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The Structure of Phytoplankton and Physicochemical Characteristics of the Kolyma River (Northeastern Siberia) in Summer

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Abstract—The first results of a study of the phytoplankton and chemical composition of water of the entire Kolyma River are reported. The study revealed the spatial structure of the phytoplankton communities of river sections with various hydrologic conditions. The high diversity of the Kolyma River phytoplankton was established. It was acknowledged that the elemental composition and physical characteristics of the water are determined by environmental factors, mainly permafrost soils. Water quality was estimated by the physicochemical characteristics, sabrobic algae, and phytoplankton biomass of the water.

Keywords: Kolyma River, northeastern Siberia, phytoplankton, physicochemical characteristics, water quality

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INTRODUCTION

The Kolyma is a large river in the arctic basin of northeastern Siberia. The river is about 2600 km long. The area of its basin is 665000 km^2 [1]. The river rises among the spurs of the Chersk Range and crosses continuous permafrost soils. The river is dammed. There is a Kolyma hydropower station; its reservoir began to be filled in 1980. Another hydropower station will come into operation near the village of Ust'-Srednekan (Fig. 1).

The Kolyma River is still hard to access. There are only two papers [2, 3] on the phytoplankton of the upper Kolyma River reporting on the preconstruction species composition, as well as the quantitative characteristics of the development and structure of the phytoplankton of the Kolyma River in the flooded area of the reservoir. L.E. Komarenko published a paper on the algal flora of the middle Kolyma River [4]. I.I. Vasil'eva and E.V. Pshennikova [5] and I.I. Vasil'eva-Kralina et al. [6] give an account of the taxonomic structure of the river phytoplankton. However, it is impossible to distinguish data on the river phytoplankton in the floristic summary [4]. The other two papers [5, 6] don't contain a list of species, so we couldn't use them in a taxonomic analysis of phytoplankton. Data on the annual dynamics of dominant species of algal plankton communities of the lower Kolyma River, according to the Hydrometeorological Service reports, are given in the paper of A.M. Nikanorov et al. [7]. Works investigating the hydrochemistry of the river are scarce and insufficient [7].

The objectives of the study were (1) to study the taxonomic and ecologic–geographic compositions, the density and biomass of the phytoplankton, and the hydrochemistry of the river and (2) evaluate water quality from phytoplankton bioindicators and hydrochemical characteristics of the water.

MATERIALS AND METHODS

Samples for the study were collected July 21, 2010, through August 7, 2010, from river sections between the bridge (the Ten'ka highway) across the upper Kolyma River and the mouth of the Anyui River (Fig. 1). The section is 2010 km long. The river was divided into six sections according to its hydrology and hydrography.

Section A extends from the bridge (the Ten'ka highway) across the upper Kolyma River to the upper part of the Kolyma reservoir. The section is 167 km long. This part of the river flows across the Nera Plateau and has a meandering, braided course. The river depth varies from 1 m on riffles to 3 m in pools. Stream velocity is about 1.0–1.5 m s^{-1}. Secchi disk depth ranges here from 1.5 to 2.1 m. The banks and bed are mostly made up of pebbles. The average water temperature is 15.8°C.

Section B, the Kolyma Reservoir, has a length of 134 km. The valley of the river narrows and the river flows through a gorge. The banks are made of sand and coarse and fine pebble. The reservoir is 4.5 m deep in its upper part and 110 m at the dam. The volume is 14.5 km^3 and the area is 440 km^2. Secchi disk depth is 2.0–2.7 m. There is almost no flow. Water temperature varies with the sampling site from 9.5 to 19.4°C.

Section C is 728 km long. It extends from the dam tail water to the Oroek village. Here the river flows across mountain ranges, its valley broadening. The section of the river abounds in riffles and shallows. The course is braided, with many channels. The banks and bed are mainly made up of pebble. The stream velocity varies from 0.4 m s^{-1} in pools to 2.1 m s^{-1} on riffles. Secchi disk depth changes from 0.8 m in the upper section to 4.0 m in the lower section. The average water temperature is 18.5°C.

Section D is 253 km long, extending from the Oroek village to the mouth of the Ozhogina River. The course of the Kolyma River is braided, with many islands. There are fewer shallows and riffles than at the previous section. The banks and bed are mainly made up of pebble, with a great deal of sand in the lower section. Stream velocity is high, varying from 0.3 to 2.1 m s^{-1}. Secchi disk depth is 2.7–3.5 m. The average water temperature is 20.6°C.

Section E is 599 km long and extends from the mouth of the Ozhogina River to that of the Omolon River. In this course the Kolyma River enters the vast Kolyma Lowland, with numerous lakes and swamps, where it flows along the Yukaghir Plateau. Therefore, the left part of the Kolyma basin is low and formed by alluvial deposits; the right part is high and mountainous. Islands are few; the river mainly follows a single course. The banks and bed are made up of sand and silt, with an admixture of pebble. Stream velocity decreases to less than 1.1 m s^{-1}, averaging 0.8 m s^{-1}. Secchi disk depth varies from 1.6 to 2.7 m. Average water temperature is 17.2°C.

Section F is 129 km long. It extends from the mouth of the Omolon River to that of the Anyui River. The left part of the Kolyma basin is low and swampy, like that of Section E, and the right one is mountainous. There are few islands; the banks are muddy. The stream velocity is lower than at Section E, averaging 0.4 m s^{-1}. Secchi disk depth varies from 1.4 to 3.0 m. Average water temperature is 13.9°C.

A total of 40 water samples and 106 phytoplankton samples were collected for hydrochemical and algological analyses, respectively. Some samples were collected from the littoral and the others from the fairway of the Kolyma River (from a depth of 0–0.3 m in both cases). There were 53 sampling sites.

Sample fixation and water chemical analyses followed standard methods [8, 9]. Gas regime components (O_2, BOD_5, and CO_2) and some physical characteristics (Secchi disk depth, odor, taste, and suspended matter) were determined in situ. Concentrations of other chemicals were determined in the laboratory. Ionic constituents: Sulfate anions were determined by turbidimetry, chlorides by mercurometry, hydrocarbonates by back titration, water hardiness by complexometric titration with eriochrome black, calcium titrometrically with trilon B, and potassium and sodium cations by flame photometry. Taste and odor were assessed organoleptically using a point scale. Physical characteristics: Water transparency was determined using a Secchi disk; the color of water was determined by light absorption using an *SF-26* spectrophotometer. Toxic

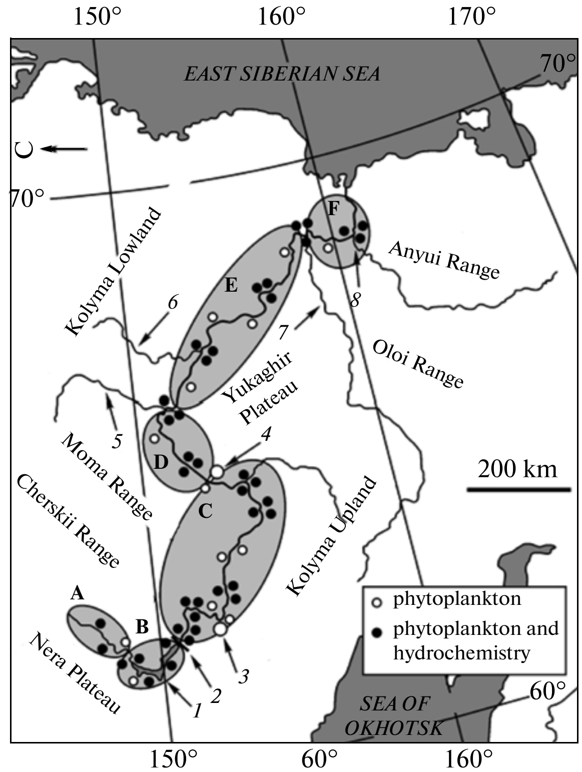

Fig. 1. The geographic location of the Kolyma River in northeastern Siberia and the sampling sites: (*1*) the Kolyma reservoir, (*2*) the dam of the Kolyma hydropower station, (*3*) the village of Ust'-Srednekan, (*4*) the village of Oroek, (*5*) the Ozhogina River, (*6*) the Sededema River, (*7*) the Omolon River, and (*8*) the Anyui River. (A–F) river sections.

pollutants: Total iron was measured by photometry with ammonium thiocyanate using an *SF-26 spectrophotometer*; phenols, petrochemicals, and anion surfactants were determined by fluorescence chromatography using a *Fluorat-02* spectrofluorometer. Other chemicals: Water pH was evaluated electrometrically using a *Multitest IPL-101* titrator; dissolved carbon dioxide by titration with phenolphthalein; dissolved oxygen by Winkler's method (iodometry); ammonium nitrogen photometrically, using Nessler's reagent and *SF-26;* nitrite nitrogen photometrically using Griss' reagent and the *SF-26*; nitrate nitrogen photometrically using sodium salicylate with the *SF-26*; phosphates by molybdenum blue method using the *SF-26*; total phosphorus by persulfate oxidation using the *SF-26*; hard-to-oxidize organic compounds (from chemical oxygen demand (COD)) photometrically using *Fluorat-02*; easy-to-oxidize organic compounds (from biological oxygen demand (BOD_5)) by Winkler's method (iodometry).

Water samples (1.5 L) for quantitative analyses of phytoplankton were concentrated on *Sartorius* membrane filters (pore size 1.2 μm) by pressure filtration using a phytoplankton concentrator of our own design

[10]. Samples for qualitative analyses were collected with an Apstein plankton net (SEFAR NITEX filter fabric, mesh size 30 μm). Microscopy was performed with an *Olympus BH2* microscope. Algal cells were counted in a Nageotte counting chamber (volume 0.01 cm^3). Biovolumes of algae were calculated by approximating the cell shape to simple geometrical shapes using our own linear measurements of cells. The volume to specific weight conversion factor was assumed to be 1. A taxonomic analysis of the phytoplankton structure involved methods of comparative floristics [11]. Hierarchical clustering was performed with the PAST data analysis package [12]. Floristic similarity was quantified with the Jaccard index. Algal biodiversity was quantified with the Shannon–Weaver index [13]. Ecological affiliations of the algae are given after S.S. Barinova et al. [14].

A complex assessment of water quality was performed using the classifications [15, 16] and the water quality standards for fisheries [17].

RESULTS

Physicochemical Characteristics. Waters of the Kolyma River had neither taste nor odor and were highly transparent (Secchi disk depth up to 4.0 m). Secchi disk depth was considerably lower (0.5–1.0 m) in confluences of some tributaries at sections C and E. The concentration of dissolved oxygen varied slightly (7.83–9.89 mg L^{-1}), making up 84–99% of the saturation level. The oxygen regime was favorable. The carbon dioxide content was low, ranging from 3.96 to 5.48 mg L^{-1}. Water pH was neutral to alkalescent, varying with the sampling site from 6.86 to 7.86. The suspended matter was low throughout the river, making up 10.00–14.20 mg L^{-1}. The color of water was low, from 5 to 14°.

According to major ionic constituents, the water had low salinity (82.96–170.26 mg L^{-1}), was very soft (0.80–1.66 mg-equiv), hydrocarbonate class (21–40%-equiv), calcium group (21–35%-equiv), type 2. Major ionic constituents were low, varying slightly with the sampling site. Hydrocarbonates were 32.95–87.87 mg L^{-1}, sulfate anions 8.17–46.59 mg L^{-1}, calcium cations 9.62–33.27 mg L^{-1}, magnesium cations 2.19–13.12 mg L^{-1}, sodium cations 5.00–10.00 mg L^{-1}, chlorides 2.84–5.32 mg L^{-1}, and potassium 0.50–2.00 mg L^{-1}.

The water of the Kolyma River had low concentrations of nitrate nitrogen (0.07–0.28 mg L^{-1}), nitrite nitrogen (0.003–0.014 mg L^{-1}), silicon (1.14–2.64 mg L^{-1}), mineral phosphorus (0.01–0.11 mg L^{-1}), and total phosphorus (0.02–0.18 mg L^{-1}). The ammonium nitrogen content at Section A was low, 0.29 to 0.36 mg L^{-1}. At Section B (the Kolyma reservoir), the ammonium nitrogen content was elevated (0.29–0.50 mg L^{-1}) and increasing downstream to Section F (0.57–0.79 mg L^{-1}). The highest concentrations of ammonium nitrogen were recorded in the mouths of the Ozhogina (0.79 mg L^{-1}), Sededema (0.86 mg L^{-1}), and Omolon (0.79 mg L^{-1}) rivers.

The content of organic matter was also relatively high. The content of hard-to-oxidize organic compounds, estimated from COD, was 35.00–38.70 mg L^{-1} and the permanganate value was 9.00–14.40 mg L^{-1}.

Most toxic pollutants were low. Phenols were 0.0003–0.0004 mg L^{-1}, anion surfactants 0.01–0.02 mg L^{-1}, and petrochemicals 0.004–0.007 mg L^{-1}. The total iron was elevated, 0.16–1.60 mg L^{-1}. The highest concentrations of total iron were recorded from the mouths of the Ozhogina and Omolon rivers.

Phytoplankton. A total of 404 phytoplankton species (462 subgenus taxa including the name-bearing species) in 8 phyla, 13 classes, 25 orders, 59 families, and 124 genera were identified in the Kolyma River, according to my identifications pooled with the earlier work [2].

The most species-rich were Chlorophyta, comprising 46.0% of the total number of species. The second most species-rich were Bacillariophyta, accounting for 35.4%. Cyanophyta and Chrysophyta were diverse (6.5 and 4.7%, respectively). Xanthophyta, Euglenophyta, and Dinophyta were less diverse and comprised 3.2, 3.0, and 1.0% of the total number of species. Only 1 species of the phylum Cryptophyta was found.

The most species-rich classes were Pennatophyceae (33.7% of the total number of species), Conjugatophyceae (25.0%), and Chlorophyceae (21.0%). The most species-rich orders were Raphales (28.0%), Desmidiales (23.8%), and Chlorococcales (18.1%).

The 7 most species-rich families included 212 algal species (52.5% of the total number of species) of the phyla Bacillariophyta and Chlorophyta. There were 27 mono- and bispecific families in the phytoplankton spectrum of the river (45.8% of the total number of families).

An analysis of the algal generic spectrum of the Kolyma River indicated the uneven distribution of the species across the genera. The 10 most species-rich genera comprised only 8.1% of the total number of genera and 39.4% of the total number of species. These genera were members of Chlorophyta and Bacillariophyta. Most of the genera (67.7% of all the algal genera of the river) were mono- and bispecific. They comprised 28.5% of the total number of species. The proportions of flora were 1 : 2.1 : 6.8 : 7.8. Generic richness was 3.3. Species variability was 1.1.

The phytoplankton of the Kolyma River was dominated by planktic forms and planktic–benthic algae (48.9% of the total number of species). The second most diverse were benthic forms (28.8%). Although many river sections had high stream velocity, in some places up to 2.1 m s^{-1}, rheofiles were as low as 1.7%. Species indifferent to stream velocity were high, 24.5%; lentic species comprised 9.1%. Three species preferring well-aerated water were identified in the water. They were diatoms *Nitzschia terrestris*

(Petersen) Hust., *Pinnularia borealis* Ehr., and *Tetracyclus rupestris* (A. Br.) Grun.

The Kolyma River had low salinity, resulting in the dominance of oligohalobic species (61.3%). Water pH changed with sampling site from neutral to alkalescent; hence, pH-indifferent species accounted for 18.8% and alkaliphiles and alkalibionts (taken together) 17.7%. Acidophiles were 7.8%. Acidobionts were absent.

As for the geographic affiliation of the algae, the greater portion of the phytoplankton consisted of cosmopolitans (57.1%). Given the environmental characteristics of the region, alpine and arctoalpine species (comprising 4.5% of the Kolyma phytoplankton) were the most interesting organisms. They included the following five species common in the river: *Didymosphenia geminata* (Lyngb.) M. Schmidt, *Gomphosphaeria lacustris* Chod. f. compacta (Lemm.) Elenk., *Hannaea arcus* (Ehr.) Patr., *Spondylosium planum* (Wolle) W. et G.S. West, and *Tabellaria flocculosa* (Roth.) Kütz. There were few oreal and circumboreal species (6.3%). Of these, only one representative, *Tribonema affine* G.S. West, was common in the river. Holarctic species were fewer, 5.8%, including the following planktic and planktic–benthic species common in the river: *Dictyosphaerium ehrenbergianum* Näg., *Pandorina charkoviensis* Korsch., and *Staurastrum cingulum* (W. et G.S. West) G.M. Smith. The geographic location of the Kolyma River accounts for the presence of the stenothermic cold-loving diatoms *Aulacosira distans* (Ehr.) Simon., *A. distans* var. *alpigena* (Grun.) Simon., *A. islandica* (O. Müll.) Simon., *A. italica* (Kütz.) Simon., *Cymbella laevis* Näg., *Diatoma hiemale* (Lyngb.) Heib., *D. hiemale* var. *mesodon* (Ehr.) Grun., *Eunotia diodon* Ehr., *E. praerupta* Ehr., *E. praerupta* var. *bidens* (W. Sm.) Grun., *Fragilaria pinnata* Ehr. var. *lancettula* (Schum.) Hust., *Gomphonema ventricosum* Greg., *Hannaea arcus* var. *amphioxys* (Rabenh.) Patr., *Pinnularia brevicostata* Cl., and *Tetracyclus rupestris*.

Individual saprobity is known for 292 species and varieties of the identified algae, comprising 63.2% of the taxa. The concentration of organic matter in the water determined the following percentages of algal bioindicators: 22.0% β-mesosaprobes, 16.1% oligosaprobes, and 31.8% intermediate β-meso- to oligosaprobity indicators. High saprobity indicators (β-α, α-β, α, ρ-α, β-ρ, and ρ) were 8.9% and low saprobity indicators (χ, χ-o, o-χ, χ-β) were 21.2%.

Section A. The species composition here was poor and consisted of 57 species (61 intraspecific taxa) in 6 phyla. The most species-rich algae were Bacillariophyta (45.6% of the total number of species) and Chlorophyta (43.9%). Two Chrysophyta, 2 Dinophyta, 1 Cyanophyta, and 1 Xanthophyta species were recorded.

The phytoplankton density was relatively low, averaging 38300 cells L^{-1}, whereas the biomass was rather high, 0.1008 mg L^{-1}. The dominant algae were Bacillariophyta that accounted for 99.8% of the total density and 99.1% of the total biomass.

The edificators were two diatoms, the dominant *Synedra ulna* (Nitzsch) Ehr. and the subdominant *Diatoma elongatum* (Lyngb.) Ag. var. *tenue* (Ag.) V. H. They are cosmopolitans, planktic–benthic species displaced from the benthos. The displacement is due to the water flow with high velocity and numerous shallow riffles. The displacement of the large-cell forms from the benthos into the water column also accounts for the increased phytoplankton biomass with fairly low density.

The biodiversity index varied with the sampling site from 3.48 to 3.92. The saprobity index averaged 1.70.

Section B (The Kolyma Reservoir). The species diversity here was higher than at Section A and counted 107 algal species (112 species and varieties) in 7 phyla. The percentage of Chlorophyta was higher (49.5%) and that of Bacillariophyta was lower (34.6%) than at the previous section. The diversity of Chrysophyta and Cyanophytes was higher than at Section A, comprising 6.5 and 3.7% of the total number of species, respectively. Dinophyta and Euglenophyta were less diverse and comprised 2.8 and 1.9%, respectively. One Xanthophyta species was found.

The density and biomass of the phytoplankton were relatively low, 17100 cells L^{-1} and 0.0154 mg L^{-1}. The phytoplankton was dominated by Chrysophyta (71.2% of the total density and 48.3% of the total biomass). The second most species-rich phylum was Bacillariophyta, which accounted for 28.2% of the total density and 40.6% of the total biomass at Section B. Contributions of the other phyla were negligible.

The edificators at Section B were different from those at the previous section. Section B was dominated by the following Chrysophyta species: *Dinobryon divergens* Imhof and *D. cylindricum* O. E. Imhof, as well as the following member of the phylum Bacillariophyta: *Diatoma elongatum* f. *actinastroides* (Krieg) Pr.-Lavr. The subdominants were species of Bacillariophyta: *Diatoma elongatum* var. *tenue, Synedra ulna*, and *Asterionella formosa* Hass. These are cosmopolitans, planktic and planktic–benthic algae.

The biodiversity index varied with sampling site from 2.03 to 4.35. The saprobity index was 1.55.

Section C. Here, the species diversity was even higher than at Section B and there were 221 algal species (242 intraspecific taxa) in 7 phyla. The number of species was dominated by Chlorophyta (48.9% of the total number of species found at Section C) and subdominated by Bacillariophyta (32.6%). There were diverse members of Cyanophyta (6.8%) and Chrysophyta (5.9%). Euglenophyta comprised as little as 2.3%. Dinophyta and Xanthophyta were represented by four species each.

The density and biomass of the phytoplankton at the section were somewhat higher than in the reservoir, 64700 cells L^{-1} and 0.0503 mg L^{-1}. The density was dominated by Bacillariophyta (63.7% of the total density) and Chrysophyta (28.5%). Biomass was dominated by Bacillariophyta (74.7% of the total biomass). Chlorophyta and Chrysophyta comprised 12.8 and 12.0% of the total biomass. Percentages of other phyla were negligible.

The dominants were the following representatives of Chrysophyta and Bacillariophyta: *Dinobryon sociale* Ehr. and *Asterionella gracillima* (Hantzsch) Heib. The subdominant was *Diatoma elongatum* var. *tenue*. These are cosmopolitans, planktic and planktic–benthic algae. The high percentage of Chrysophyta here was probably due to the flora from the Kolyma reservoir.

The biodiversity index varied from 2.65 to 5.19. The saprobity index was 1.61.

Section D. A total of 172 phytoplankton species (186 intraspecific taxa) in 7 phyla were identified at Section D. Like at Section C, the number of species was dominated by Chlorophyta (49.4% of the total number of species identified at Site D). The second most species-rich phylum was Bacillariophyta, which accounted for 35.5%. There were diverse members of Chrysophyta (5.8%) and Cyanophyta (5.2%). Dinophyta and Euglenophyta comprised as little as 1.7%. Xanthophyta was represented by 1 species.

The density and biomass of the phytoplankton were somewhat higher than at the previous section, 161000 cells L^{-1} and 0.0764 mg L^{-1}. The phytoplankton was dominated by Bacillariophyta, which accounted for 63.4% of the total density and 62.9% of the total biomass at the section. Like at Section C, the Chrysophyta algae retain high density (20.5%). The percentage of Chlorophyta was 21.3% and that of Chrysophyta was 15.5% of the total biomass at Section D. The contribution of the other algal phyla to the density and biomass of the phytoplankton was negligible.

The composition of Section D edificators was only slightly different from that at the previous section and included Bacillariophyta and Chrysophyta. The dominant was *Asterionella gracillima* and the subdominants were *Synedra tabulata* (Ag.) Kütz. and *Dinobryon sociale*. The edificator complex consisted of cosmopolitans, planktic algae and a benthic alga. The stream velocity here was high and displaced some benthic algae into the water column. Some of the displaced species continued active vegetation.

The biodiversity index varied with sampling site from 3.37 to 5.19. The saprobity index was 1.92.

Section E. A total of 233 phytoplankton species (254 intraspecific taxa) in 7 phyla were identified here. The percentage of Chlorophyta was somewhat higher than at the upstream sections (54.5% of the total number of species) and that of Bacillariophyta was lower (26.6%). There were diverse members of Cyanophyta (7.3%). Xanthophyta (3.4%) and Euglenophyta (3.0%) were more diverse than at the previous sections. The percentage of Chrysophyta was lower (3.4%). Four Dinophyta members were recorded.

The density and biomass of the phytoplankton were even higher than at the previous sections, 831400 cells L^{-1} and 0.1396 mg L^{-1}. The density was dominated by Cyanophyta (66.0% of the total density) and subdominated by Chlorophyta (19.1%). The third densest algae were Bacillariophyta (14.2%). The biomass was dominated by Bacillariophyta (42.5% of the total biomass); however, Chlorophyta (30.5%) and Cyanophyta (25.0%) made a considerable contribution. Contributions of members of the other phyla to the density and biomass were negligible.

The composition of edificators at Section E was different from that at Section D. The dominant was a member of Cyanophyta, *Aphanizomenon flos-aquae* (L.) Ralfs. The subdominants were members of Bacillariophyta and Cyanophyta, *Asterionella gracillima, Anabaena scheremetievii* Elenk., and *Aulacosira granulata* (Ehr.) Simon. These are cosmopolitans, planktic and planktic–benthic algae.

The Section E phytoplankton communities are largely affected by the flora of the large left-hand tributaries of the Kolyma River, the Ozhogina and Sededema rivers. The rivers are well-warmed and slow-flowing, crossing the vast Kolyma Lowland, which is abundant in swamps and lakes (Fig. 1). The rivers are hospitable for the development both of autochtonous and allochtonous phytoplankton, the latter introduced from numerous lentic water bodies. The maximum density and biomass were recorded in the mouths of the rivers, 1623500 cells L^{-1} and 0.2151 mg L^{-1} in the mouth of the Ozhogina River and 2475600 cells L^{-1} and 0.2514 mg L^{-1} in the mouth of the Sededema River. The density and biomass of Chlorophyta, especially Cyanophyta, increase right at the mouths of the rivers and remained high throughout Section E both in the littoral and along the fairway. Cyanophyta comprised 80.3% of the total density and 49.0% of the total biomass at the mouth of the Ozhogina River and 82.4 and 76.4% at the mouth of the Sededema River, respectively.

The biodiversity index varied from 4.30 to 4.92. The saprobity index was 1.68.

Section F. A total of 187 phytoplankton species (205 intraspecific taxa) in 7 phyla were identified at Section F. The number of species was dominated by Chlorophyta (49.7% of the total number of species) and subdominated by Bacillariophyta (34.2%). There were diverse Cyanophyta members (9.1%). Chrysophyta (3.2%) was less diverse than at the previous sections. The percentages of Dinophyta and Xanthophyta were low (1.6% each). One representative of Euglenophyta was recorded.

The density and biomass of the phytoplankton were somewhat lower than at Section E, 221400 cells L^{-1} and 0.0571 mg L^{-1}. Both density and biomass were dominated by Bacillariophyta, which made up 47.8% of the total density and 70.8% of the total biomass at Section F. Cyanophyta members remained highly important (42.8% of the total density and 16.2% of the total biomass). Chlorophyta comprised 6.8% of the total density and 7.7% of the total biomass. Chrysophyta accounted for 2.6 and 4.1%, respectively. Contributions of the other algal phyla to the density and biomass of the phytoplankton were negligible.

The edificator complex consisted of members of Bacillariophyta and Cyanophyta, planktic and planktic–benthic algae, cosmopolitans. The dominant was *Aulacosira granulata* and the subdominants were *Asterionella gracillima* and *Aphanizomenon flos-aquae*.

The Section F phytoplankton was largely affected by the flora of the Omolon River, a right-hand tributary. The Omolon River is the largest tributary of the Kolyma River, rising in the Kolyma Upland and flowing across the Yukaghir Plateau (Fig. 1). The Omolon basin lies in the mountainous area. The river is poorly warmed; water temperature in the mouth was 12.0°C, according to my measurements. The river has inhospitable conditions for phytoplankton development. The phytoplankton near the mouth of the Omolon River consisted of only 58 species and had low density (3400 cells L^{-1}) and biomass (0.0119 mg L^{-1}). The lower number of species, density, and biomass of the Kolyma phytoplankton were also recorded at other sampling sites downstream of the mouth of the Omolon River.

The biodiversity index varied with sampling site from 2.66 to 5.03. The saprobity index was 1.73.

DISCUSSION

The water of the Kolyma River has a low content of most chemicals. Low salinity and hardness of the water are due to permafrost soils that limit soil drainage. Relatively high ammonium nitrogen, hard-to-oxidize organic compounds, permanganate value, and total iron are characteristic of northern rivers flowing through the permafrost area [18]. High concentrations of the chemicals are caused by the intensive thawing and ablation of permafrost soils in summer and are natural in origin. The easy-to-oxidize compounds (from BOD_5) : permanganate value ratio is 5 to 9, suggesting that the natural decomposition of organic sediments is occurring in the river, resulting in the accumulation of organic matter. The chemical composition of the Kolyma River is substantially affected by the Kolyma reservoir and large tributaries (the Ozhogina, Sededema, and Omolon rivers).

Our data on the concentrations of most chemicals in the water are consistent with the available data on the water chemistry of the river-mouth area [7]. However, our studies showed content of phenols and oil products by an order below the values specified by A.M. Nikanorov et al. [7] (0.005 and 0.05 mg L^{-1}, respectively). It should be noted that the authors in their work operate on data from yearbooks of the State Service of observation of the environment for the years 1979–1994. This time period includes the period of the most active economic activities in the region manifested in a lot of shipping, a high number of settlements, and a high volume of domestic wastewater. Since the economic downturn in the 1990s, the load on the aquatic ecosystem of northeastern Siberia has decreased significantly. This, in our opinion, may be the reason for the decrease in concentration of these two toxic components.

The data obtained indicate that the phytoplankton of the Kolyma River is highly diverse in species. For instance, the plankton of the other rivers in northeastern Siberia (Anabar and Olenek) includes 221 and 240 algal species, respectively [19, 20]. The planktic communities of the Amga and Aldan, southeastern Siberian rivers, consist of 216 and 166 species, respectively [21, 22]. The phytoplankton community of the middle Lena River consists of 456 species [23] and that of the Yana River consists of 330 species [24, 25], but these are the results of long-term sampling, not of a single sampling event.

The phyla Chlorophyta, Bacillariophyta, and Cyanophyta comprise 87.9% of the total number of species. This is characteristic of North Siberian rivers and those of the North American Arctic [26–28].

Kolyma phytoplankton diversity increases from the headwaters to the mouth due to tributaries and a mouthwardly increasing number of diverse biotopes within the river. A similar phenomenon has been found for other Siberian [19–21, 25, 29, 30] and European rivers [31]. The biodiversity index increases towards the mouth of the river.

The density and biomass of the Kolyma phytoplankton are low, ranging from 3400 to 2475600 cells L^{-1} and from 0.0020 to 0.2514 mg L^{-1}. Our data are consistent with the available data on the density of phytoplankton in the lower reaches of the river, which varies with seasons and years from 27000 to 1900000 cells L^{-1} [7]. The algal density and biomass are dominated by Bacillariophyta in most of the studied river sections. This is characteristic of other large northern rivers [20, 25, 26, 30, 32, 33]. The exception is the Kolyma reservoir, where the density and biomass are dominated by Chrysophyta, and the lower course of the river (sections E and F), where density is dominated by Cyanophyta. The dominance by Chrysophyta in summer and fall in northern and mountainous oligotrophic lentic and slow-flowing lotic water bodies has been frequently mentioned by some investigators [34–36]. The mass increase of Cyanophyta is characteristic of well-warmed slow-flowing rivers in various regions of the world [37].

The river continuum concept states that river phytoplankton forms under the influence of upstream courses and tributaries [38]. The phytoplankton of Sections C and D is substantially affected by the Kolyma reservoir. The effect is reflected as increased density and biomass of the Dinobryon species of the Crysophyta phylum. The phytoplankton at Sections E and F is largely affected by left-hand tributaries (the Sededema and Ozhogina rivers), downstream of which Cyanophyta increases abruptly. At Section F, the density and biomass of the phytoplankton decrease

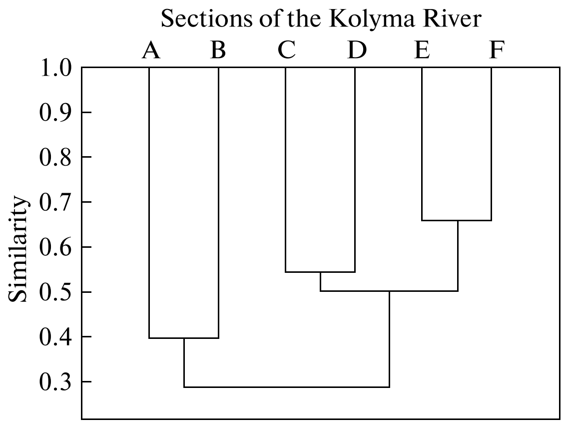

Fig. 2. Floristic similarity of the phytoplankton communities of different sections of the Kolyma River.

downstream of the confluence of the right-hand tributary (the Omolon River).

Overall, the density and biomass of the Kolyma phytoplankton increase from the headwaters to the mouth of the river. The main cause is water flow with low velocity in the lower course of the river, water flow being the principal factor limiting phytoplankton development [39]. The exception is high biomass in the upper Kolyma River (Section A), caused by the displacement of large-celled forms from the benthos into the water column. A similar phenomenon has been found for other rivers of the region whose upper courses have high stream velocity and numerous shallow riffles [20, 21].

The most floristically similar are contiguous sections with similar habitat conditions (Fig. 2). The floristic break between sections B and C is due to the abrupt change in hydrological regime downstream of the dam. Another floristic break occurs between sections D and E, where the Kolyma River discharges from the mountainous area to enter the Kolyma Lowland.

The edificators of the Kolyma phytoplankton are cosmopolitans, planktic and planktik-benthic algae, including 1 benthic species. Bacillariophyta algae are among the edificators throughout the river. The dominants of Section B (the Kolyma Reservoir) and Section C include representatives of the phylum Chrysophyta. Section D is subdominated by Chrysophyta algae. The lower Kolyma River (Sections E and F) is also dominated and subdominated by Cyanophyta representatives, in addition to Bacillariophyta. Our data on the set of dominants are confirmed by long-term observations of the Hydrometeorological Service at the lower reaches of the river, near the mouth of the Omolon River (the border between sections E and F) [7]. For several years, researchers have noted among edificators such algae species as *Aulacosira granulata* and *Aphanozomenon flos-aquae*.

According to the classification [15], the water of the river is "slightly polluted." In regards to the phytoplankton biomass, classification [16] rates the water as "ultimately pure" to "pure"; according to the saprobity index, it is "pure" to "fairly pure"; according to the physicochemical variables, it is "pure" to "moderately polluted," quality class 1 to 4. Concentrations exceeding MAC were found for total iron (1.6–16.0), hard-to-oxidize organic compounds (2.3–2.6), and ammonium nitrogen (1.0–2.3).

CONCLUSIONS

The physicochemical characteristics of the water are shaped by environmental factors, mainly permafrost soils.

The development of Kolyma phytoplankton is limited by water flow.

An analysis of the spatial structure of the taxonomic composition and quantitative characteristics of the Kolyma phytoplankton revealed its variability at various river sections. The situation agrees well with the river continuum concept [38] and is due to consistent headwater-to-mouth changes in the hydrological and physicochemical factors affecting phytoplankton.

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