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Characteristics of Algocenoses of Small Water Reservoirs at the Territory of the National Park “Nizhnyaya Kama” being Influenced by Oil Production.

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ABSTRACT

There was investigated chemical composition of water and bottom sediments as well as characteristics of algocenoses (number of species, population, biomass, saprobity index, Shannon index for population and biomass) in 8 water reservoirs at the territory of the National Park “Nizhnyaya Kama” (the Republic of Tatarstan, Russia). The water reservoirs under investigation are polluted with oil as a result of accidental spills at time of its transportation and production which has been carried out at the water shed area since the sixties of the 20th century. Oil products accumulation in bottom sediments was revealed, their content in sediments exceeded the content in water by 47-889 times. There were determined dominant complexes of algae species depending on the range of oil products content in water and bottom sediments. A response reaction of algae to high oil products concentration in water (0.48-1.44 mg/l) and bottom sediments (9137-17780 mg/kg) is expressed by reduction of species diversity and decrease of quantitative characteristics of algae up to complete disappearance. Through a correlation analysis there was identified a dependency between algal community indices (number of species, biomass, Shannon index for population) and a content of nutrient substances (ammonium salts, nitrites) as well as of ferrum. No significant correlation dependencies between oil products content in water, bottom sediments and the algal community indices were revealed.

Keywords: algocenosis, phytoplankton, algae, the National Park “Nizhnyaya Kama”, the Kuibyshev Water Storage Basin, vegetation.

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INTRODUCTION

Oil production influence on hydrobiocenoses functioning is being a subject of wide speculation in the scientific literature. After ingress into a water reservoir or water course oil generates a whole range of migration forms, i.e. water-soluble, film-like, emulsified, sorbed on suspended solids and living organisms, cumulated by aquatic organisms, bottom one [1], [2]. All of these forms differ from each other by physical and chemical properties as well as by the level of toxicity for various life forms, namely for neuston, plankton, nekton, benthos. The experiments with use of isolates of the White Sea littoral community supposing introduction of oil products [3] into the same showed that even the least of the used concentrations (0.02 g/kg) of oil products in bottom sediments (BS) had influence on micro- meio- and macrobenthos. At that the least resistant taxonomic units (polychaetes, crayfish, shellfish) experienced abrupt reduction of population density and the most resistant (diatomic algae, Phytomastigina) to the contrary experienced growth of population. The structure of communities was disturbed, furthermore noticeable recovery of psammophilous community started after one year, however even two years later population density of some interstitial species remained below the control number.

Biotesting of rivers and lakes of Nizhnevartovsk district of Tyumen region demonstrated that bottom deposits with relatively low oil content (0.14-0.3 g/kg) promote growth of chlorococcales and macrophytes and with high content (2.0-22.4 g/kg) inhibit growth of the same [4]. At the same time inhibition of photosynthetic activity, reduction of production and increase of destruction, dieaway of a significant part of cells of *Scenedesmus* green algae species can be observed.

Other investigators also ascertained that the species diversity and ecological structure of algae communities changed as a result of the influence of pollution from oil exploration drilling. There was determined different directional effect of the human intervention processes [5-7].

Positive trends in algal flora changes consisting in algae species diversity growth and complication of the structure of communities in the impact lakes as compared to the baseline state can be observed under the conditions of insignificant ingress of pollutants and successful self-purification processes. With anthropogenic load increase the composition of the dominant algae complexes gets reduced and alters. The results of a number of investigations [8] are indicative of a medium grade of pollution of water reservoirs in the impact zones even 20 years after conservation of wells at the oil production territories.

The work by O. V. Stepanyan and G. M. Voskoboynikov [9] state that oil is a complex nonspecific toxicant influencing every part of algae vital activity starting from subcellular and cellular levels and ending with inter-population and inter-species relations of the organisms. The algae responsive reaction to high oil and oil products concentrations may consist in species diversity reduction, decrease of lifetime, rate of growth and photosynthesis in adult species as well as in inhibition of genesis of spores, gametophytes and germs.

This work was targeted at algocenoses investigation in small water reservoirs of the National Park "Nizhnyaya Kama" (the Republic of Tatarstan, Russia) which suffer from considerable pollution from oil production at the water shed area which started in the sixties of the past century and is in progress till the present time.

MATERIALS AND METHODS

The State Nature National Park "Nizhnyaya Kama" was founded in 1991, it is located at the northeast of the Republic of Tatarstan (Russia) and covers the area of 26460 ha (Fig. 1). The Park is situated at the intersection of the zones of mixed forest, southern boreal forest and forest steppe in the valley of the Kama river and its affluents, namely the Toyma river, the Kriusha river, the Shylninka river. The Park territory is a stepped dissected plain with the average watershed attitudes of 165 m, the territory is dismembered by the river valleys entrenched at the depth of up to 70 m. The territory has a lightly rolling surface. Overall slope of the surface is towards the Kama river valley.

Starting form the sixties of the past century and up to the present time there were located 139 oil production facilities at the land plots adjoining the National Park. The oil production territory is partially included in the National Park territory and constitutes a single ecosystem with the same [10].

A lot of water reservoirs with various hydrological statuses are located at the Park territory. Standing water and slow circulation water bodies are the most numerous; these are dead lakes of different size and a variety of marshes which were suffering from massive oil pollution as a result of spilling at time of drilling and transportation especially during the first years of the oil fields development.

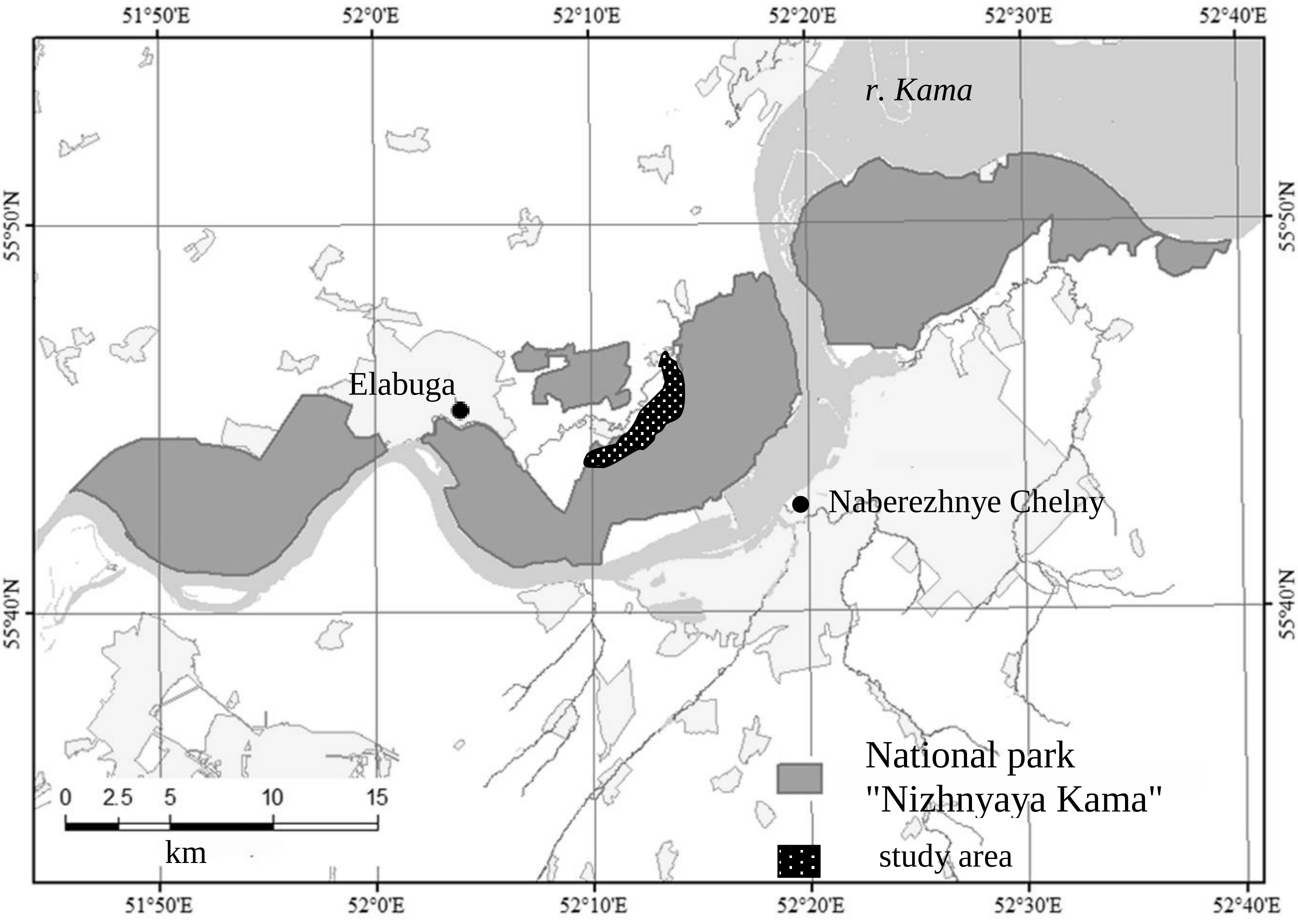

Figure 1: Schematic map of the National Park "Nizhnyaya Kama".

In the course of a complex expedition in August 2007 there were explored 8 water bodies in the National Park "Nizhnyaya Kama" (Table 1). Chemical analysis of water and bottom sediments was performed according to the methods given in [11-16].

Water quality assessment was carried out on the basis of comparison with the corresponding MACs [17], bottom sediment assessment was made against MACs approved in Tyumen region as an ecologic and fishing industry standard of oil products content in bottom sediments [4].

Taking and processing of algological samples was performed according to the standard practice [18]. Such indices as species composition, population and biomass were used for description of algae communities. Species diversity was evaluated with use of the Shannon index calculated in terms of biomass (HB) and species number (HN) [19]. In order to assess a saprobiological state of the water bodies the saprobity index (*S*) determined by *Pantle-Buck* technique in *Sladecek* modification [20] for plankton communities was used.

Table 1: A list of the investigated small water bodies of the National Park "Nizhnyaya Kama".

No.	Coordinates latitude/ longitude	Water body description	Influencing facilities (wells)
1.	55°47'1.16"N (55.783656) / 52°14'15.49"E (52.237636)	A marsh in a pine forest, small water table, oil coat.	+
2.	55°46'58.38"N (55.782882)/ 52°13'56.95"E (52.232486)	A marsh, some areas of open water, film.	+
3.	55°46'43.75"N (55.778819)/ 52°14'21.67"E (52.239353)	A marsh in a spruce and birch forest, oil film in some areas.	+
4.	55°46'36.78"N (55.776884) 52°14'3.75"E (52.234374)	A water body at an open oil production area, argillaceous bottom, macrophytes vegetation.	+
5.	55°46'16.93"N (55.771369)/ 52°14'19.2"E (52.238666)	A sphagnum bog in a spruce forest. Oil film.	+
6.	55°45'54.63"N (55.765175)/ 52°13'47.06"E (52.22974)	A marsh in a spruce forest, no oil film.	-
7.	55°45'52.54"N (55.764595)/ 52°14'10.55"E (52.236263)	A marsh in a pine forest, near a road. Oil film.	-
8	55°45'49.06"N (55.763627)/ 52°13'24.2"E (52.223388)	A water body by a road, artificial pond. Clear water, oil film on the surface.	+

«+» presence, «-» - absence of wells in the water body watershed.

A correlation analysis between the chemical composition of water and the algocenosis indices was performed with use of the Spearman criterion for $p<0.05$.

RESULTS OF INVESTIGATION

Chemical characteristics of water and bottom sediments

All of the water bodies had increased content of ferrum (Table 2) which is peculiar to acid waters in marshes facilitating transition of dissolved forms of ferrum from solid phase (deposit in bottom sediments) into water. Water of 5 of the investigated water bodies demonstrated oil products MACs excess and one water body showed chlorides MACs excess (No. 4). High oil products content (548 – 17780 mg/kg) was registered in bottom sediments of all water bodies, the norm was exceeded by 40 -899 times.

Table 2: Chemical composition of water and bottom sediments in the investigated water bodies

Water body No.	pH	Ferrum, mg/l	Chlorides, mg/l	Ammonium ions, mg/l	Oil products	
					Water, mg/l	BS, mg/kg
MAC	6.5-8.5	0.3	350	2.6	0.3	20
1	5.2	0.71±0.03	1.37±0.20	0.44±0.09	**0.48**±0.03	**933**±36
2	5.1	0.37±0.02	11.8±0.18	0.61±0.07	0.07±0.01	**794**±123
3	5.7	0.34±0.02	138±21	0.33±0.08	0.07±0.01	**548**±67
4	4.9	0.3±0.05	**2455**±106	0.40±0.07	**7.03**±1.2	**9137**±539
5	3.2	**8.73**±0.8	ND	**37.3**±0.29	**1.44**±0.9	**5335**±675
6	4.0	**3.03**±0.9	1.95±0.90	2.36±0.13	0.18±0.09	**4634**±1034
7	3.9	**5.44**±1.1	2.06±0.32	**7.15**±0.22	0.06±0.05	**2614**±986
8	4.5	0.12±0.04	4.88±0.65	0.64±0.08	0.04±0.03	**17780**±1987

ND – not determined; the values exceeding the norm are given in bold.

Algological characteristic of the water bodies

Composition of algal flora of the investigated water bodies of the National Park "Nizhnyaya Kama" (except for water body No. 8) included 63 species referring to 6 groups. Among them 5 species refer to blue-green algae, 10 to euglenales, 3 to dinoflagellates, 24 to diatoms, 2 to chrysophyceae algae and 19 to green algae. In a quantitative sense diatoms, euglenales and green algae dominated. Species diversity of algae in the investigated water bodies except for those with very high concentration of oil products was high enough; the number of detected species varied from 5 to 28, at the average the number of simultaneously detected species made 15.9±3.4. The indices of species diversity vary in number from 0.1 to 3.7 (2.3±0.5 at the average) and in biomass from 0.2 to 3.7 (2.4±0.5 at the average) (Table 3, Fig. 2).

Table 3: Structural characteristics of algocenoses of the small water bodies in the National Park "Nizhnyaya Kama" under oil pollution conditions

Indices	Mean ± Standard Error	Median	Min	Max	Standard Deviation
N, mln.cells/l	23.7±8.6	15.2	3.1	64.0	22.8
B, mg/l	16.0±5.0	13.6	2.9	36.6	13.2
HN	2.3±0.5	2.4	0.1	3.7	1.3
HB	2.4±0.5	2.3	0.2	3.7	1.2
S	1.2±0.2	1.3	0.3	1.9	0.5

N – number, *B* – biomass, *HN* – species diversity index in terms of number, *HB* – species diversity index in terms of biomass, *S* – saprobity index.

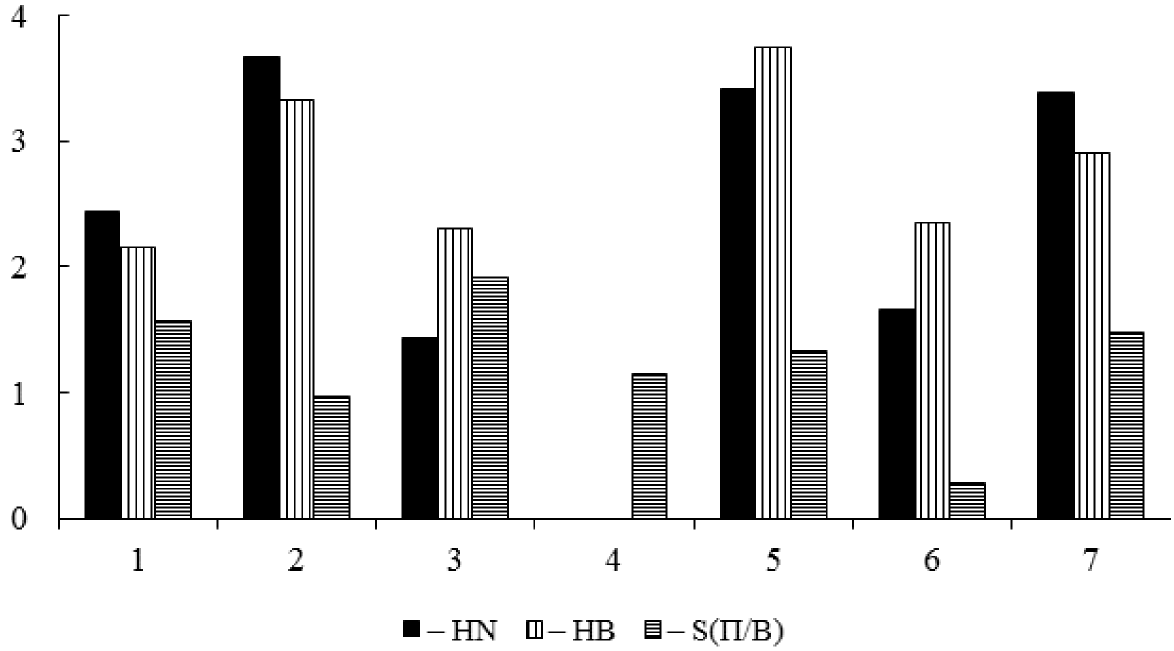

Figure 2: Species diversity indices in terms of number (HN) and biomass (HB) for phytoplankton, S – saprobity index of small water bodies of the National Park "Nizhnyaya Kama" (X-axis presents numbers of the investigated water bodies).

Diatoms of the following geni: *Navicula* (the occurrence frequency of 75%), *Pinnularia* (65%), *Cymbella* (38%) and *Nitzschia palea* (Kiitz) W.Sm. (50%) which are indicative of high concentration of organic or mineral substances were the most numerous and frequent in the examined water bodies. Among euglenales high frequency was characteristic for the following geni: *Euglena viridis* Ehr. (50%), *Trachelomonas planctonica* Swir. (38%), *Trachelomonas volvocina* Ehr. (63%). Among green algae of *Scenedesmus guadricauda* (Turp.) Breb genus were of the most frequent occurrence. At the same time high diversity and number of desmids of *Cosmarium* and *Staurastrum* geni typical for swamped sites can be observed. Blue-green algae are generally presented by *Oscillatoria* and *Anabaena* geni which get quite numerous in the water reservoirs near drilling well platforms. Besides all of the investigated water bodies demonstrated massive outgrowth of filamentous algae as an effect of high content of mineral substances. These are green algae of *Spirogyra, Cladophora* and *Ulothrix* geni. The number of chrysophyceae algae is noticeably lower in this group of water bodies.

The average algae population is equal to 23.7±8.6 mln. cells/l, among them blue-green algae take 16.5±8.4%, diatoms – 16.0±5.0% and green algae – 20.5±10.7%. The average algae biomass is equal to 107.5±91.6 mg/l. In terms of biomass euglenales (15.7±8.2%), diatoms (61±12.5%) and green algae

(21.9±11.3%) prevail. In different water bodies the quantitative indices of algae cells vary from 3.1 mln. cells/l to 64.0 mln. cells/l in terms of number and from 2.9 to 36.6 mg/l in terms of biomass (Fig. 3).

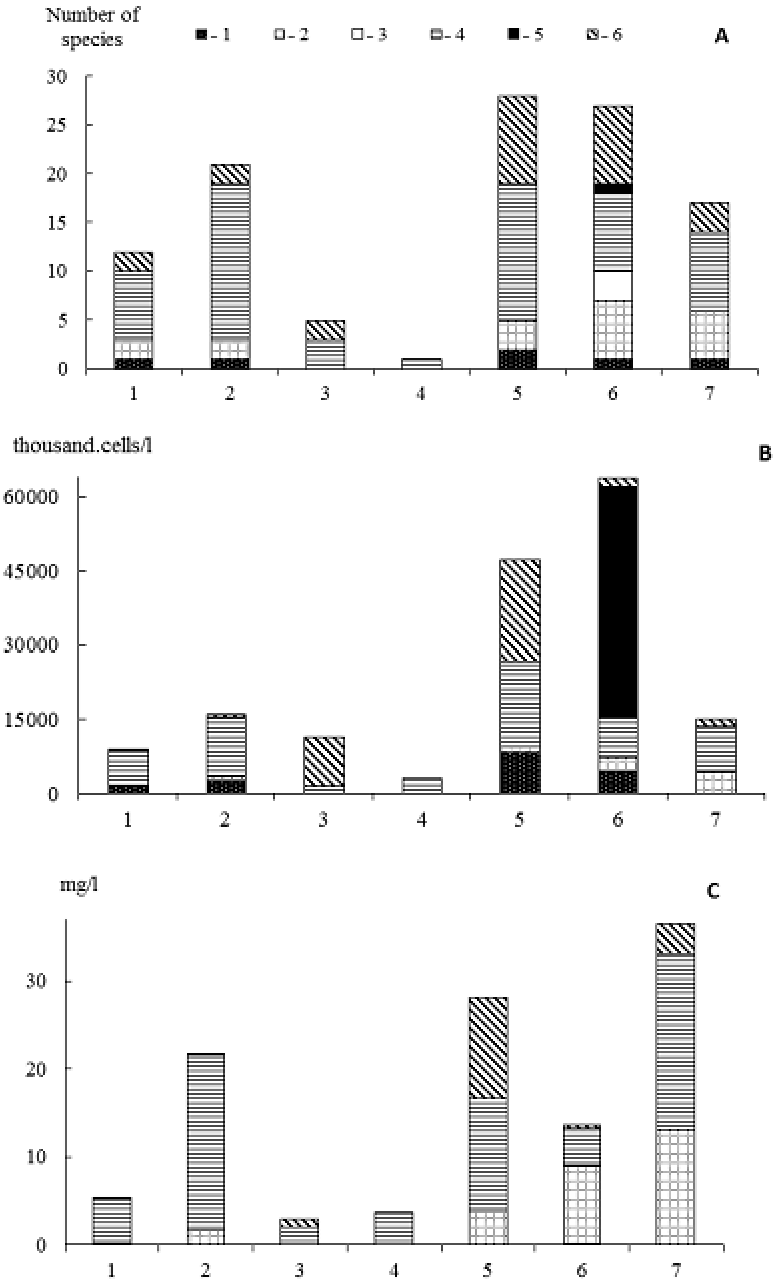

Figure 3: Indices of phytoplankton in the water bodies of the National Park "Nizhnyaya Kama": ***A*** **– number of species;** ***B*** **– population (th. cells/l);** ***C*** **– biomass (mg/l) (the investigated water bodies are shown along the X-axis):** ***1*** **– blue-green algae,** ***2*** **– euglenales,** ***3*** **– dinoflagellates,** ***4*** **– diatoms,** ***5*** **– chrysophytes,** ***6*** **–green algae.**

Water quality of the investigated water bodies as calculated based on hydrobiological indices is being assessed as clean to moderately polluted for the surface layers and dirty to polluted for the benthal layers.

DISCUSSION OF RESULTS

The explored water bodies demonstrated ambiguous reaction of algal flora to ingress of pollutants from the drilling well platforms. No algae were found out in water reservoir No. 8. It appears that oil products accumulated in the bottom sediments have toxic effect on algae, it is that water body where the maximum content of oil products in bottom sediments was observed (17780 mg/kg) (Table 4). During the period of investigation in water reservoir No. 4 where oil products content in water made 7.03 mg/l were found only diatoms of *Pinnularia* genus with the biomass of 3.76 mg/l. The same water body is marked by high chlorides content which can have even more intensive inhibiting effect on algae growth then presence of oil products. In the water bodies with less degree of pollution (No. 1 and No. 5) oil products content was within the range of 0.48-1.44 mg/l, there were found insignificant population of diatoms and green chlorococcales. In the water bodies with low indices of oil hydrocarbons content (0.04-0.18 mg/l) the content of phytoplankton was higher which was demonstrated by predominance of diatoms, green chlorococcales and euglenales.

Table 4: Predominant complexes of planktonic algae species in the water bodies with various oil products content in water.

Oil products content: water (mg/l) / BS (mg/kg)	Predominant complexes
0.18 / 4634	*Oscillatoria* sp., *Tabellaria fenestrata, Trachelomonas volvocina, Scenedesmus guadricauda, Achnanthes* sp., *Navicula* sp., *Pinnularia legumen, Trachelomonas planctonica, Pinnularia mesolepta, Navicula peregrine, Chrysocapsaceae* sp.
0.48 / 933	*Oscillatoria planctonica*, *Navicula peregrina*, *Navicula* sp., *Navicula rhynchocephala*, *Achnanthes* sp., *Pinnularia mesolepta*
1.44 / 5335	*Dictyosphaerium pulchellum*, *Oscillatoria planctonica*, *Tabellaria fenestrata*, *Navicula* sp., *Scenedesmus guadricauda*, *Nitzschia palea*, *Nitzschia acicularis*, *Eunotia* sp., *Cosmarium subprotumidum, Staurastrum neglectum, Stephanodiscus hantzschii, Trachelomonas volvocina, Euglena viridis*
7.03 / 9137	*Pinnularia* sp.
0.04 / 17780	no algae detected

The results of the carried out investigations show that algae growth was greatly influenced by the ammonium ions content in water. The water reservoirs with high ammonium salts content had the highest quantitative indices for euglenales and green volvocales. The analysis of correlation dependencies between the chemical composition of water and the indices of algocenoses demonstrated presence of strong connection between the content of ammonium and ferrum in water and number of species as well as algae biomass (Table 5). There were determined negative dependencies between water hardness and algae biomass. No direct dependence between oil products content and algae community indices was found out.

Table 5: Correlations between chemical analysis and algae parameters (Spearman Rank Order Correlations (p<0.05))

Variables	Number of species	Number of cells, thous/l	Biomass, mg/l	– S(P/B)	– HN	– HB
Ammonia	**0.86**	0.71	**0.93**	-0.36	0.68	**0.79**
Nitrates	0.36	0.53	0.40	-0.40	-0.04	0.13
Nitrites	0.68	0.54	**0.89**	-0.18	0.54	0.57
Sulfates	-0.46	-0.71	-0.07	0.18	0.07	-0.39
Chlorides	-0.60	-0.37	-0.43	0.09	-0.49	-0.20
Phosphates	0.65	0.54	0.63	0.13	0.32	0.52
Oil products	-0.04	-0.21	-0.25	-0.29	-0.25	-0.29
Hardness	-0.57	-0.43	**-0.89**	0.04	**-0.89**	-0.75
Ferrum	**0.82**	0.68	**0.82**	-0.07	0.61	0.71

Marked coefficients with significance (p<0.05)

Some authors state [1] that under conditions of low oil hydrocarbons concentrations in aquatic environment the intensity of algae growth and photosynthesis increases however the further rise of oil products content results in physiological processes inhibition, reduction of species composition and phytoplankton biomass. A mechanism of oil products indirect action towards algae is apparently connected with reduction of illumination level due to oil film and as a result inhibition of photosynthetic processes, at the same time the significance of organic loadings for mixotrophs increases. In this competitive struggle for light those algae can win which are able to prompt and complete adaptation to weak light [9], [21].

The analysis of indicative group of diatoms showed that with increase of mineralization in the water bodies in the impact zone the part of halophiles grew as compared to the number of halophiles in the baseline water bodies. It may well be that many of them demonstrate high resistibility to complex pollution which accompanies oil production processes.

CONCLUSION

The major part of water reservoirs at the territory of the National Park "Nizhnyaya Kama" were affected by oil pollution due to oil production and accidental spills. The carried out investigations showed that bottom sediments which accumulated large quantities of oil products may act as a source for secondary water pollution.

The quantitative and qualitative indices of planktonic algae depend on the nature and extent of water reservoirs pollution by oil products. The influence of oil in small concentrations may have a positive effect on some algae and negative on other. Under the conditions of low oil products quantity ingress which does not interfere in the natural self-purification processes the specie richness and the algae population increase can be observed in the impact water bodies as compared to the baseline ones. The algae responsive reaction to high oil products concentrations in water (0.48-144 mg/l) and in bottom sediments (9137-17780 mg/kg) consists in species diversity reduction, decrease of quantitative characteristics of algae up to complete disappearance.

Through a correlation analysis there was identified a dependency between algal community indices (number of species, biomass, Shannon index for population) and a content of nutrient substances (ammonium salts, nitrites) as well as of ferrum which is a biogenic element. With increase of water hardness inhibiting action on algae growth becomes more intensive. No significant correlation dependencies between oil products content in water, bottom sediments and the algal community indices were revealed.

FINDINGS

In the most of water bodies at the territory of the National Park "Nizhnyaya Kama" bottom sediments which accumulated large quantities of oil products are a source of secondary pollution of water. The influence of oil in small concentrations may have a positive effect on some algae and negative on other. Under the conditions of low oil products quantity ingress which does not interfere in the natural self-purification processes the specie richness and the algae population increase can be observed in the impact water bodies as compared to the baseline ones.

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