Seasonal patterns of Potamoplankton in a Large Lowland River of Temperate zone (Upper Ob as a case study, Russia)

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ABSTRACT: The paper presents the results of seasonal potamoplankton dynamics in a Siberian lowland river and its relationships with environmental variables. The sampling was carried out every 10-15 days from April to September 2001 at the left and right banks including the midstream of the Upper Ob River close to the big industrial center, Barnaul city (53°21'24"N, 83°47'14"E). The presence of 145 species (158 taxa) with predominance of diatoms (45.6% of total number of species) and green algae (35.8%) was noted. Remarkable seasonal potamoplankton variations were revealed using measures of inclusions and a multigraph. The correlation analysis indicated that physical factors (e.g. hydrological variables) and major nutrients (e.g. nitrates) were of equal importance for controlling the variation in structure and abundance of the large lowland Upper Ob River potamoplankton. Based on the regional trophic classification, the Upper Ob River can be currently characterized as oligo-mesotrophic since the total abundance and biomass of algae were less than 1260×10^3 cells/L and 780 mg/m^3 throughout the sampling seasons. The results of the saprobiologic analysis showed that the greatest number of bioindicators belong to β-mesosaprobionts that is indicative of the β-mesosaprobic environment. Water quality was ranked among I-III classes. Our study presents a baseline for monitoring the planktonic component in the river ecosystem as a main factor of its stability. In spite of the regional aspect of the study, the investigation of potamoplankton in the environments of the south of West Siberia will be useful for understanding of phytoplankton development in large unregulated lowland rivers.

Key words: Potamoplankton, Composition, Abundance, Seasonality, Water quality

INTRODUCTION

The anthropogenic impact on the environment during the 20th century led to a substantial disturbance and pollution of running waters. Less than 17% of the present-day continental surface can be considered without direct human footprint, such parts of the Earth river system can be found in Canada and Alaska, Amazonia, Congo Basin and in some Siberian rivers (Meybeck, 2003). In Eurasia, 19 large river systems with total mean annual discharge of 24.929 m^3/s are left unaffected by fragmentation of the river channels by dams and water regulation resulting from reservoir operation (Dynesius and Nilsson, 1994). Nutrient inputs into rivers around the world increase algal biomass and cause eutrophication (Muylaert et al., 2009). The conservation and efficient use of water resources call for the study of biota in river ecosystems and their monitoring (Verasztó et al., 2010). Potamoplankton is the primary producer of organic matter, an important constituent of self-purification processes, and an indicator of river pollution. The composition and abundance of algae, the ratio of different-sized organisms, the presence of indicator species and the ratio of different functional groups (Reynolds et al., 2002) are indicators of ecological state of water and its quality.

The Ob is the largest river in Russia and the second longest in Asia. The investigation of the Ob potamoplankton was initiated in the mid XX before and during the construction of the Novosibirsk reservoir. The main features of the potamoplankton from the upper reach of the river were studied by Yakubova (1961). Initially, potamoplankton brought to the Ob by rivers Biya and Katun was very poor. In summer, downstream it was enriched with euplanktic elements from diatoms (species of *Aulacoseira* Thr., *Asterionella* Hass., *Diatoma* Bory), some green (*Pandorina* Bory, *Eudorina* Ehr., *Oocystis* Näg., *Pediastrum* Meyen, *Dictiosphaerium* Näg., *Actinastrum* Lagerh., *Closterium* Nitzsch.) and golden
algae (*Dinobryon* sp.), cyanobacteria (*Limnococcus* (Komárek et Anagnostidis) Komárková, *Gomphosphaeria* Kütz.)). Complete data on the Upper Ob plankton were presented by Kuksn (1964) and coauthors (Kuksn *et al.*, 1972), Solonevskaya (1964), Naumenko (1995, 1996). The investigation of the Ob River potamoplankton near Barnaul (the largest city in the Upper Ob basin) was initiated by the Laboratory of Aquatic Ecology of IWEP SB RAS in 1991. The plankton was studied during both high and low water periods (Mitrofanova, 1996, 1999). In spring, the potamoplankton was diverse but not abundant; diatoms appeared as the dominant group (65.9% of total number of species). The total abundance and biomass were less than $167.5 \times 10^3$cell/L and $407.8$ mg/m$^3$, respectively. Small-celled pennate diatoms *Achnanthes* sp., *Diatoma* tenue Ag. and *Cyclotella* sp., large ones *Ulnaria ulna* (Nitzsch.) Comp., *Synedra gibbosa* Ralfs and *Cymatopleura solea* (Breb.) W. Smith were found to be dominant. In autumn, the abundance of the potamoplankton reached $204.9 \times 10^3$cell/L and $203$ mg/m$^3$, and small chlorococcalean green algae dominated in the plankton. The previous studies indicate that only scanty information on the Upper Ob River potamoplankton is available. The objectives of this study were as follows: (1) to make a comprehensive assessment of the seasonal diversity and abundance of the potamoplankton of relatively unregulated river in the environments of the south of West Siberia; (2) to assess the water quality and the recent status of the river using the qualitative and quantitative characteristics of potamoplankton as a basis for monitoring. The fundamental question we addressed was to define the most important factor of the potamoplankton development in the Upper Ob, the unregulated large lowland river in the temperate zone of the Northern hemisphere.

**MATERIALS & METHODS**

Ob River is 3650 km long, its catchment basin is $2.9 \times 10^6$ km$^2$ with an average water discharge of $12.7 \times 10^6$ m$^3$/s (max. $42.8 \times 10^6$ m$^3$/s) at the river mouth and in the Upper Ob near Barnaul – $1.49 \times 10^6$ m$^3$/s (the data available for the period of 1936-1990 (Yang *et al.*, 2004)). According to the recent river classification (Korytny, 2001), the Ob River system is the largest in Russia and one of the largest in the world (Dynesius and Nilsson, 1994). The Ob valley is divided into three large different basins: Upper, Middle and Lower.

The river section from the confluence of rivers Biya and Katun up to Tom’ River is the Upper Ob; from Tom’ to Irtysh – the Mid Ob; and from Irtysh to the Gulf of Ob – the Lower Ob. In the vicinity of Barnaul, on the left side, the Ob valley adjoins a large slope of the Ob plateau elevated at 80-100 m above the valley bottom. On the right side, gentle sand slopes of three terraces of the ancient riverbed are found covered with pine forests. The bed of Ob River is 0.8-1.0 km wide and consists of sandy-clayey soils. The riverbed is characterized by numerous shallows and islands. The mean depth is 4-6 m with maximum values between 10 to 12 m. The Upper Ob is a typical plain river, though about 36% of its water is supplied from glaciers, the melting of which causes the second, more powerful, flood in June-July.

For analysis, we used the data for 2001 obtained from the West Siberian Hydrometeocenter station located downstream from Barnaul (State Water., 2003).

The water samples were taken twice a month from April to September, 2001 near Barnaul city. The investigation covered the high water (the second half of April and mid-June) and the low water (July-August) periods as well as the one in early autumn (September). The sampling was made from the bridge in the mid water course and near the river’s banks (50-100 m downstream the bridge) (Fig. 1). Processing of samples was carried out by means of standard hydrobiological methods (Wetzel and Likens, 2000). Water was collected from the surface by a bucket. The potamoplankton samples were fixed with formalin (4%) and concentrated by sedimentation method. Phytoplankton was counted using the counting chamber “Nazhotta” of 0.085 ml volume and a light microscope (Laboval 4) at a 600x magnification. The results were expressed in terms of cell abundance using the formula:

$$N = n \frac{V_1}{(V_2 V_3) 0.001}$$  \hspace{1cm} (1)

where $N$ – abundance of potamoplankton, $10^3$ cells/L, $n$ – number of cells in the counting chamber, $V_1$ – volume of concentrated sample, ml, $V_2$ – volume of sample, L, $V_3$ – volume of counting chamber, ml.

Biomass was estimated by calculation of specific biovolume based on dimensions of each individual using proper geometric approximations and a specific density of 1 mg/cm$^3$:

$$B = \frac{N V_4 n}{n}$$  \hspace{1cm} (2)

where $B$ – biomass, mg/m$^3$, $N$ – abundance of potamoplankton, $10^3$ cells/m$^3$, $V_4$ – volume of an algae cell, cm$^3$, n – specific density.

Subsamples of cleaned material treated with hydrogen peroxide were dried on coverslips, then coated with Au–Pd and studied by a HITACHI S-3400N scanning electron microscope.

The algae names were verified with the current algae catalogues, archives and bases on the websites. Species richness was assumed as the number of species present in each sample. The species with the
highest relative abundance (cell number or biomass) were taken as dominant. The frequency of domination was calculated using the formula:

$$D = \frac{n}{N} \times 100\%$$

(3)

where \( n \) – number of samples with dominant species, \( N \) – number of total samples (Kozhova, 1970). The species diversity was calculated following Shannon and Weaver (Shannon and Weaver, 1963). The saprobic index was calculated applying the method of Pantle and Buck as modified by Sládeček (Uniform methods, 1977, 1983). We used Spearman rank correlations to test association between potamoplankton characteristics and environmental variables (Excel 2013). Statistically significant correlation coefficients (\( p < 0.05 \)) are shown in the table in bold.

The composition of potamoplankton sampled in different dates was compared using the measures of inclusion (Andreev, 1980):

$$\sigma (A; B) = \frac{c}{b} \text{ and } \sigma (B; A) = \frac{c}{a}$$

(4)

where \( \sigma (A; B) \) – the measure of inclusion of flora B in flora A, \( \sigma (B; A) \) – the measure of inclusion of flora A in flora B, \( a \) – number of species in flora A, \( b \) – number of species in flora B, \( c \) – number of common species both for flora A and B. The multigraph served as a visual presentation of the intersection matrix based on measures of inclusions. Sufficiently strong overlaps of \( \sigma \geq 55 \) were assumed. The state of the river was described according to the complex ecological classification of surface water quality (Oksiyuk et al., 1994). The Abakumov’s concept (1991) of ecological modifications was used to assess the status of the river. A total of 34 samples were analyzed during the study.

RESULTS & DISCUSSION

Most studies of potamoplankton dynamics in lowland rivers was conducted for regulated rivers (Verasztó et al., 2010; Descy et al., 2012). The flow regime of the Upper Ob sites under study has not been modified with different hydraulic interventions yet (Istvánovics et al., 2010). The large Novosibirsk reservoir (capacity greater than 25 km\(^3\)) and three mid-size dams were built in the Ob basin in the mid 1950s-1980s (Yang et al., 2004); all of them are downstream from Barnaul and the study sites. The Upper Ob is a typical lowland river with low flow velocity (usually not more than 1 m/s and about 0.7 m/s during low water), relatively high water discharge (the average water runoff at Barnaul in April-November, 2001 was 2446 m\(^3\)/s), low water temperature in spring (0.2 ºC in early April), high water temperature in summer (up to 22.2 ºC in mid August) and low transparency (0.40–0.62 m during the studied period). The high left sand-clay bank of the Ob River upstream from Barnaul, being destroyed constantly, imports much suspended solids.

![Fig. 1. The scheme of the Ob River basin (A) and potamoplankton sampling sites in the river near Barnaul city (B), 2001.](image)
Seasonal patterns of potamoplankton in a large lowland river

to the water that decreases its transparence to a minimum. As is generally known due to the Coriolis effect the left banks of meridional rivers in the Northern hemisphere are always higher and steeper than the right ones. Our results demonstrated that hydrological and hydrophysical characteristics favor the potamoplankton development in the investigated section of the river. A total of 145 algal species (158 taxa) from eight major taxonomical groups were described. Bacillariophyceae (66 species, or 45.6% of the total number of species identified in the samples) and Chlorophyta (52 species, 35.8%) dominated, Cyanobacteria and Euglenophyta contained 13 (8.9%) and six species (4.1%), respectively. All other groups consisted of a small number of species: Chrysophyceae (three species, 2.1%), Cryptophyta (two species, 1.4%), Dinophyta (two species, 1.4%) and Xanthophyceae (one species, 0.7%). Different combinations of diatoms and green algae are among the main characteristics of potamoplankton in large world rivers. Diatoms amount to 50.6% of the total species number in the Mid Lena potamoplankton (Remigialo and Gabyshhev, 1999) and 38.9% for the whole Ob River system (Naumenko, 1995). The Upper Ob has higher percentage of diatoms in contrast to its other parts due to the influence of mountainous effluents. Safonova (1996) stated that diatoms in Katun River (a mountain river, one of the sources of Ob River) constituted 77.8% of the total number of species. Relatively high abundance of diatom species was reported from the Morava River (40.4%), the tributary of the Danube (Hašler et al., 2007), from Narva River 31.5%, Estonia–Russia (Pirssoo et al., 2010) and Moscow River 35.5% (Kriksunov et al., 2006). In the more eutrophic Irtysh River, the contribution of diatoms to the phytoplankton was less (15.8%), and green algae dominated (53%) (Bazhenova, 2005). The predominance of green algae was also observed in the potamoplankton of other eutrophic rivers such as River Minho in Spain (48.1%) (Vasconcelos and Cerqueira, 2001) and Tisza, the Danube River tributary (44.9%) (Rzáničanin et al., 2005) or even less (29.8%) (Istvánovics et al., 2010). In the tropic Nile River (Upper Egypt) (Kobbia et al., 1991) and in the subtropical Yeshrmak River (Turkey) (Soylu and Gönülöl, 2003), however, the dominance of diatoms also occurred. Thus, the rivers with less trophic state usually have higher relative abundance of diatoms in the potamoplankton composition than in more eutrophic lotic ecosystems. It was noted that the species selectivity in turbid rivers is more likely to favor diatoms, especially those with high surface/volume ratios (Reynolds, 1994).

Throughout the study period, the Upper Ob River potamoplankton with high species richness was described. The number of coexisting species varied from 19 to 56 (Fig. 2A) with an average of 42 ± 2 species. Similar mean taxonomic richness was found, for example, in the large lowland Loire River in France – 47 taxa per sample with the range from 10 to 84 (Descy et al., 2012). The majority of Bacillariophyceae taxa (44) in the Ob River potamoplankton was benthic, 16 species can be attributed to planktonic ones, the others have uncertain habitat preference. The number of diatom species did not show striking seasonal variations: 20 to 28 species were present throughout the study period with the exception of late April and May when the number of diatoms species was 19 and 15, respectively. In the flood period, benthic diatoms were the main taxa and sometimes the only group in the plankton due to their detachment from the riverbed. The real planktonic diatoms are an important element in the planktonic community of lowland rivers. The group of small centric diatoms (6-9 µm in cell diameter) in the Ob River potamoplankton was represented by Discostella pseudostelligera (Hust.) Houk et Klee, D. cf. stelligera (Cl. et Grun.) Houk et Klee, and Stephanodiscus minutulus (Kütz.) Cl. et Möll. We observed also larger centrics like S. hantzschii Grun., S. invisiatus Hohn et Heller. f. invisiatus, S. triporus Genkal et Kuzmina, Cyclodystephanos dubius (Fricke) Round, Cyclotella bodanica Eulen., but these taxa and another small centric diatom Cyclotella atomus Hust. were not abundant. At the beginning of the study period, we revealed the centric diatom Aulacoseira granulata (Ehr.) Sim. (= Melosira granulate var. angustissima (Ehr.) O. Müll.). All these taxa were identified using a SEM Hitachi S-3400N (Fig. 3). The development of smaller forms of algae, especially diatoms, i.e. Cyclotella sp. (about 6 µm in diameter) and S. hantzschii (8-9 µm) is characteristic of the Upper Ob potamoplankton that indicates a slight increase in the trophic status of the river. In the mid of XX century, when the Upper Ob was an oligotrophic river, the large diatoms were dominant in its potamoplankton (Yakubova, 1961). A. granulata was found downstream in Middle and Lower Ob River. It is common knowledge that the potamoplankton of temperate rivers appeared as a dominated group (with emergence of small-celled algal taxa) in summer (Kiss et al., 1994).

Green algae were the second most diverse group, including euplanktic Chlorococcales taxa. The most abundant genus was Scenedesmus Meyen with 15 species, among the Volvocales Pandorina morum (O. Müll.) Bory and species of Chlamydomonas Ehr. and Platymonas G.S. West were found. The number of green algae increased gradually from 1-6 species in April-May up to 26 in July. This can be related to their life cycle since in winter most of green algae remain in resting stage. With increase in temperature they begin to develop. Cyanobacteria were not diverse. Most of the species revealed mainly in summer belonged to
Oscillatoria Vauch. and Microcystis (Kütz.) Elenk. genera as well as Gloeocapsa (Kütz.) Hollerb., Lyngbya Ag., Merismopedia (Meyen) Elenk., Phormidium Kütz. The rare unicellular ñyanobacteria Pseudoncobyrsa lacustris (Kirchn.) Geit. (not marked by previous studies) was found in September. Euglenophyta were represented by a few species of Euglena Ehr., Phacus Duj, Trachelomonas Ehr. and Strombomonas Defl. genera. The rest of the groups had only 1-3 species.

As noted by many authors, damming and resulting fragmentation is a major disturbance to large river ecosystems nowadays that can influence on hydrobiont communities (Blocksom and Johnson, 2009), including algae in the water column. The Upper Ob is the least disturbed stream, algae communities are in natural conditions and potamoplankton is well developed that is seen from the Shannon Index, high enough for this section of the Upper Ob. The biodiversity varied from 2.31 to 3.64 bit/specimen (estimated from cell abundance) and 2.19-3.66 bit/specimen (estimated from biomass) (Fig. 4A), with average values of 3.19±0.09 and 2.97±0.14 bit/specimen, respectively.

A special technique, the measures of inclusion and the multigraph (Andreev, 1980) were used for the comparison of the Ob River potamoplankton composition in different sampling dates. Three seasonal groups of algae communities were revealed: (1) potamoplankton observed just after the ice-breaking; (2) potamoplankton of the first and second floods; (3) potamoplankton of the low water in summer and autumn (Fig. 5). It should be noted that the measures of inclusion are asymmetrical measures of similarity reflecting a degree of proximity of one object relative to another one (Semkin et al., 2009). Generally, they are more informative and reflect the relations «the whole – parts». The multigraph shows what communities involve more common or original species, and species of which communities are present in another ones. These findings are in accordance with

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Fig. 2. Seasonal variations in (A) number of species, abundance (×10^3 cells/L), biomass (mg/m³), water temperature (°C) and (B) relative diversity (number of species, %) of potamoplankton in the midstream of the Ob River near Barnaul city, 2001 (CYA – Cyanobacteria, CHR – Chrysophyceae, BAC – Bacillariophyceae, XAN – Xantophyceae, CRY – Cryptophyta, EUG – Euglenophyta, DIN – Dinophyta, CHL – Chlorophyta)
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those for other rivers of the Northern hemisphere (Descy, 1987; Kiss et al., 1994; Skidmore et al., 1998; Várhiró et al., 2007) and confirm the compositional uniformity of the potamoplankton of holarctic rivers, i.e. seasonal variation in the potamoplankton composition and shift of diatoms ‘† green algae commonly observed in lowland rivers (Reynolds, 1994). The density of the Ob River potamoplankton near Barnaul city was not high and the mean biomass did not exceed 1 g/m³ during the growing season 2001. The total abundance of potamoplankton ranged between 33.5×10^3 on May 22 (flood) and 1259×10^3 cells/L on August 31 (low water) (Fig. 2A). The biomass varied from 99.5 to 780.8 mg/m³ and showed similar seasonal changes: in April, it was high due to the presence of large-sized benthic diatoms. Gradual increase in biomass and its second maximum were noted from late May to mid August. The mean abundance and biomass of potamoplankton were 332.9±52.3×10^3 cells/L and 322.9±35.7 mg/m³, respectively. In the cross section of the river, these values were the highest in the midstream (391.3×10^3 cells/L and 351.7 mg/m³), and the lowest – at the left bank (259.9×10^3 cells/L and 269.5 mg/m³). Thus, the seasonal variation of the potamoplankton density is unimodally distributed with maxima in late summer and the biomass – bimodally with peaks in early spring and late summer. The seasonality with unimodal biomass distribution was observed for the potamoplankton in other Siberian rivers, i.e. the Irtysh (Bazhenova, 2005), the main tributary of Ob River, and the Lena (Remigulio and Gabychev, 1999), one of the largest rivers in the central part of Eurasia. Comparing the recent findings for the Ob River potamoplankton with that of the previous years, we got the conclusion that the abundance of potamoplankton was constant during

the last decade revealing $15.5 \times 10^3$ cells/L throughout the flood period and up to $154.9 \times 10^3$ cells/L in September (Mitrofanova, 1996, 1999). The diatoms prevailed in the plankton throughout the whole period of investigation both in cell density and in biomass (Fig. 2B). The domination frequency of small centric diatoms reached 46.2%. The share of this group was high in the samples (18.2-63.0% expressed in cell density). These taxa showed a characteristic seasonality. They were subdominant in spring, but their contribution to the potamoplankton density increased during the vegetation period. The centric diatoms with large frustules were not dominant in the potamoplankton. In spring, the abundance of *Aulacoseira granulata* was rather high (Fig. 3). In flood periods, the large-sized benthic pennate diatoms *Cocconeis placentula* Ehr., *Cymatopleura elliptica* (Brebb.) W. Smith, *Navicula peregrina* (Ehr.) Kütz. and

![Graphs](image)

**Fig. 4.** Seasonal variations in Saprobic, Shannon indices and water discharge ($x10^7$ m$^3$/day) (A), correlation the number of species, density, biomass of the potamoplankton with water discharge (B-D) and nutrients with biomass (F-H), seasonal variation of nutrients and water temperature (E) in the midstream of the Ob River near Barnaul city, 2001.
Didymosphaenia geminata (Lyngb.) M. Schmidt prevailed in the potamoplankton. Other large-celled algal taxa, such as Glenodinium quadridens (Stein) Schill. (domination frequency – 23.1%) from Dinophyta and diatom Melosira varians Ag. (15.4%) were occasionally abundant. Green algae were dominant and subdominant during summer. The share of green algae exceeded that of the diatoms in late May. Here, the species of genus Monoraphidium Kom.-Legn. (20.6% of total density), i.e. M. contortum (Thur.) Kom.-Legn. (16.9% of total abundance), M. arcuatum (Korsh.) Hind., M. griffithii (Berk.) Kom.-Legn. were the most abundant.

The quantitative development of smaller forms of algae, especially diatoms, i.e. Cyclotella and Stephanodiscus species is one of the features of the Upper Ob potamoplankton. One more characteristic of the Ob River potamoplankton is the prevalence of benthic diatoms in species number and biomass. Immediately after the breakup of river’s ice, the centric diatoms (Aulacoseira spp. – 15.5% of total abundance) were the most abundant in the potamoplankton, whereas the benthic forms prevailed in mid and late spring. The larger contribution of benthic diatoms to potamoplankton abundance during the flood period is one of the peculiarities of plankton in rivers of the Northern hemisphere; the Ob River is not an exception (Mitrofanova, 1999). The small centric diatoms dominated in the summer assemblages of Ob River (up to 63.0% of total abundance at the end of August). Even in rivers where potamoplankton predominates a significant portion of the community can be benthic or epiphytic taxa. Sedimentation of the main channel populations and local inputs of algae from dead zones, weed-beds, and benthos could represent the important processes contributing to community structure (Reynolds, 1994). These mechanisms and sources would contribute to the variation in taxonomic composition between rivers (Chételat et al., 2006).

The study sites of the Ob River potamoplankton were situated on the different banks of the river and in the midstream. We expected higher algal biomass in the samples taken close to the banks because during the periods of low water the shallows and river arms served as potamoplankton sources (Stoineva, 1994). However, the potamoplankton of the Upper Ob was more abundant in the midstream and less near the left bank. Perhaps, such a distribution of the plankton algae

Fig. 5. The oriented multigraph of binary relations based on the set of multitude descriptions of species composition of the Ob potamoplankton near Barnaul city during the period of open water, 2001: I – potamoplankton observed just after the ice-breaking; II – potamoplankton of the first and second floods; III – potamoplankton of the low water in summer and autumn; overlaps with σ e” 55 were used. The arrows show direction and how many species of one algae community are included in another one, %.
was due to the specific features of the river at the sampling sites, e.g. high sand-clay left bank, constant water turbidity, the coastal erosion, high concentration of suspended material and low water transparency. Similar distribution of the potamoplankton along the channel cross-section was already discussed in a previous study of the Upper Ob (Mitrofanova, 1999). The algae density in the river near Barnaul on April 30, 1998 was the highest in the midstream (125.3×10^3 cells/L) and the lowest near the left bank (91.5×10^3 cells/L). A different spatial distribution of the potamoplankton was revealed in Lena River with its peak in development occurred near the left bank close to Yakutsk city (Remigailo and Gabyshev, 1999), though the absolute values of the potamoplankton number and biomass were within the same limits.

In general, the potamoplankton of the Upper Ob River is less abundant than that of the more eutrophic rivers like the Lower Danube River in Serbia (Čađjo et al., 2006) and the Hungarian Danube section (Schmidt, 1994). The high water level during flood periods probably deteriorated potamoplankton development in Ob River near Barnaul. It is well known, that hydrological and hydrodynamic factors, such as discharge or water residence time, are essential for the plankton development in rivers (Reynolds and Descy, 1996). We analyzed the correlation between the potamoplankton characteristics, abiotic variables and water discharge (Table 1). The density of the potamoplankton was strongly negatively correlated with water runoff and slightly – with the concentration of ammonia nitrate. The number of species was strongly positive correlated with water temperature and negatively correlated with nitrates. As is generally known the development of the most part of algae species is depended on the water temperature, especially warmer one, e.g. green algae which are abundant in the potamoplankton in summer. Moreover, the available nutrients in the water influence on the species development as well. The Saprobic Index was strongly correlated practically with all analyzed parameters. The positive correlation was established between the Saprobic Index and water temperature, as well as phosphates, the negative one – between the Saprobic Index and nitrates. Thus, most of the potamoplankton characteristics have some strong correlations with environmental variables considered, and physical factors (e.g. hydrological variables) and major nutrients (e.g. nitrates) were of equal importance for controlling the variation in structure and abundance of the large lowland Upper Ob River potamoplankton.

Some dimensional dependences among the key abiotic factors were identified due to the analysis of the Spearman rank correlation coefficient and water discharge changes (Fig. 4B-D, F-H). The curves of changes in potamoplankton characteristics along the axis of water discharge are of a cupped or domed shape. This means that characteristics of the potamoplankton may be changed to maximum permissible levels of a key factor. However, with further quantitative increase of the factor and its influence, the development of potamoplankton vary. Hydrochemical characteristics of the Ob River water and water temperature are important factors for the potamoplankton development. According to the literature, the hydrochemical state of the river near Barnaul remains virtually all the year round (Temerev, 2006). The municipal-industrial effluents from the city made an effect on the total amount of dissolved solids, the content of suspended matter, concentration of nitrates and nitrites, hardness, alkalinity, oxidation susceptibility and biological oxygen demand (Yatsenko and Vasiliev, 2008, Eyrikh et al., 2008). The data on some hydrochemical characteristics for the Ob River water in 2001 are shown in Fig. 4E. The spring maximum of nutrient concentrations was induced by flood and deterioration of self-purification processes in the river ecosystem. The second maximum occurred in late summer during the period of low water. However, none of these variables exceeded the maximum allowable concentration and did not influence strongly on the river plankton. Upstream from Barnaul there are no large cities or other sources of pollution. Thus, the structure

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Table 1. Spearman rank correlations (n=12) of hydrological, hydrophysical and hydrochemical parameters with characteristics of the potamoplankton in Ob River near Barnaul, 2001: N – density, B – biomass.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coefficient of correlation</th>
<th>Number of species</th>
<th>Shannon Index</th>
<th>Saprobic Index</th>
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<td></td>
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<td>Biomass</td>
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<td>on B</td>
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<tr>
<td>Phosphates</td>
<td>0.51</td>
<td>0.31</td>
<td>-0.45</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Table 2. The correspondence of biological indicators to the classes of water quality.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Class of water quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Very pure</td>
</tr>
<tr>
<td>1 Maximum pure</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>2a Very pure</td>
<td></td>
</tr>
<tr>
<td>2b Quite pure</td>
<td></td>
</tr>
<tr>
<td>3a Pure enough</td>
<td></td>
</tr>
<tr>
<td>3b Slightly contaminated</td>
<td></td>
</tr>
<tr>
<td>4a Moderately contaminated</td>
<td></td>
</tr>
<tr>
<td>4b Heavily contaminated</td>
<td></td>
</tr>
<tr>
<td>5a Highly contaminated</td>
<td></td>
</tr>
<tr>
<td>5b Extremely contaminated</td>
<td></td>
</tr>
<tr>
<td>Biomass, g/m³</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Saprobiic Index</td>
<td>= 0.5</td>
</tr>
<tr>
<td>Shannon Index</td>
<td>&gt;3.06</td>
</tr>
<tr>
<td>Trophic status</td>
<td>Oligotrophic</td>
</tr>
<tr>
<td>Saprobiic status</td>
<td>Xeno-</td>
</tr>
<tr>
<td>Crisis zone</td>
<td>Background state</td>
</tr>
<tr>
<td>Ecological modification</td>
<td></td>
</tr>
</tbody>
</table>

Note: typical characteristics for the Ob River potamoplankton near Barnaul city are in grey cells; References: Oksiyuk et al., 1994 (class of water quality, biomass, trophic status); Barinova et al., 2006 (the Saprobiic and Shannon Indices, saprobiic status and crisis zone); Abalkumov 1994 (the theory of ecological modifications).
and abundance of the potamoplankton here could be determined most likely by local physical and chemical conditions than by anthropogenic impact. Prediction of present potamoplankton development in the Upper Ob implied the analysis of the data on chlorophyll-a concentrations in the river near Barnaul for 2001 (Kirillova et al., 2007) and 2012 (Kotovshchikov and Dolmatova, 2013). In April-September, 2001 chlorophyll-a concentration varied from 2.8 to 12.0 in midstream with 7.2±1.1 mg/m$^3$ on the average (Kirillova et al., 2007) and average potamoplankton biomass was 322.9±35.7 mg/m$^3$. Thus, the mean ratio of chlorophyll-a in biomass was counted as 2.2%. In 2012, under extremely low mean water discharge (1438 m$^3$/s for the period of open water) chlorophyll-a concentrations varied from 1.8 till 37.3 mg/m$^3$ at the average of 12.2±0.9 mg/m$^3$ (Kotovshchikov and Dolmatova, 2013). At the same proportion of chlorophyll-a in biomass, the average biomass in 2012 was expected to be approximately 500 mg/m$^3$. However, even such a low river runoff and high chlorophyll-a content averaging between 10-30 mg/m$^3$ could not change the trophic state of the Upper Ob that is still oligotrophic by average potamoplankton biomass up to 1 g/m$^3$ during the growing season (Trifonova, 1990).

The results of the saprobiologic analysis show that 54 saprobic indicators among 158 species and forms exist in the potamoplankton. The greatest number of bioindicators belong to β-mesosaprobionts (34 taxa, or 63%). The Saprobi Index varied from 1.32 to 2.10 (Fig. 4A), and the mean value was 1.67±0.03 that corresponds to the oligo-beta-mesosaprobic zone (up to 2.50) and moderate organic pollution of the Upper Ob River near Barnaul during the ice-free period. Previously, the status of the Upper Ob was perceived as mesotrophic (Naumenko, 1995, 1996). The Saprobi Index highly correlated with water temperature and phosphates amount (Table 1). The lack of high value and significant seasonal variations of Saprobi Indices can be related to a less contamination and/or the river’s capability to self-purification. According to the complex ecological classification of water quality (Oksiyuk et al., 1994) and the qualitative/quantitative characteristics of the potamoplankton, the Ob water near Barnaul is qualified as “slightly contaminated” (Table 2). By the six-class evaluation scheme of the Water Framework Directive (Directive 2000/60/EC. 2000) it is a “moderately contaminated” water body (Chovanec et al., 2000). In Russia, we use the scheme consisted of five classes and nine categories of water quality. The difference among the five- and six-classes schemes of ecological classification of water quality is given in Table 2. A set of the methods for river plankton assessment based on the characteristics of algae community as a whole and on their functional groups has been developed. For instance, the Hungarian potamoplanktic method (Borics et al., 2007) uses the functional groups of phytoplankton specified by Reynolds et al. (2002). The method is focused on those environmental elements that are specific for rivers or ecologically important (Piirsoo et al., 2010). A number of indices of water quality were determined solely for diatoms—the index of Descy (1979), the diatom assemblage index of organic water pollution (Watanabe et al., 1988), etc. All these indices are specific in different water bodies; therefore, they should be adapted to a concrete water body. Sometimes the estimate of the factor could be based on expert judgment and the settings of the boundaries of index could be rather subjective (Borics et al., 2007).

In the study, we used the method that allows to characterize the changes in the Ob River ecosystem occurred over the last few years. It is based on the theory of ecological modifications (Abakumov, 1991) since different conditions of aquatic ecosystems correspond to different levels of anthropogenic load. The environmental state can be classified as follows: (a) a background stage; (b) a stage of ecological progress or human-induced environmental stress; (c) a stage of ecological regress; (d) a stage of ecological modulation. The first one admits the ecosystem state restructuring feasible, without its complexity or simplification. The second is manifested in the increased biocenoses diversity, complexity of interspecific interactions, spatial and temporal heterogeneity caused by complication of the food chain. The stage of ecological regress is characterized by decrease in species diversity and spatial-temporal heterogeneity, interspecific interactions and simplification of trophic chains. The last stage—when some extra load may bring the ecosystem to the crisis, is the boundary one. The ecosystem stages correspond to classes of water quality used in the European water quality classification following the scheme of the Water Framework Directive. According to the description of crisis zones by Barinova et al. (2006), the ecosystem stages also correspond to the stages of “reversible changes” and “threshold state”, (Table 2). As the authors note, when the Saprobi Index ranges from 0 to 3.0, the algae community can move either in the direction of saprobity increase and diversity reduction, or towards the opposite one (“reversible changes”). This state is called the restoration of natural conditions due to self-purification processes. When the Saprobi Index varies from 3.0 to 3.5, the biodiversity decreases and it is very hard for the community to return to the previous trophic level; it is feasible only at the conservation projects implementation (“threshold state”). Currently, the state of the Upper Ob can be attributed to the stage of “ecological progress”.
CONCLUSIONS

This study suggests that the ecosystem of the unregulated large lowland river, the Upper Ob near Barnaul is in stable state maintained by active processes of self-purification due to the presence of diverse and abundant potamoplankton. The composition and seasonal changes of plankton are similar to those in other large lowland regulated or unregulated but less eutrophic rivers of the Northern hemisphere. The analysis indicated that physical factors (e.g. hydrological variables) and major nutrients (e.g. nitrates) were of equal importance for controlling the variation in structure and abundance of the large lowland Upper Ob River potamoplankton. The ecological state of the sampling area is assessed as “quite pure” by potamoplankton biomass and “slightly contaminated” – by the Saprobi Index, thus corresponding to I (very pure), II (pure) and III (slightly contaminated) classes of water quality. According to the description of crisis zones, the environmental status of the river is still good and corresponds to the stages of “reversible changes” and “threshold state”. Similar to numerous large world rivers, the Upper Ob is in need of care to avoid its deterioration, especially during the flood periods when the potamoplankton is not diverse and can’t maintain the self-purification processes. The “ecological regress” state (Abakumov, 1991) was not revealed because the decrease in potamoplankton diversity, simplification in the food chain and temporal structure are absent. This study can be used as a basis for monitoring of large unregulated rivers.

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REFERENCES


Bazhenova, O. P. (2005). The potamoplankton of Upper and Middle Irysh River in the conditions of regulated run-off. (Omsk: Omsk State Agrarian University Publisher)


Kirillova, T. V., Kotovshchikov, A. V., Kirillov, V. V. (2007). The content of chlorophyll-α in phytoplankton as indicator


Korytny, L. M. (2001). The catchment basin concept in nature management. (Irkutsk: Institute of Geography SB RAS Publisher)


Mitrofanova, E. Yu. (1999). The potamoplankton of Ob River as an indicator of its water quality. (In V. V. Zuev (Ed.), The ecology of floodplain of Siberian rivers and the Arctic (pp. 57-62). Novosibirsk: Nauka Publisher)


