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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 (53º21'24"N, 83º47'14"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/m³ 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.

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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 167.5×10^3cell/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 204.9×10^3cell/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 2.9×10^6 km^2 with an average water discharge of 12.7×10^3 m^3/s (max. 42.8×10^3 m^3/s) at the river mouth and in the Upper Ob near Barnaul – 1.49×10^3 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 600× magnification. The results were expressed in terms of cell abundance using the formula:

$$N = n\,V_1 / ((V_2\,V_3)\,0.001) \quad (1)$$

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:

$$B = N\,V_4\,n \quad (2)$$

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

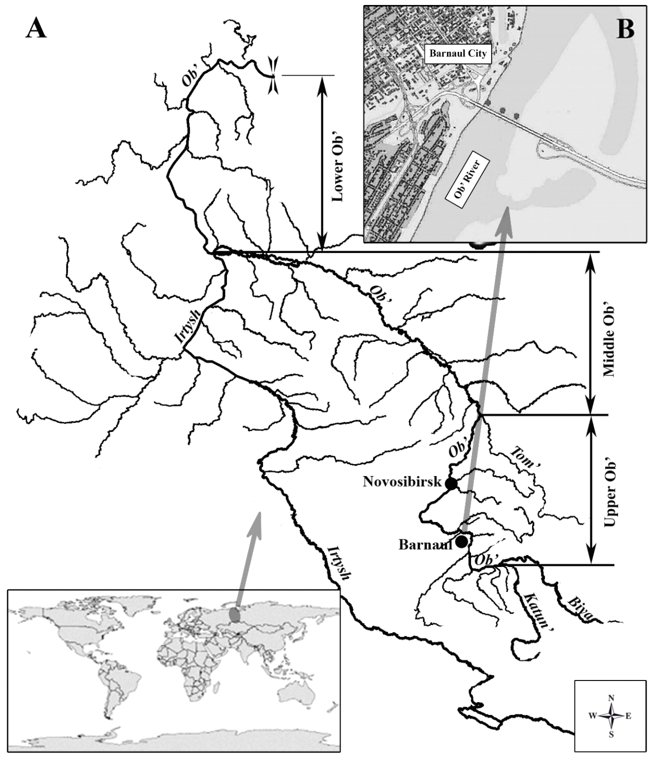


Fig. 1. The scheme of the Ob River basin (A) and potamoplankton sampling sites in the river near Barnaul city (B), 2001

highest relative abundance (cell number or biomass) were taken as dominant. The frequency of domination was calculated using the formula:

$$D = (n/N)\ 100\% \quad (3)$$

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 Sladeček (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):

$$\sigma (A; B) = c/b \text{ and } \sigma (B; A) = c/a \quad (4)$$

where σ (A; B) – the measure of inclusion of flora B in flora A, σ (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 to the water that decreases its transparance to a minimum. As is generally known due to the Coriolis effort 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 (Remigailo and Gabyshev, 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 (Piirsoo *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%) (Ržaničanin *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 Yesihrmak River (Turkey) (Soylu and Gönülol, 2003), however, the dominance of diatoms also occured. 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. invisitatus* Hohn et Heller. f. *invisitatus*, *S. triporus* Genkal et Kuzmina, *Cyclostephanos 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).

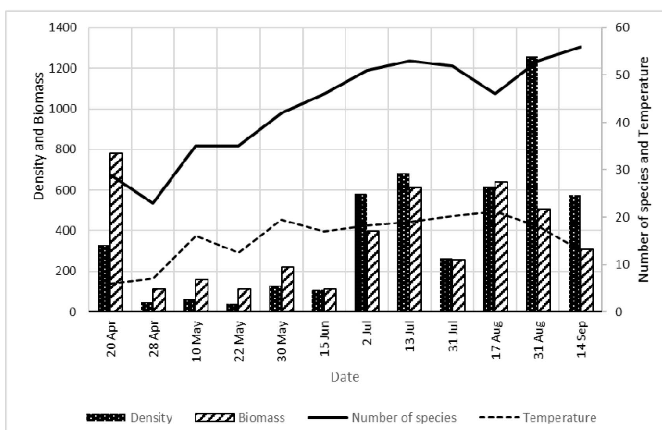
Green algae were the second most diverse group, including euplanktic Chlorococcales taxa. The most abundant genus was *Scenedesmus* Meyen with 15 species, among the Volvocales *Pandorina morum* (O.Müll.) Bory and species of *Chlamydomonas* Ehr. and *Platymonas* G.S. West were found. The number of green 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

A



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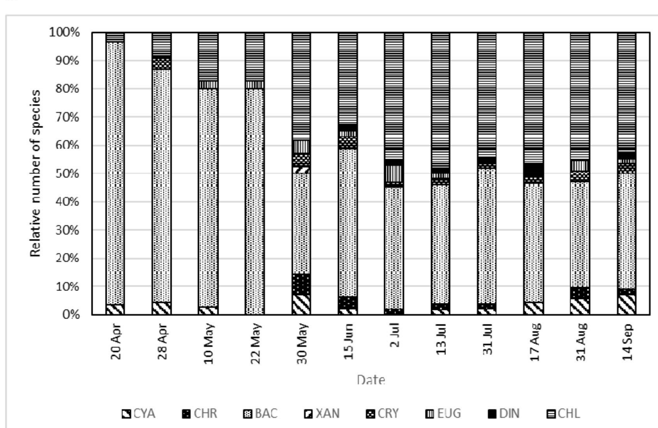

Fig. 2. Seasonal variations in (A) number of species, abundance (×10^3 cells/L), biomass (mg/m^3), water temperature (°C) and (B) relative diversity (number of species, %) of potamoplankton in the midstream of the Ob River near Barnaul city, 2001 (CYA – Cyanobacteria, CHR – Chrysophyceae, BAC – Bacillariophyceae, XAN – Xantophyceae, CRY – Cryptophyta, EUG – Euglenophyta, DIN – Dinophyta, CHL – Chlorophyta)

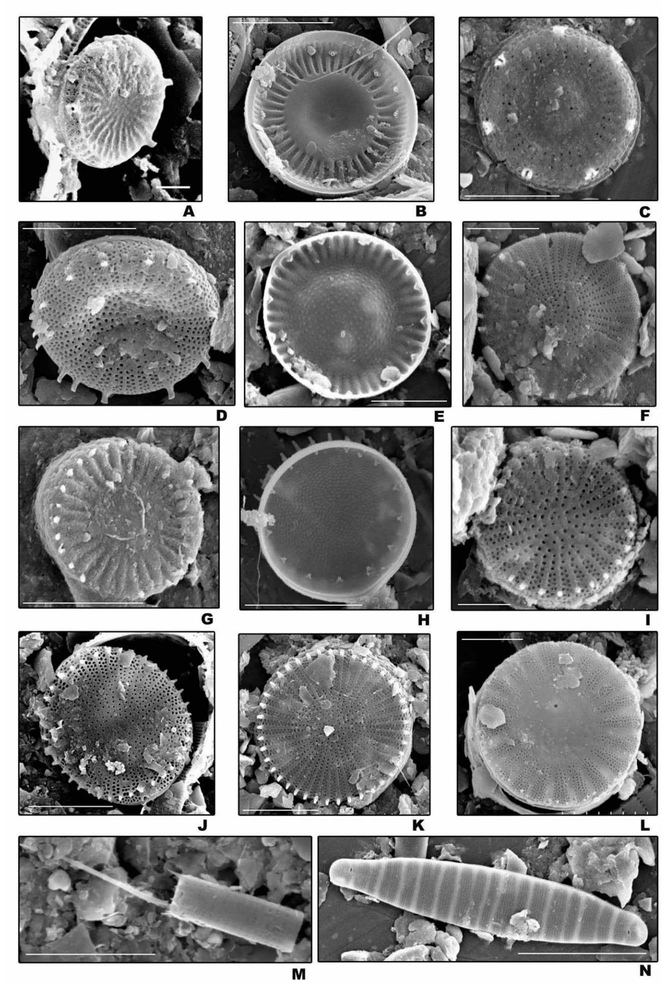

Fig. 3. Dominant diatoms of the Ob River potamoplankton: A, C – *Discostella pseudostelligera* (Hust.) Houk et Klee, B – *D.* cf. *stelligera* (Cl. et Grun.) Houk et Klee, D-F – *Cyclostephanos dubius* (Fricke) Round, G – *Cyclotella meneghiniana* Kütz., H – *Stephanodiscus hantzschii* Grun., I – *S. minutulus* (Kütz.) Cl. et Möll., J – *S. triporus* Genkal et Kuzmina, K – *S. invisitatus* Hohn et Hell. f. *invisitatus*, L – *Cyclotella atomus* Hust., M – *Aulacoseira granulata* (Ehr.) Sim., N – *Diatoma tenuis* Ag. SEM. Scale bar: A – 1 µm, I, L – 2 µm, B-F, J-K – 5 µm, G-H, M-N – 10 µm.

those for other rivers of the Northern hemisphere (Descy, 1987; Kiss *et al.*, 1994; Skidmore *et al.*, 1998; Várbíró *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/m^3 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/m^3 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/m^3, 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/m^3), and the lowest – at the left bank (259.9×10^3 cells/L and 269.5 mg/m^3). 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 (Remigailo and Gabyshev, 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 15.5-42.1×10^3 cells/L throughout the flood period and up to 154.9×10^3 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* (Breb.) W. Smith, *Navicula peregrina* (Ehr.) Kütz. and

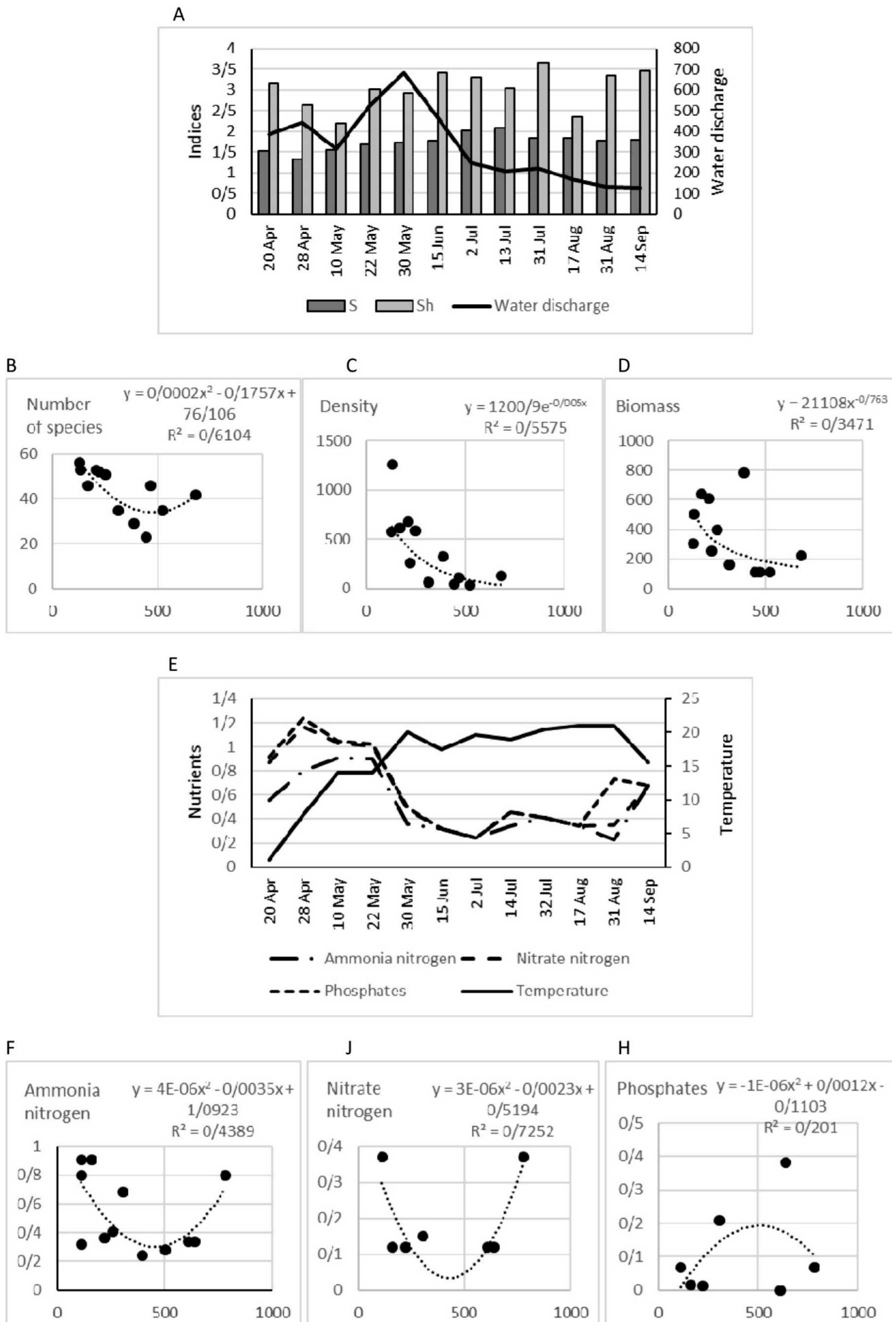

Fig. 4. Seasonal variations in Saprobic, Shannon indices and water discharge (x10^7 m^3/day) (A), correlation the number of species, density, biomass of the potamoplankton with water discharge (B-D) and nutrients with biomass (F-H), seasonal variation of nutrients and water temperature (E) in the midstream of the Ob River near Barnaul city, 2001.

Didymosphaenia geminata (Lyngb.) M. Schmidt prevealed 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

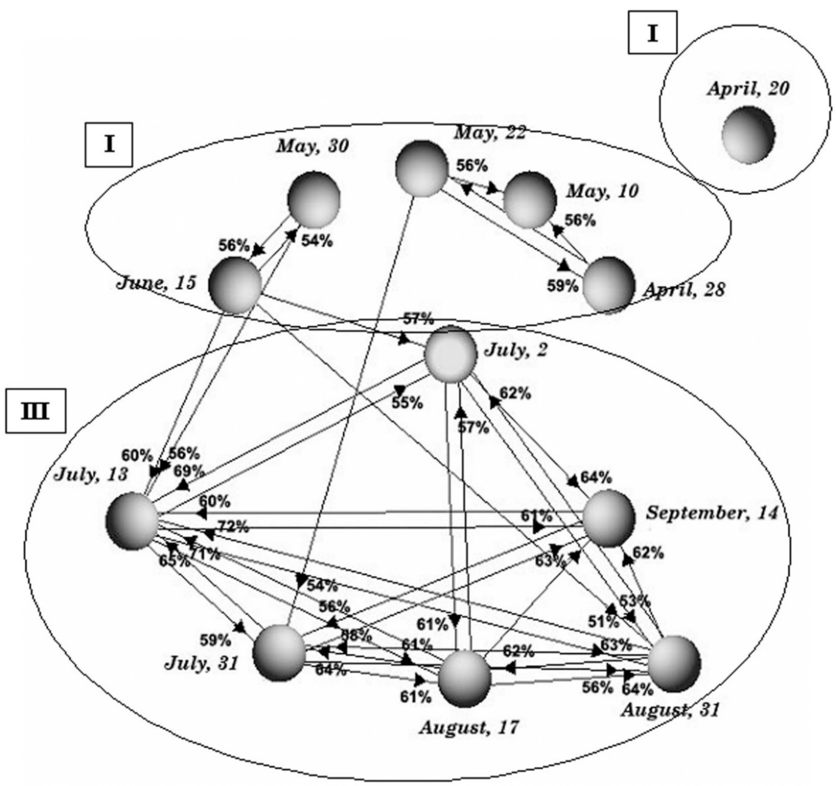

Fig. 5. The oriented multigraph of binary relations based on the set of multitude descriptions of species composition of the Ob potamoplankton near Barnaul city during the period of open water, 2001: I – potamoplankton observed just after the ice-breaking; II – potamoplankton of the first and second 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, %.

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.

Parameter	Coefficient of correlation					
	Density	Biomass	Number of species	Shannon Index		Saprobic Index
				on N	on B	
Water discharge	-0.74	-0.48	-0.60	0.44	0.02	-0.44
Water temperature	0.51	0.08	0.80	0.10	0.11	0.83
Ammonia nitrate	-0.56	-0.28	-0.72	0.22	0.29	-0.74
Nitrate nitrogen	-0.37	0.09	-0.78	-0.30	0.16	-0.74
Phosphates	0.51	0.31	0.31	-0.45	0.02	0.87

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, 2006, 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 occured 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

Table 2. The correspondence of biological indicators to the classes of water quality.

Indicator	Class of water quality								
	I Very pure	II Pure		III Slightly contaminated		IV Dirty		V Very dirty	
	1 Maximum pure	2a Very pure	2b Quite pure	3a Pure enough	3b Slightly contaminated	4a Moderately contaminated	4b Heavily contaminated	5a Highly contaminated	5b Extremely contaminated
	I Very pure		II Pure	III Moderately contaminated		IV Contaminated		V Dirty	VI Very dirty
Biomass, g/m^3	<0.1	0.1-0.5	0.6-1.0	1.1-2.0	2.1-5.0	5.1-10.0	10.1-50.0	50.1-100.0	>100.0
		0.1-0.8							
Saprobic Index	= 0.5	0.6-1.0	1.0-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0
			1.32-2.10						
Shannon Index	>3.06	3.06-2.30	2.30-1.89	1.89-1.52		1.52-1.25		1.25-1.11	
	2.31-3.64								
Trophic status		Oligotrophic		Mesotrophic		Eutrophic		Polytrophic	Hypertrophic
Saprobic status	Xeno-	Oligo-		β-meso-		α-meso-		Poly-	
Crisis zone	Reversible changes						Threshold state	Irreversible changes	
Ecological modification	Background state	Ecological progress				Ecological regress		Ecological modulation	

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 Saprobic and Shannon Indices, saprobic status and crisis zone); Abakumov 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 amounted 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 Saprobic 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 Saprobic Index highly correlated with water temperature and phosphates amount (Table 1). The lack of high value and significant seasonal variations of Saprobic 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 Saprobic 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 Saprobic 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 Saprobic 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

Abakumov, V. A. (1991). Ecological modifications and biocenoses development. (In V. A. Abakumov, L. M. Sushchenya, (Eds.), Ecological modifications and criteria of ecological standardization (pp. 18-40). Leningrad: Gidrometeoizdat)

Andreev, V. L. (1980). Classification constructions in ecology and taxonomy. (Moscow: Nauka)

Barinova, S. S., Medvedeva, L. A. and Anissimova, O. V. (2006). Diversity of algal indicators in environmental assessment. (Tel Aviv: Pilies Studio)

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

Blocksom, K. A. and Johnson, B. R. (2009). Development of a regional macroinvertebrate index for large river bioassessment. Ecological indicators, **9**, 313-328.

Borics, G., Várbiró, G., Grigorsky, I., Krasznai, E., Szabo, S. and Kiss, K. T. (2007). A new evaluation technique of potamoplankton for the assessment of the ecological status of rivers. Arch. Hydrobiol. Suppl., **161 (3-4)**, 465-486.

Cadjo, S., Miletic, A. and Djurkovic, A. (2006, May). Phytoplankton, physicochemical and saprobiological characteristics of the Danube river, on the stretch through Serbia. (Paper presented at the Conference on Water Observation and Information System for Decision Support, Ohrid, Repaplic of Macedonia)

Chételat, J., Pick, F. R., Hamilton, P. B. (2006). Potamoplankton size structure and taxonomic composition: Influence of river size and nutrient concentrations. Limnology & Oceanography, **51**, 681-689.

Chovanec, A., Jäger, P., Jungwirth, M., Moog, O., Muhar, S., Schmutz, S. (2000). The Austrian way of the assessing the ecological integrity of running waters: a contribution to the EU Water Framework Directive. Hydrobiologia, **422/423**, 445-452.

Descy, J.-P. (1979). A new approach to water quality estimation using diatoms. Beih. Nova Hedw., **64**, 305-323.

Descy, J.-P. (1987). Phytoplankton composition and dynamics in the river Meuse (Belgium). Arch. Hydrobiol., Suppl. 78 (2), Algological Studies, **47**, 225-245.

Descy, J.-P., Leitao, M., Everbecq, E., Smitz, J. S., Deliége, J.-F. (2012). Phytoplankton of the River Loire, France: a biodiversity and modeling study. J. of Plankton Research, **34 (2)**, 120-135.

Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy, of 23 October 2000. Official J. of the European Communities, **327**, 1-72.

Dynesius, M., Nilsson C. (1994). Fragmentation and flow regulation of river systems in Northern third of the world. Science. New Series, **266 (5186)**, 753-762.

Eyrikh, A. N., Eyrikh, S. S., Serykh, T. G., Tretjakova, E. I. (2008). Problems of ecoanalitical control over large rivers (Ob River as a case study). Polzunov Vestnik, **1-2**, 157-160.

Hašler, P., Hindak, F., Hindakova, A. (2007). Phytoplankton of the Morava and Dyje Rivers in spring and summer 2006. Fottea, Olomouc, **7**, 49-68.

Istvánovics, V., Honti M., Vörös, L., Kozma, Z. (2010). Phytoplankton dynamics in relation to connectivity, flow dynamics and resource availability – the case of a large, lowland river, the Hungarian Tisza. Hydrobiologia, **637**, 121-141.

Kirillova, T. V., Kotovshchikov, A. V., Kirillov, V. V. (2007). The content of chlorophyll-*a* in phytoplankton as indicator of the long-term dynamics of Ob River water quality at Barnaul city. (In G. G. Onishchenko (Ed.), Drink waters of Siberia (pp. 115-120). Barnaul: Five Plus Publishing).

Kiss, K. T., Ács, É., Kovács, A. (1994). Ecological observations of *Skeletonema potamos* (Weber) Hasle in the River Danube near Budapest (1991-92, daily observations). Hydrobiologia, **289**, 163-170.

Kobbia, I. A., Hassan, S. K. M., Shoulkamy, M. A. (1991). Dynamics of potamoplankton succession in the river Nile at Minia (Upper Egypt); as influenced by agricultural runoff. J. of Islamic Academy of Science, **4**, 234-241.

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

Kotovshchikov, A. V., Dolmatova, L. A. (2013). Seasonal dynamics of phytoplankton pigment characteristics in the upper Ob River in 2012 and its correlation with hydrochemical and hydrological parameters. (Paper presented at the XV School-conference of young scientists "Biology of the inner waters". Kostroma)

Kozhova, O. M. (1970). The formation of potamoplankton in Bratsk reservoir. (In O. M. Kozhova (Ed.), The formation of environment and life in Bratsk reservoir (pp. 26-171). Moscow: Nauka Publisher)

Kriksunov, E. A., Pushkar, V. Ya., Lobyrev, F. S., Burmensky, V. A., Shchegolkova, N. M., Bobyrev, A. E. (2006). Structure functional organization of biocenoses and ichthyofauna of Moscow River near the city. Water Resourses, **33**, 701-710.

Kuksn, M. S. (1964). A review of Ob River algaeflora study. (In T. G. Popova (Ed.), Algae and Fungi of Siberia and the Far East. I (8) (pp. 13-18). Novosibirsk: Nauka Publisher)

Kuksn, M. S., Levadnaya, G. D., Popova, T. G., Safonova, T. A. (1972). Algae of Ob River and its floodplain. (In T. G. Popova (Ed.), Algae and Fungi of Siberia and the Far East. II (4) (pp. 3-44). Novosibirsk: Nauka Publisher)

Meybeck, M. (2003). Global analysis of river systems: from Earth system controls to Anthropocene syndromes. Phil. Trans. R. Soc. Lond., **B 338**, 1935-1955.

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)

Mitrofanova, E. Yu. (1996). The taxonomic composition and abundance of algae in different parts of Ob River in 1991-1994. (In A. N. Kupriyanov (Ed.), Botanical investigations in Siberia and Kazakhstan (pp. 139-147. Barnaul: Altai State University Publisher)

Muylaert, K., Sanchez-Pérez, J.M., Teissier, S., Sauvage, S., Dauta, A., Vervier, P. (2009). Eutrophication and its effect on dissolved Si concentrations in the Garonne River (France). J. of Limnology, **68**, 368-374.

Naumenko, Yu. V. (1995). Algae of Ob River potamoplankton. (Novosibirsk: Nauka Publisher)

Naumenko, Yu. V. (1996). The potamoplankton of Ob River. Dissertation, Central Siberian Botanical Garden, Novosibirsk.

Oksiyuk, J. P., Zhukinsky, V. N., Braginsky, L. P., Linnik, P. N., Kuz'menko, M. I., Klenus, V. G. (1994). An Integrated Ecological Water-Quality Classification for Continental Surface Waters. Hydrobiological J., **30**, 80-95.

Piirsoo, K., Pall, P., Tuvikene, A., Viik, M., Vilbaste, S. (2010). Assessment of water quality in a large lowland river (Narva, Estonia/Russia) using a new Hungarian potamoplanktic method. Estonian J. of Ecology, **59**, 243-258.

Remigailo, P. A., Gabyshev, V. A. (1999). The peculiarities of the potamoplankton development in Middle Lena River (Russia). Algology, **9**, 122-123.

Reynolds, C. S. (1994). The long, the short and the stalled: on the attributes of phytoplankton selected by physical mixing in lakes and rivers. Hydrobiologia, **289**, 9-21.

Reynolds, C. S., Descy, J.-P. (1996). The production, biomass and structure of phytoplankton in large rivers. Arch. fur Hydrobiologie, **113**, 161-187.

Reynolds, C. S., Huszar, V., Kruk, C., Naselli-Flores, L., Melo, S. (2002). Towards a functional classification of the freshwater phytoplankton. J. of Plankton Research, **24**, 417-428.

Ržaničanin, A., Cvijan, M., Krizmanič, J. (2005). Phytoplankton of the Tisa river. Arch. Biol. Sci., **57**, 223-235.

Safonova, T. A. (1996). Algae of Katun River (Gorny Altai, Russia): Diversity, taxonomic composition. Algology, **6**, 42-48.

Schmidt, A. (1994). Main characteristics of the phytoplankton of the Southern Hungarian section of the River Danube. Hydrobiologia, **289**, 97-108.

Semkin, B. I., Oreshko, A. P., Gorshkov M. V. (2009). On the use of bioinformation technologies in comparative floristic studies. II. Measures of inclusion of descriptive sets and their application. Bulletin of the botanical garden-institute of FEB RAS, **4**, 58-78.

Shannon, C. E., Weaver, W. (1963). The Mathematical Theory of Communication. (Champaign: University of Illinois Press, IL, USA)

Skidmore, R. E., Maberly, S. C., Whitton, B. A. (1998). Patterns of spatial and temporal variation in phytoplankton chlorophyll a in the River Trent and its tributaries. Science of the Total Environment, **210/211**, 357-365.

Solonevskaya, A. V. (1964). Dynamics of seasonal development and runoff of the Upper Ob potamoplankton within Kamen' city and Dubrovino set. (In T. G. Popova (Ed.), Algae and Fungi of Siberia and the Far East. I (8) (pp. 69-81). Novosibirsk: Nauka Publisher)

Soylu, E. N., Gönülol, A. (2003). Potamoplankton and seasonal variations of the River Yesilirmak, Amasya, Turkey. Turish J. of Fisheries and Aquatic Sciences, **3**, 17-24.

State Water Cadaster. Surface waters. Annual data on the regime and resources of surface waters in 2001. (2003). Rivers and canals. The Ob basin, **6 (0-3)**. (Novosibirsk: Gidrometeoizdat)

Stoineva, M. P. (1994). Shallows of the lower Danube as the additional source of potamoplankton. Hydrobiologia, **289**, 171-178.

Temerev, S. V. (2006). Interaction of water ecosystems with the water-collection surface for the Ob-Irtysh basin as an example. Siberian Ecological J., **6**, 773-783.

Trifonova, I. S. (1990). Ecology and succession of the lake phytoplankton. (Leningrad: Nauka Publisher)

Uniform methods of water quality study. 3. Methods of biological analyses of water. Appendix 2. Atlas of saprobic organisms. (1977). (Moscow)

Uniform methods of water quality study. 3. Methods of biological analyses of water. (1983). (Moscow)

Várbíró, G., Ács, É., Borics, G., Érces, K., Fehér, G., Grigorszky, I., Japport, t., Kocsis, G., Krasznai, E., Nagy, K., Nagy-László, Z., Pilinszky, Z., Kiss, K. T. (2007). Use of Self-Organizing Maps (SOM) for characterization of riverrine phytoplankton associations in Hungary. Arch. fur Hydrobiologie, **17**, 383-394.

Vasconcelos, V., Cerqueira, M. (2001). Phytoplankton community of river Minho (international section). Limnetica, **20**, 135-141.

Verasztó, Cs., Kiss, K. T., Sipkay, Cs., Gimesi, L., Vadadi-Fülöp, Cs., Türei, D., Hufnagel, L. (2010). Long-term dynamic patterns and diversity of phytoplankton communities in a large eutrophic river (the case of River Danube, Hungary). Applied ecology and environmental research, **8 (4)**, 329-349.

Watanabe, T., Asai, K., Houki, A. (1988). Biological information closely related to the numerical index DAIpo (Diatom Assemblage Index to Organic Water Pollution). The Jap. J. of Diatomology, **4**, 49-60.

Wetzel, R. G., Likens, G. E. (2000). Limnological Analyses. Third Edition. (New York: Springer-Verlag)

Yakubova, A. N. (1961). Main features of algae vegetation of Ob River in its upper reaches. Proceedings of Biological Institute, **7**, 65-79.

Yang, D., Baisheng Ye. B., Shiklomanov, A. (2004). Discharge Characteristics and Changes over the Ob River Watershed in Siberia. J. of Hydrometeorology, **5**, 595-610.

Yatsenko, E. S., Vasiliev, V. P. (2006). Anthropogenic pollution of the Ob River ecosystem near Barnaul city. Geography and natural resources, **2**, 48-52.