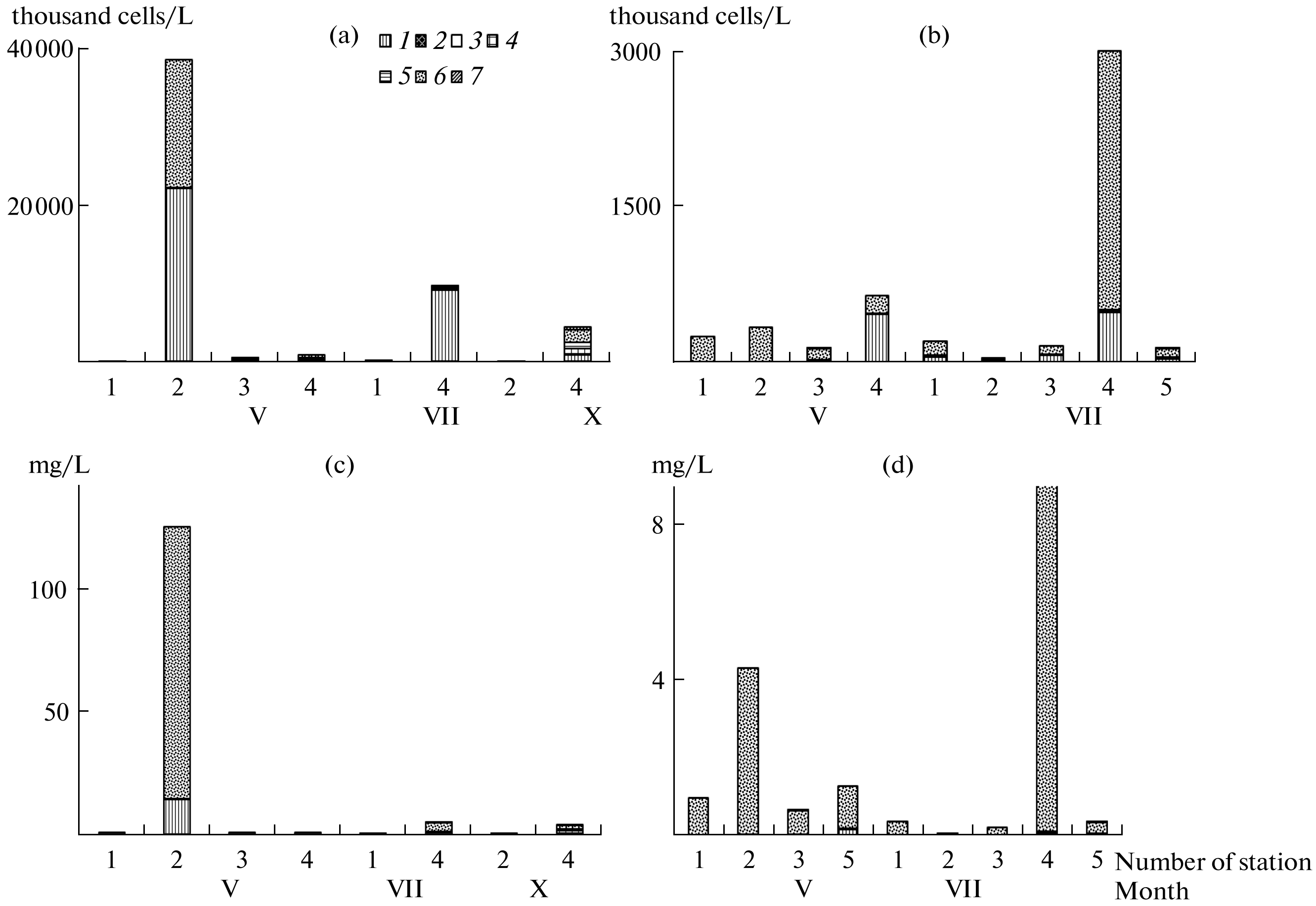
Phytoplankton. A total of 138 taxa ranking lower than genus and belonging to 8 divisions (120 in 2007 and 70 in 2011) were recorded in phytoplankton of the Shava River. As is typical for lotic systems, diatoms prevailed in the species composition of phytoplankton and comprised 79 species, green algae was 22 species, euglenophytes 13 species, golden algae 11 species, blue-green 7 species, dinophytes 3 species, cryptophytes 2 species, and yellow-brown algae 1 species.

In 2007 the largest number of phytoplankton species (34) and the maximal values of abundance and biomass were recorded in May in the site of the accidental spill of oil products (station 2) 38710 thousand cells/L and 125.15 mg/L, respectively (Figs. 1a, 1b). Blue-green algae of the genus *Oscillatoria* formed 57.6% and diatoms with a dominant *Synedra ulna* (Nitzsch.) (22.2% of the total biomass) formed 42.2% of the abundance. Diatoms formed 88.6% of the biomass (*S. ulna* 51%, *Melosira varians* 11.6%, and *Oscillatoria* sp. 11.4%). The trophic index was 93.6; it characterized the state of the river in the site of the accidental spill as hypertrophic with the water quality class "polluted" and the rank "very polluted." At stations downstream from the site of the accident, a gradual decrease in the number of species, abundance, and biomass was observed and the water quality improved at the distance from the oil spill and during the vegetation period. The smallest number of species (18) and minimal values of abundance and biomass of phytoplankton 76.5 thousand cells/L and 0.44 mg/L, respectively (Figs. 1b, 1d), were recorded in the background station in the river. Diatoms with a dominant *Synedra ulna* (40% of the total abundance) and golden algae with a dominant *Chrysococcus rufescens* Klebs (11.8%) formed 85% of the phyto*plankton abundance.* Diatoms with a dominant *Synedra ulna* (75.5% of the total biomass) formed 99.5% of the biomass. Low values of the total biomass determined the trophic state of the river at the background station as oligotrophic (the trophic index 36.6) with water quality class "clean" and the rank "very clean."

Studies of 2011 demonstrated a general tendency toward decreasing values of structural parameters of phytoplankton and the improvement of water quality in the river at the site of the oil spill to background levels (figure). The diatom algae *S. ulna* formed 53% of the abundance in spring, the blue-green algae *Aphanizomenon flos-aquae* (L.) Ralfs comprised 25% of the abundance in summer. Cells of *Synedra ulna* formed 90.5% of biomass in May, diatoms (75.5%), and green algae (20.3%) with dominant *Cocconeis placentula* Ehrb. (26.8%), *Navicula capitata* Rhrb. (19.1%) and *Chlamydomonas* sp. (20.3%) formed biomass in July. The trophic state of the river was meso-oligotrophic at the site of the accident in May, with the water quality class "satisfactory clean" and the rank "weakly polluted," and it was "extremely clean" in June.

The abundance and biomass of algae at the background station were low (235.2–264.5 thousand cells/L and 0.36–0.95 mg/L, respectively). Diatoms *Gomphonema angustatum* (Kütz.) Rabenh. (32–38%), *Synedra ulna* (10.7–46.2%), *Cocconeis placentula* (19.1%), blue-green *Aphanizomenon flos-aquae* (23.8%), and green algae (14.3%) dominated by abundance. The diatom *Synedra ulna* (98%) prevailed as usual in the biomass. The trophic state in the background river portion was oligotrophic-mesotrophic, with the water quality class "clean" and ranks "very clean–quite clean."

As a result of a comparison of the phytoplankton community in the background portion of the Shava River (station 1) and the river portions subjected to the impact of oil pollution (the site of the oil spill, station 2, and the site of oil-pollutant outflow, stations 3–5), the parameters were determined and criteria were developed for monitoring the recovery of the phytoplankton community after the impact of oil pollutants: (1) the species composition of phytoplankton during the vegetation season in the site subjected to



Structure and dynamics of abundance (a, b) and biomass (c, d) of phytoplankton in the Shava River in 2007 (a, c) and 2011 (b, d): (*1*) blue-green algae, (*2*) cryptophytes, (*3*) dinophytes, (*4*) euglenic algae, (*5*) golden algae, (*6*) diatoms, and (*7*) green algae.

rehabilitation from oil pollution should include ≥4 divisions with the presence of representatives of diatoms of ≥50%, green algae to 23%, and euglenophytes to 7% of the total abundance in the sample; the portion of other divisions of algae (blue–green, golden, dinophyte, and cryptophyte) can vary from 2 to 13%); (2) quantitative parameters of phytoplankton during the vegetation period in this river part can vary from 70 to 265 thousand cells/L, and the portion of diatoms should be ≥50% and blue-greens ≤25% in the total abundance; values of the biomass of phytoplankton can vary in the range from 0.1 to 1.0 mg/L during the period of open water and the portion of diatoms in the total biomass should be >90%, regardless of the season; and (3) the trophic state and water quality determined according to the biomass of phytoplankton, i.e., the trophic state of the river portion under rehabilitation, should tend to the oligo-mesotrophic level with the class of "clean" water. When the above-stated criteria will be satisfactory, the rehabilitation of the river portion subjected to oil pollution should be regarded as completed according to the parameters of the phytoplankton community.

In 2007 a partial recovery of the phytoplankton structure in polluted parts was observed in the Shava River as a result of rehabilitation activities and processes of natural self-purification. Such a tendency was confirmed by the studies conducted in 2011.

Zooplankton. In May 2007, 9 species were recorded in the zooplankton of the Shava River, including 6 species of rotifers, 1 species of cladocerans, and 2 species of copepods. Rotifers of the genus *Notholca* dominated. Solitary invertebrates were recorded in the water column at the background station in the site of the pipeline damage and downstream the river. The abundance of zooplankton at stations varied from 1.2 up to 112.3 thousand ind/m^3 and biomass varied from 0.001 up to 0.13 g/m^3. Values of the saprobity index were not significant; the structure of the community was considered disturbed according to low values of the Shannon index of diversity and the Simpson index of dominance (Table 2). The species richness and quantitative parameters of zooplankton increased in summer 2007 because of seasonal changes in the community composition and the reduction of oil-product concentrations in water (Table 3). A total of 14 species

Table 2. Dynamics of abundance (N, thousand ind/m^3), biomass (B, g/m^3), indexes of saprobity, Shannon and Simpson indexes of zooplankton in the Shava River in spring 2007 (above the line) and 2011 (under the line)

Group, index	1		2		3		4		5	
	N	B	N	B	N	B	N	B	N	B
Rotifera	4.76/0.04	0.004/0	6.83/0.16	0.006/0.0001	83.81/1.02	0.058/0.0004	0.40/0	0.001/0	0.60/0.06	0.001/0
Cladocera	0/0	0/0	0/0	0/0	0/0.02	0/0.0001	0/0	0/0	0.10/0	0.001/0
Copepoda	2.04/0.06	0.014/0	3.41/0.38	0.009/0.0003	28.44/0.51	0.226/0.0011	1.40/0.36	0.003/0.0002	0.50/0.20	0.008/0.0002
Всего	6.80/0.10	0.018/0.0001	10.24/0.55	0.016/0.0003	112.25/1.55	0.283/1.55	1.80/0.36	0.003/0.0002	1.20/0.26	0.009/0.0002
S	x		–/1.42		1.31/1.43		x		1.31/1.78	
H	x		–/1.58		0.15/1.04		x		2.14/	
C	x		–/0.66		0.03/0.32		x		0.78/0.44	

Here and in Tables 2–4: 1–5 are numbers of stations; "x" means values of an index cannot be calculated because of the presence of one to two species of zooplankton in a sample.

of invertebrates were recorded, 6–8 species at each station. *Euchlanis dilatata* Ehrenberg or *Mesocyclops leuckartii* (Claus) dominated by abundance; *Eudiaptomus graciloides* (Lilljeborg), *Euchlanis dilatata*, and *Mesocyclops leuckarti* dominated by biomass at different stations. Values of abundance and biomass were low. In October 2007, 16 species were recorded in zooplankton. The dominant complex by abundance was formed by *Bosmina longirostris* Leydig, *Peracantha* truncate (O.F. Müller), *Eucyclops macrurus* (Lilljeborg), *Mesocyclops leuckarti*, or *Keratella quadrata* (Müller). *Pleuroxus aduncus* (Jurine) or *Trichotria truncate* (Whitelegge) dominated by biomass. The abundance varied from 3.69 to 4.52 thousand ind/m^3; biomass varied from 2.78 to 3.22 g/m^3 (copepodite stages of Cyclops formed relatively high biomass). During the seasons under study, the portion of the Shiva River downstream from the site of the spill of oil products was the most disturbed judging by the values of biotic indexes, testifying to a possible secondary pollution of the river by oil products.

Twenty-two species were recorded in zooplankton in 2011. In spring, rotifers of the genus *Notholca* and *Keratella quadrata* dominated; in summer 2011 *Chydorus* sphaericus (O.F. Müller) (station 1), *Euchlanis dilatata* (station 2), *Keratella quadrata*, and *Trichocerca longiseta* (Schrank) and *Ceriodaphnia reticulate* (Jurine) (station 4) prevailed. In spring 2011 the abundance of zooplankton was low and varied from 0.1 thousand ind/m^3 (station 1) up to 0.54 thousand ind/m^3 (station 2); the biomass varied from 6×10^{-5} g/m^3 (station 1) to 0.0016 g/m^3 (station 3). Copepoda prevailed among zooplankton groups. In summer the species richness and quantitative parameters of zooplankton increased slightly compared to spring. In summer 2011 the abundance of zooplankton varied from 0.04 thousand ind/m^3 (station 1) up to 144.6 thousand ind/m^3 (station 4); the biomass varied from 8×10^{-5} (station 1) to 3.8 g/m^3 (station 4). In August 2007, as compared to 2011, the abundance of zooplankton varied from 2.09 to16.86 thousand ind/m^3. The biomass was low and constituted 0.03–0.05 g/m^3 at all stations. In summer 2011 the river belonged to the category of "moderately polluted" according to the index of saprobity (class III of water quality); values of the Shannon index were similar to their values in 2007.

Thus, zooplankton in the Shava River in 2007 and 2011 was characterized by low species richness and quantitative parameters that can be not only the result of oil pollution, but also determined either by natural features of the river (it flows through a swamp) or by anthropogenic impact in the upper reaches of the river (cattle pasturing along the banks). After the input of oil products in the river, zooplankton was characterized by minimal values of quantitative parameters and a disturbed structure. In 2007 the river part downstream from the oil spill was the most polluted in terms of the biotic indexes; in 2011 such a tendency was not found.

Table 3. Dynamics of abundance (N, thousand ind/m^3) and biomass (B, g/m^3) of zooplankton in the Shava River in summer and autumn 2007 (above the line) and 2011 (under the line)

Group, index	Summer										Autumn			
	1		2		3		4		5		2		3	
	N	B	N	B	N	B	N	B	N	B	N	B	N	B
Rotifera	1.14/0	0.001/0	9.53/0.13	0.010/0	–/0.04	–/0.0001	1.42/5.94	0.010/0.0013	–/0.12	–/0	0/–	0.001/–	1.75/–	0.010/–
Cladocera	0.18/0.04	0.001/0.0001	0.36/0.02	0.001/0.0002	–/0	–/0	0.24/51.48	0.001/2.2426	–/0.04	–/0.0004	0.40/–	0.020/–	0/–	0.001/–
Copepoda	0.76/0	0.040/0	6.96/0	0.010/0	–/0.02	–/0	4.57/87.14	0.020/1.5668	–/0.04	–/0.0009	0.38/–	0.010/–	1.25/–	0.020/–
Total	2.09/0.04	0.050/0.0001	16.86/0.15	0.030/0.0002	–/0.06	–/0.0001	6.22/144.56	0.030/3.8107	–/0.20	–/0.0014	0.78/–	0.020/–	3.00/–	0.020/–
S	1.58/–		1.44/1.59		–/1.37		1.61/1.56		–/1.59		1.37/–		1.63/–	
H	1.48/–		0.83/0.58		–/1.00		2.4/2.32		–/1.45		2.65/–		1.71/–	
C	0.50/–		0.29/0.24		–/0.50		0.79/0.67		–/0.52		0.82/–		0.53/–	

Table 4. Quantitative parameters of zoobenthos in the Shava River in 2007 and 2011 and values of Simpson, Shannon, and Woodiwiss indexes

Parameter	2007											2011								
	Spring					Summer			Autumn			Spring				Summer				
	1	2	3	4	5	1	2	4	1	2	3	1	3	4	5	1	2	3	4	5
N, @ экз./м^2	500	325	350	428	450	63	276	664	139	102	38	214	202	301	153	389	74	67	58	125
B, g/m^2	14.80	0.27	5.53	21.40	1.28	1.16	0.78	27.90	0.79	1.21	1.13	2.83	4.38	2.07	11.72	2.48	0.20	0.33	2.13	0.46
Number of species	7	5	5	11	5	2	3	6	6	6	1	5	5	4	7	6	3	5	5	4
C	0.81	0.70	0.67	0.72	0.38	0.47	0.32	0.22	0.77	0.81	0	0.76	0.50	0.49	0.77	0.64	0.36	0.78	0.77	0.43
H	2.81	2.32	2.32	3.46	2.32	0.96	0.96	0.76	2.38	2.51	0	2.19	1.51	1.28	2.46	1.89	0.96	2.24	2.22	1.22
W	6	2	5	5	2	5	3	1	4	4	0	5	2	4	7	5	2	3	3	4

When developing criteria for zooplankton rehabilitation, we compared structural indexes of the community in the background station and in the stations subjected to the impact of oil pollution and following the dispersion of oil products. Based on this comparison, the rehabilitation of the community in the Shava River can be judged by the following criteria: (1) the species composition of zooplankton contains >1 species; (2) without pollution the abundance of zooplankton is not <0.1 thousand ind/m^3 in spring and 0.04 thousand ind/m^3 in summer and the biomass should be 6.5×10^{-5} g/m^3 in spring and 7.8×10^{-5} g/m^3 in summer; (3) the index of saprobity is not <1.6 (β-mesosaprobic zone, "moderately polluted" water, class III of water quality) and the Shannon index should be >1bit/ind and Simpson index <0.5. Based on these criteria, a conclusion can be made about the completion of the process of zooplankton rehabilitation to the background level by 2011.

Zoobenthos. In 2007 and 2011, a total of 40 species of zoobenthos were detected in the Shava River, among which there were 2 bivalved mollusks, 8 gasteropods, 7 oligochaetes, 2 leeches, 2 mayflies, 2 caddis flies, 1 crustacean, 4 water beetles, 4 aquatic bug, 6 chironomids, 3 dragonflies, 1 horsefly, and 1 biting midge.

The community of zoobenthos responded to the input of oil products by the decrease in species richness, disappearance of larvae of mayflies and crustaceans, and the increase in the abundance of oligochaetes. A smaller number of species was detected in zoobenthos in 2011 than in 2007, but larvae of caddis flies appeared in zoobenthos in 2011. Quantitative parameters of zoobenthos also decreased as the result of water pollution by oil products in 2007 (Table 4). Oligochaetes, gasteropods, and crustaceans dominated downstream from the site of the oil spill; dominance of any groups in the background station was not observed. In 2011 oligochaetes dominated only at the site of the accident (station 2) and a small number (8 ind/m^2) was recorded downstream from the spill site (station 3).

The values of the Shannon index were 2.6–2.8 bit/ind. and the values of the Simpson index were 0.6–0.8 in the background portions of the Shava River. Values of the index of the species diversity decreased in the site of the accidental spill of oil products and downstream from the site. After rehabilitation activities in 2007–2009, the species diversity increased and values of indexes approached the values recorded in the background station (Table 4). The Woodiwiss index characterized water in the background station in 2007 as 'clean"; it decreased in the site of the accidental pollution; and the water quality increased downstream to 7 balls, which characterized water as "clean." In terms of the Shannon and Simpson indexes, waters in most stations were classified as "moderately polluted." Based on the results of the studies of zoobenthos for an assessment of the degree of the community recover, the following criteria were developed for the autumn period on average along the river channel: (1) the species composition should contain ≥7 groups with the obligatory presence of mayflies and water beetles; (2) the ratio of the groups of zoobenthos should be as follows: the portion of oligochaetes in the community should be ≤7% of the total abundance and ≤3% of the total biomass; and (3) biotic indexes should correspond to the category "weakly polluted" or higher.

Parameters of zoobenthos in 2011 testified to the rehabilitation of communities at stations 3–5. At the site of the accident (station 2), the structural indexes of communities of bottom macroinvertebrates indicated the secondary pollution of bottom sediments by oil products.

DISCUSSION

Data on the impact of oil pollution on plankton hydrobionts were mainly obtained experimentally; information about accidental oil spills concerns to a larger extent marine ecosystems. Our studies confirmed the stimulating effect of the oil impact on the development of river phytoplankton [3]. The maximal number of species, abundance, and biomass of plankton algae were registered in the site of the accidental oil spill in the Shava River; their decrease to the background values was observed 4 years after the accident.

Similar studies of zooplankton were conducted in the Kolva River (Komi Republic), where the accidental spill of oil products reduced the species richness, abundance, and biomass of communities and their recovery happened 3 years after the accident [12]. Similar trends were observed in the Shava River. Cladocerans and juvenile copepods were the most sensitive groups to pollution [2, 9], which is confirmed by our studies. The abundance of cladocerans in the Shava River was extremely low, and they disappeared completely after the accidental inflow of oil products.

The tendency of species diversity and the total biomass of macrozoobenthos to decrease at the site of input of oil products and downstream from the site was noted by many researchers [6, 9, 11, etc.]. A significant decrease in the values of the Shannon index and an increase in the fraction of chironomids and, more rarely, oligochaetes were recorded in polluted rivers of Udmurtia [11]. Our data testify to an increase in the portion of oligochaetes in the total abundance and biomass of macrozoobenthos. This can be probably explained by the fact that the species of chironomids (*Prodiamesa olivacea* (Meigen) tolerant to pollution and recorded in rivers of Udmurtia was not found in the Shava river. Larvae of caddis flies and bivalved mollusks were the most sensitive to pollution [11]. Oil pollution of the Shava River caused the mortality of larvae of mayflies and crustaceans, and larvae of caddis flies appeared in the studied portion of the river 4 years after the accidental spill. The rate of rehabilitation of zoobenthos was lower than that of plankton communities. The results coincide with published data [6, 7, 9, 11] and supplement them.

Thus, the structural parameters of communities of phytoplankton, zooplankton, and zoobenthos make it possible to assess changes in water quality as a result of the input of oil products and the consequent decrease in their concentrations because of the rehabilitation activities and natural self-purification of the river.

Criteria for monitoring the rehabilitation of hydrobiont communities after the impact of oil pollution were developed by comparing the structural parameters of communities in the background and polluted stations. The criteria for all studied components included parameters of the species structure, quantitative characteristics of communities, and values of biotic indexes of species diversity and saprobity.

CONCLUSIONS

A total of 138 taxa of the rank below genus were found in phytoplankton of the Shava River, as well as 45 species of zooplankton, and 40 species of zoobenthos. Structural parameters of communities of phytoplankton, zooplankton, and zoobenthos reflect the state of the river and allowed us to assess its state after the accidental spill of oil products. Rehabilitation activities in the Shava River eliminated to a larger degree the consequences of the accidental spill of oil products. An analysis of the species structure, quantitative characteristics, and values of biotic indexes is necessary for monitoring the rehabilitation of hydrobiont communities. The rehabilitation of plankton communities in the oil-polluted Shava River happened faster than the rehabilitation of communities of zoobenthos. These approaches and criteria can be recommended for assessing the impact of oil products and the rehabilitation of communities of hydrobionts in small plains rivers in the temperate zone of European Russia on the basis of a comparison with background stations characterized by similar current velocities, depths, and degrees of overgrowth.

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