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Phytoplankton of the Amga River and Chemical Composition of the Water: Contemporary State

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Abstract—This is the first study of phytoplankton of the full length of the Amga, a large river crossing Central and Southern Yakutia. The study has revealed characteristics of phytoplankton assemblages and formation of the hydrochemical regime of the river. We conducted a complex assessment of the water quality based on physicochemical indices, saprobic algae, and phytoplankton biomass. The results can serve as reference data for monitoring the river status during the operation of the East Siberia–Pacific Ocean oil pipeline.

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The Amga is a large river crossing Central and Southern Yakutia and the largest tributary of the Aldan River. The Amga River has a length of 1360 km and drains a basin of 75 000 km^2 [1]. The basin resembles an uncommonly narrow strip, averaging 80 km in width, between the catchments of the Lena and Aldan rivers. As a result, the tributaries of the Amga are scarce and mostly ephemeral, drying out during summer-autumnal low-water. The Amga is characterized by shallow riffles alternating with slow deep long pools [2]. It is considered to be one of the most slow-moving of large Yakutian rivers, its stream velocity being 0.3–0.6 m/s. The river is mainly snow-fed. Despite severe winters, the river does not freeze up due to some contribution from groundwater sources. The duration of the open-water period is 149 days.

Data on the Amga phytoplankton were published only in Rozhkova et al. [3] based on phytoplankton collections of 1992. The work dealt with seasonal aspects of phytoplankton growth in the upper reaches and some tributaries that join them. Unfortunately, the authors did not publish the list of planktic algae revealed, so we were unable to use the data in our study. The literature on the Amga hydrochemistry views the river at full length and is based on the analyses of the early 1990s [2, 4–6].

There is no industry in the Amga basin, so the ecosystem of the river bears no industrial pressure. However, the construction of the underwater East Siberia–Pacific Ocean (ESPO) oil pipeline across the Amga in 2008 has posed an environmental risk to the entire river. Hence, reference data on aquatic ecosystems of the Amga are to be collected. In future the data can serve as basis for biological monitoring of the river in case of a possible environmental disaster. The objectives of the study were: (1) to obtain reference data on phytoplankton and hydrochemistry of the Amga River and (2) to assess the Amga water quality from physicochemical indices, saprobic algae, and phytoplankton biomass.

MATERIALS AND METHODS

The study was based on phytoplankton samples collected from the upper reaches in July 2006 and the middle and lower reaches in August 2009, covering 1276 km of the river. A total of 64 planktic algal and 26 water samples were collected for floristic and hydrochemical analyses, respectively. One and a half liter samples for phytoplankton quantitative analyses were taken from the surface water (0–0.3 m depth) in the littoral zone and the fairway. Phytoplankton was concentrated on *Sartorius* membrane filters (pore size 1.2 μm) by pressure-filtration using our own phytoplankton concentrator [7]. Samples for qualitative analyses were collected with an Apstein plankton net (SEFAR NITEX filter fabric, mesh size 30 μm). Microscopic inspection was done using the *Olympus* BH-2 microscope. Phytoplankton taxonomic structure was analyzed using traditional methods of comparative floristics [8]. Floristic analyses were done using the Sorensen index. Algal biodiversity was quantified with the Shannon–Weaver index [9]. Data on ecological affiliation of algae were given according to Barinova et al. [10].

Chemical analyses of water samples followed traditional procedures [11, 12]. Concentrations of O_2 and CO_2 and biological oxygen demand (BOD_5), as well as some physical characteristics, such as water transparency, odor, taste, and suspended particles, were determined *in situ*. Concentrations of other chemicals were determined in the laboratory. Salts were determined as follows. Sulfate-anion was determined by turbidimetry; chlorides, by mercurometry; hydrocarbonates, by back titration; water hardness, by trilonometry with eriochrome black; calcium, titrometrically with trilon B;

and potassium and sodium, by flame photometry. Odor and taste were determined organoleptically on a point scale. Physical characteristics were determined as follows: transparency, using the Secchi disk, and color, by light absorption using the SF-26 apparatus. Concentrations of toxicants in water were determined using the following methods: total iron, photometrically with thiocyanic ammonium using the SF-26 apparatus; phenols, petrochemicals, and surfactants, by fluorescence chromatography with the *Fluorat* 02 apparatus. Other chemical characteristics were determined as follows: pH, electrometrically using the *Multitest* IPL-101 apparatus; dissolved carbon dioxide, titrometrically with phenolphthalein; dissolved oxygen, by the Winkler method (iodometry); ammonium nitrogen, photometrically with Griss' reagent using SF-26; nitrate nitrogen, photometrically with sodium salicylate using SF-26; phosphates, by forming phosphorus-molybdenum complex, using SF-26; total phosphorus, by persulfate oxidation, using SF-26; organic compounds difficult to oxidize (from chemical oxygen demand, COD), photometrically using *Fluorat*-02; organic compounds easy to oxidize (from biological oxygen demand, BOD_5), by the Winkler method (iodometry).

Results of the study were compared to Maximum Allowable Concentrations (MAC) for fisheries [13]. A complex assessment of water quality was conducted using the classifications by Sladecek [14] and Oksiyuk, Zhukinskii, Braginskii, et al. [15].

RESULTS AND DISCUSSION

Phytoplankton

Our study revealed 216 algal species (237 subgenus taxa, including the name-bearing type species) in 7 phyla, 12 classes, 20 orders, 51 families, and 87 genera (Table 1).

The most species-rich were chlorophytes (44.4% of the total number of species). The second most diverse were diatoms (33.8%). Diverse members of cyanobacteria (12.5%), chrysophytes (4.2%), and euglenophytes (2.8%) were present. Dynophytes and xanthophytes were minor components accounting for only 1.9% and 0.5%, respectively. The cyanobacteria : chlorophytes ratio was 1 : 3.6. It was close to that for the Aldan River (1 :2.6) that crosses the arid zone of Central Yakutia like the Amga River [16].

Class dominants were Pennatophyceae (31.0% of the species composition), Chlorophyceae (29.2%), and Conjugatophyceae (15.3%). Order dominants were Chlorococcales (25.9%), Raphales (25.9%), and Desmidiales (14.8%).

The 10 species-richest families that included 124 chlorophyte, diatom, and cyanobacterial species (57.6% of the total number of species) were Desmidiaceae and Scenedesmaceae (10.2% of the species composition each), Cymbellaceae, Oscillatoriaceae, and Surirellaceae (5.6% each), Closteriaceae, Naviculaceae, and Selenestraceae (4.2% each), and Nitzschiaceae and Oocystaceae (3.7% each). There were 27 mono- and bispesific families making up 52.9% of the total number of families.

The 9 species-richest genera that included 98 species in the chlorophyte, diatom, and cynobacterial phyla were *Scenedesmus* (8.8% of the species composition), *Cosmarium* (8.3%), *Cymbella* and *Oscillatoria* (5.1% each), *Closterium* and *Surirella* (4.6% each), *Nitzschia* (3.7%), *Oocystis* (2.8%), and *Monoraphidium* (2.3%). Mono- and bispecific genera comprised 80.5% of the number of genera and accounted for 41.2% of the species composition. The Amga phytoplankton had the proportion of 1 : 1.7 : 4.2 : 4.6. Genus richness was 2.5 and species variability was 1.1.

Nineteen algal species, new to the flora of Yakutian water bodies, were recorded from the river for the first time by us (see Table 1).

Table 1. Taxonomic composition of the Amga River phytoplankton

Order	Number of							Percentage of total number (216) of species
	classes	orders	families	genera	species	species and varieties	species new to Yakutian flora	
Cyanophyta	3	4	11	14	27	27	1	12.5
Dinophyta	1	1	1	3	4	4	1	1.9
Chrysophyta	2	3	4	7	9	9	3	4.2
Xanthophyta	1	1	1	1	1	1	–	0.5
Bacillariophyta	2	4	17	27	73	86	4	33.8
Euglenophyta	1	1	2	4	6	8	1	2.8
Chlorophyta	2	6	15	31	96	102	9	44.4
Total	12	20	51	87	216	237	19	100

The Amga phytoplankton was dominated by true planktic species and planktic-benthic ones (54.9% of the species composition). Benthic and epibiontal algae were less abundant (27.9%). Stream velocity was ≤0.6 m/s, resulting in high numbers of lentic species and those indifferent to water flowing regime (45.1%). Lotic species were 5. The Amga River had medium salinity resulting in the prevalence of oligahalobic species (60.3%). Water pH was alkalescent, hence it had high percentage of pH-indifferent species (23.6%), and alkaliphiles and alkalibionts (18.1%). Six acidophilic taxa were recorded and acidobionts were absent. Cosmopolitan species accounted for as much as 65.0%; temperate species made up as little as 4.2%; arctoalpine and circumboreal species were 2.5%; stenothermic psychrophilic algae were only 3 species.

Of the algal species revealed in the Amga River, 164 species and varieties (69.2% of the total number of taxa) were saprobity indicators. Concentrations of organic substances determined the following phytoplankton structure: saprobity indicators consisted of 22.6% β-mesosaprobes and 34.2% species charactersic of between β-meso- and oligosaprobic environment. High-saprobity indicators accounted for 12.8% and low-saprobity, 15.2%. Saprobity index varied from station to station from 1.58 to 2.32, averaging 1.89 and indicating oligo-β-mesosaprobic self-purification zone.

Morphometrically, the Amga River is divided into 3 parts: the upper, middle, and lower reaches.

The 429 km long upper reaches extend from the headwater to the Verkhnyaya Amga Village. During low-water, stream velocity is 0.6 m/s. The river bed consists of pebbles. There are numerous small riffles.

In the upper reaches, we revealed 29 algal species (31 intraspecific taxa) in 3 phyla. The most species-rich were diatoms (62.1% of the total number of species) and the second species-richest were chlorophytes (31.0%); chrysophytes accounted for only 6.9%. In this part of the river, phytoplankton cell numbers averaged 27 600 cells/l and biomass, 0.0211 mg/l. Biomass production was highest in diatoms accounting for 83.6% of the total number of species and 78.6% of biomass. The codominants were chlorophytes that amounted to 14.5% of the phytoplankton number of species and 20.3% of phytoplankton biomass. The biomass and number of species of chrysophytes were low. Rozhkova et al. [3] had reported, too, that in the Amga upper reaches highest species richness, cell numbers, biomass, and vegetation were shown by diatoms. The dominance was shared with *Synedra ulna* (Nitzsch) Ehr., *Nitzshcia sublinearis* Hust., and *Synedra tabulata* (Ag.) Kütz., planktic-benthic and benthic species mixed to the plankton from shallow periphyton-covered riffles with low stream velocity. The species diversity index Hb was high, varying from station to station from 3.00 to 3.28. Saprobity index was 1.90, indicating oligo-β-mesosaprobic self-purification zone.

The 383 km long middle reaches stretch from the Verkhnyaya Amga Village to the mouth of the Bielime River. Stream velocity is as low as 0.4 m/s. In this part of the river, slow pools are longer and shallow riffles are fewer. The river bed consists of small pebbles.

In the middle reaches of the Amga we recorded 147 algal species (157 intraspecifc taxa) in 6 phyla. Like in the upper reaches, the most abundant were chlorophytes comprising as much as 43.5% of the total number of species and the second most abundant, diatoms, 36.7%. There were diverse members of cyanobacteria (11.6%) and chrysophytes (4.1%); the numbers of xanthophytes and dinophytes were low (2.0% each).

Cell numbers and biomass of the phytoplankton were lower than those in the upper reaches, 21 800 cells/l and 0.0070 mg/l, respectively. Highest number of species and biomass were recorded for diatoms accounting for 46.1% of the total number of species and 65.6% of biomass. The percentages of chlorophytes in the algal communities were high, 39.3% of the total number of species and 32.5% of phytoplankton biomass. Biomass of members of other phyla was low. Cyanobacteria averaged 13.5% of the total number of phytoplankton species but had low biomass as they were mainly represented by small-cell species. It is noteworthy that cyanobacteria comprised as much as 95.8% of the total number of species due to mass growth of *Microcystis pulverea* (Wood) Forti emend. Elenk. f. *delicatissima* (W. et G. S. West) Elenk at a station in the middle reaches, near the mouth of Munduruchchu River.

Phytoplankton edificator species included both members of diatoms and chlorophytes: *Diatoma elongatum* (Lyngb.) Ag. var. *tenue* (Ag.) V. H., *Monoraphidium irregulare* (G. M. Smith) Kom.-Legn., *Synedra tabulata*, *Closterium moniliferum* (Bory) Ehr., and *Cocconeis placentula* Ehr. Biodiversity index averaged 3.30. Saprobity index was 1.88, indicating oligo-β-mesosaprobic self-purification zone.

The 548 km long lower reaches extend from the mouth of the Bielime River to where the Amga joins the Aldan River. Stream velocity here is even lower than higher upstream, averaging 0.3 m/s. The river bed is of sand and in some places, of small pebbles.

Species richness of the lower reaches compared to that of the middle reaches and counted 138 species (152 intraspecific taxa) in 7 phyla. Like in the middle reaches, the dominants were chlorophytes (46.4% of the total number of species), diatoms (32.6%), and cyanobacteria (12.3%) Chrysophytes, euglenophytes, and dinophytes were poorly represented, making up only 2.9%, 2.9% and 2.2%, respectively. Only one xanthophyte species was recorded in the lower reaches.

Cell numbers and biomass of the phytoplankton were higher than in the middle reaches, 35 500 cells/l and 0.0182 mg/l, respectively. Like in the middle reaches, highest cell numbers and biomass were shown by diatoms (50.9% of cell numbers and 91.0% of biomass). The percentage of cyanobacteria was 27.5% of the total number of species and that of chlorophytes, 21.6%. Chlorophytes averaged 8.0% of the total phytoplankton biomass in the lower reaches. Percentages of other phyla were low.

The dominants are mostly the same as in the middle reaches of the river: *Diatoma elongatum* var. *tenue*, *Monoraphidium irregulare*, *Closterium moniliferum, Nitzschia acicularis* W. Sm., and *Cocconeis placentula*. Biodiversity index for the lower reaches was 3.39. Saprobity index was 1.90, indicating oligo-β-mesosaprobic self-purification zone.

Thus, the middle and lower reaches of the river were similar in terms of species diversity. The upper reaches are less species-rich due to different patterns of seasonal and interannual phytoplankton growth as phytoplankton was sampled in the upper, middle, and lower reaches in different seasons and years.

The taxonomic structure of phytoplankton communities was consistent throughout the river: chlorophytes and diatoms were the most abundant. In the upper reaches, highest number of species was recorded for diatoms, while in the middle and lower reaches they gave way to chlorophytes, percentages of other phyla becoming higher.

The patterns in the number of species and biomass of phytoplankton did not change significantly in different parts of the river. Highest number of species and biomass were shown by diatoms and second highest by chlorophytes throughout the river. The middle and lower reaches were dominated by cyanobacteria. High species numbers and biomass in the upper reaches were due to, firstly, seasonal succession as the material was sampled in the beginning of the vegetative season and in the middle and lower reaches, in the end of the vegetative season; secondly, due to increased contribution from benthic species to the abundance and biomass of the phytoplankton by mixing from the periphyton on shallow riffles into the water column of the upper reaches. In the middle and lower reaches the abundance and biomass of phytoplankton tended to increase toward the river mouth.

The main factor that limited planktic algal growth was low biogenic content. Hence, abundance and biomass of the planktic algae were low, varying from 100 to 1 986 600 cells/l and 0.0004 to 0.0507 mg/l from station to station.

Similarity coefficients, calculated for different parts of the river, showed highest similarity (0.58) between the middle and lower reaches due to similar habitat conditions. Low floristic similarities for middle–upper reaches (0.18) and upper–lower reaches (0.16) were due to seasonal and interannual differences.

Dominant species of all the reaches were the same and included members of diatoms; in the middle and lower reaches, the dominants also included chlorophytes. Phytoplankton biodiversity index (Hb) was slightly increasing from the headwater to the mouth of the river.

Analysis of the spatial structure of the taxonomic composition, numbers of species, and biomass of the Amga phytoplankton showed that these characteristics were highly uniform among different parts of the river, whereas other Yakutian rivers studied likewise—from the headwater to mouth—had clear distinctions among the upper, middle, and lower reaches [16, 17]. The distinctions were in agreement with the river continuum concept by Vannote et al. [18] and were due to natural headwater-to-mouth changes of hydrological and physicochemical factors that affect river phytoplankton, as well as tributaries of the river. Unlike other Yakutian rivers, the Amga has uniform hydrology throughout and little tributarial input.

The existing works on the phytoplankton of Yakutian rivers [16, 17, 19, 20] highlight that Yakutian phytoplankton is largely affected by stranger flora and that its species composition is augmented with tributarial invasions. In the Amga phytoplankton, stranger species are low compared to other large Yakutian rivers. For instance, planktic : periphyton species ratio is 1 : 0.51 for the Amga; 1 : 0.83 for the Anabar; 1 : 0.95 for the Lena; and 1 : 1.00 for the Aldan River. The explanation is that the Amga is a very slow-moving river, while the main limiting factor for river phytoplankton growth is stream velocity [21]. Invasion by stranger species from tributaries is low due to few tributaries.

Hydrochemistry

Water samples from all the reaches had neither odor nor taste, the water was transparent to the bottom, and pools were 4.0–4.5 m deep, water pH alkalescent (Table 2). Characteristically, the entire river was oversaturated with oxygen and had no dissolved carbon dioxide. This was a natural result of photosynthesis in higher aquatic plants that were observed to be actively vegetating in the river. These (mostly Potamogetonaceae members) grew abundantly not only along the coasts but in some places overgrew thickly the fairway. This phenomenon is not characteristic of other Yakutian rivers. It should be mentioned that this specific gas regime had been found by Savvinov et al., but they did not find any explanation to it [4].

Although the river is fed primarily by snowmelt, there is another alimentation source: groundwater. Dual alimentation is uncommon for other rivers of the region. As a result, the Amga has moderately hard, fresh water with medium salinity. Ionically, the water is hydrocarbonate class, Mg-Ca group, type II. Prevalent ions are hydrocarbonates (37–47%-equiv), calcium (15–29%-equiv), and magnesium (12–29%-equiv) in the entire stream. Salts and their proportions are nearly the same throughout the river due to its hydrology. None of the salts is higher than MAC.

Table 2. Average concentrations of chemicals in the Amga River

Components	MAC values for water consumption and fishery	Upper reaches	Middle reaches	Lower reaches
Salts				
Salinity, mg/l	1000.00	240.63	266.96	297.73
Total hardness, mg-equiv/l	7.00	2.87	3.25	3.62
Ca, mg/l	180.00	19.84	36.15	39.46
Mg, mg/l	40.00	22.84	17.60	20.04
Na, mg/l	120.00	6.59	6.30	7.69
K, mg/l	50.00	1.00	0.75	0.62
Hydrocarbonates, mg/l	Not limited	179.02	171.1	187.57
Chlorides, mg/l	300.00	2.22	1.35	1.55
Sulfates, mg/l	100.00	9.58	33.72	40.79
Organoleptic characteristics				
Odor, points	2	0	0	0
Taste, points	2	0	0	0
Physical characteristics				
Suspended solids, mg/l	–	5.60	11.88	25.32
Transparency, m	>4 m	4.50	4.50	4.00
Color, deg.	20	18	17	20
Chemical characteristics				
pH	6.5–8.5	7.58	8.24	8.41
Dissolved CO_2, mg/l	–	Absent	Absent	Absent
Dissolved O_2, mg/l	>6.0	13.53	10.73	11.63
O_2 saturation, %	100	**110.00**	**114.51**	**123.09**
$N–NH_4$, mg/l	0.39	0.06	0.24	0.18
$N–NO_2$, mg/l	0.02	0.001	0.017	0.009
$N–NO_3$, mg/l	9.1	0.11	0.07	0.09
$P–PO_4$, mg/l	0.2	0.00	0.01	0.01
P_{tot}, mg/l	0.2	0.01	0.06	0.07
Organic compounds difficult to oxidize (estimated from COD), mg/l	15	10.4	14.68	9.53
Organic compounds easy to oxidize (estimated from BOD_5), mg/l	<2.0	0.81	1.01	1.09
Toxic pollution indices				
Fe_{tot}, mg/l	0.10	0.00	**0.21**	**0.44**
Oil chemicals, mg/l	0.05	0.02	0.02	0.02
Phenols, mg/l	0.001	**0.005**	**0.004**	**0.004**
Anion-active detergents, mg/l	0.10	0.03	0.03	0.03

Note: Boldface indicates values higher than MAC (MAC values for water consumption and fishery).

The Amga water had low concentrations of biogenic and organic components (Table 2). Phosphorous (phosphates and total phosphorus) and nitrogenous compounds (nitrate, nitrite, and ammonium N) were low. The river had low content of organic complex: organic compounds difficult to oxidize (estimated from chemical oxygen demand, COD) and organic compounds easy to oxidize (estimated from biologic oxygen demand, BOD_5). Distribution of the complex of biogenic and organic compounds along the river was uniform and none of them exceeded MAC.

Note that the entire river had concentrations of total iron and phenols (Table 2) two to four times higher than

MAC. This phenomenon was of natural origin. High total iron was due to intensive snow melting and soil leaching during summer and fall. Active growth of higher aquatic plants resulted in increased concentrations of phenols as samples were collected during the end of the vegetative season when plant development cycle ends and most phytomass dies off and decomposes. Increased phenols had been noted by Savvinov et al. [4] but the cause was not explained.

CONCLUSIONS

The Amga phytoplankton was relatively species-rich. Many algae new to the regional flora were found in the river for the first time. Characteristic uniform full-length hydrology of the river and low tributarial input resulted in uniform spatial taxonomic composition, phytoplankton quantitative characteristics, and chemical components in different parts of the river. Due to the specific hydrology, percentage of stranger algal species was low compared to other Yakutian rivers. Oxygen oversaturation, absence of carbon dioxide, and increased phenols were due to natural causes. According to Sladecek's classification [14], the Amga water is slightly polluted. Oksiyuk, Zhukinskii, and Braginskii's classification [15] categorizes the full length of the river as 'ultimately pure' according to phytoplankton biomass; 'fairly pure' according to the saprobic index; 'ultimately pure' to 'fairly pure' according to physicochemical characteristics.

The data obtained on the phytoplankton structure and physicochemical characteristics of the Amga River can be reference data for further biological monitoring of the river ecosystem.

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