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Water Quality of the Anabar River Indicated by Phytoplankton Structure and Hydrochemical Characteristics

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Abstract—This is the first study of phytoplankton structure and physicochemical characteristics of the full length of the Anabar River—a large river in the Arctic basin. The study has revealed characteristics of phytoplankton assemblages and hydrochemistry of the reaches of the river. Water quality was found to decrease where mineral resources industry operates. The data on phytoplankton structure and physicochemical characteristics of the upper reaches of the Anabar River can serve as reference for monitoring the river status during commercial development of the area.

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Key words: Anabar River, phytoplankton, physicochemical water characteristics, water quality

The Anabar is a large river in the Arctic basin in the northeastern Siberia. It has a length of 939 km and drains a catchment of 100000 km^2. The basin of the river lies beyond the polar circle. The river originates in tundra bogs on the Anabar Plateau and crosses three soil-vegetable zones: boreal taiga, forest-tundra, and tundra. Instead of a delta, the river has a typical estuary—the Anabar Bay [1]. The 559-km long upper reaches are called Bol'shaya Kuonamka and downriver of the Malaya Kuonamka tributary it is called Anabar (see the Figure).

Data on algae of the Anabar River are given in Komarenko and Vasil'eva [2] and Kirillov et al. [3], the works being based on phytoplankton collections of the late 1960s and early 1980s. The samples were mainly collected from the middle reaches between the Ebelyakh and the Billyakh tributaries. One-station samples were collected from the upper and lower reaches. Unfortunately, these works viewed the phytoplankton in general without specifying whether a species belonged to the river bottom, water column, or periphyton. Data on the Anabar hydrochemistry are also scarce [1, 3, 4] and characterize only the middle reaches. Before our study, phytoplankton and physicochemical characteristics of the upper reaches—the Bol'shaya Kuonamka River—had not been investigated.

The Anabar River is of high ecologic and economic importance to the region and is home to commercial fish and waterfowl. In the middle reaches' basin mineral resources are being developed. In the upper reaches' basin, there are neither villages nor industry; however diamond deposits have been discovered and are to be mined soon.

The work is aimed at obtaining reference data on phytoplankton composition and hydrochemistry of the upper reaches of the Anabar before the area comes into intensive development.

MATERIALS AND METHODS

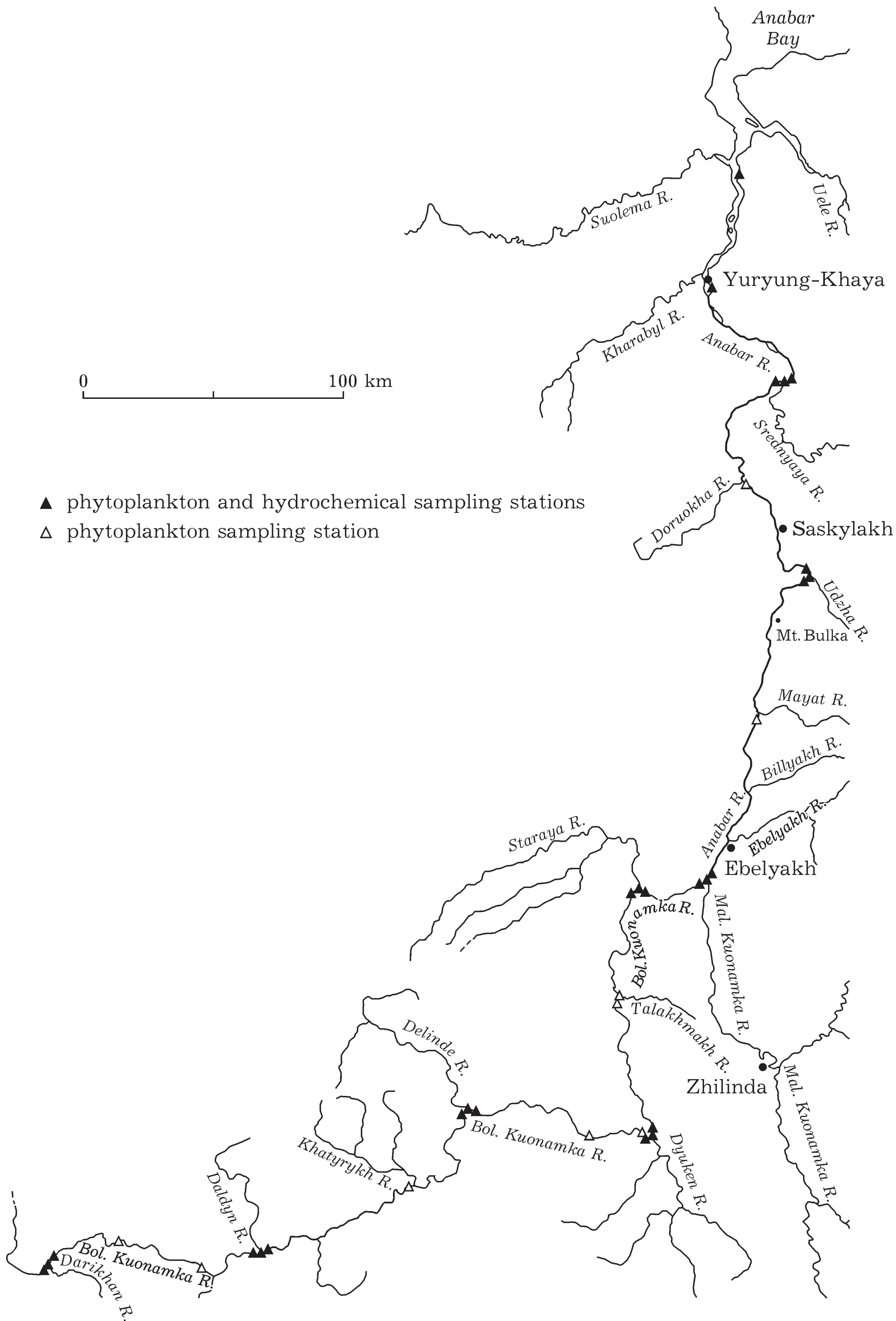
The study covered a 897-km stretch from the mouth of the Darikhan River to the Anabar Bay (see the sketch map). A total of 70 phytoplankton and 27 water samples were collected for floristic and hydrochemical analyses, respectively. One and a half liter water samples for quantitative analyses of phytoplankton were taken from the littoral zone or channel epilimnion to the 0 to 0.3 m depth. Phytoplankton was concentrated by pressure-filtration through Sartorius membrane filters (pore size 1.2 μm) using our own phytoplankton concentrator [5]. Samples for qualitative analyses were collected with an Apstein plankton net (gauze №35???). Microscopic inspection was done with an Olympus BH-2 microscope. Phytoplankton taxonomic structure was analyzed using traditional floristic methods [6]. Similarity was calculated with Sorensen index, and phytoplankton biodiversity, with Shannon–Weaver index [7].

Chemical analyses of water samples were done using traditional methods [8]. The results were compared to Minimum Allowable Concentrations (MAC) for fisheries [9]. Water quality was estimated according to the classifications in Shornikova [10] and Ratkovich [11].

RESULTS AND DISCUSSION

Phytoplankton

According to our data and the literature, the Anabar phytoplankton is estimated at 342 species (378 intra-



Sketch map of the study area

specific taxa including a name-bearing type) in 8 phyla, 13 classes, 29 orders, 70 families, and 118 genera.

Our study revealed 221 phytoplankton species (230 subgenus taxa including a name-bearing type) in 7 phyla, 12 classes, 27 orders, 60 families, and 92 genera (see table).

The taxonomic spectrum is dominated by diatoms (36.7% of the total number of species), chlorophytes (29.4%), and cyanobateria (17.6%), the phytoplankton structure being typical of boreal water bodies [12–14]. Diverse members of xanthophytes (8.6%) and crysophytes (5.9%) are present. Dynophytes are a minor

Taxonomic composition of the Anabar Phytoplankton

Phylum	The number of						Percent of the total number of species (221 sp.)
	classes	orders	families	genera	species	species and subspecies	
CYANOPHYTA	3	6	13	18	39	39	17.6
DINOPHYTA	1	1	1	1	3	3	1.4
CHRYSOPHYTA	1	2	3	6	13	13	5.9
XANTHOPHYTA	2	3	7	10	19	19	8.6
BACILLARIOPHYTA	2	6	18	28	81	89	36.7
RHODOPHYTA	1	1	1	1	1	1	0.5
CHLOROPHYTA	2	8	17	28	65	66	29.4
Total	12	27	60	92	221	230	100

component accounting for only 1.4%; a single rhodophyte species was observed. Class dominants are Pennatophyceae (32.6% of the species composition), Conjugatophyceae (19.0%), Hormogoniophyceae (13.1%); order dominants are Raphales (24.9%) and Desmidiales (16.7).

The 10 largest families that include 119 clorophyte, cyanobacterial, diatom, crysophyte, and xanthophyte species are Desmidiaceae (10.9% of the species composition), Oscillatoriaceae (7.7%), Fragilariaceae and Closteriaceae (5.4% each), Naviculaceae (5.0%), Dinobryonceae (4.5%), Eunotiaceae (4.1%), Tribonemataceae, Cymbellaceae, and Nitschiaceae (3.6% each). There are 36 mono- and bispecific families, which make up 60.0% of the total number of families.

The 12 species-richest genera that include 92 chlorophyte, cyanobacterial, diatom, xanthophyte, and crysophyte species are *Closterium* and *Cosmarium* (5.4% of the species composition each), *Oscillatoria* and *Eunotia* (4.1% each), *Tribonema* and *Cymbella* (3.6% each), *Synedra*, *Dinobryon*, and *Nitzschia* (2.7% each), *Pinnularia*, *Gomphonema*, and *Cosmoastrum* (2.3% each). Mono- and bispecific genera account for 71.7% of the number of genera and 37.1% of the number of species. The Anabar phytoplankton has the following proportions: 1:1.5:3.7:3.8. Genus richness is 2.4 and species variability is 1.0.

Of the 182 algal species and subspecies revealed in the Anabar, 177 species are recorded in the water bodies of the Anabar basin for the first time and 180 species (185 species and subspecies) are new to the river. In the river we registered 31 phytoplankton species new to Yakutian water bodies, and 3 diatom and chlorophyte genera *Actinocyclus*, *Sidercystopsis*, and *Roya*, new to the Yakutian algal flora.

The Anabar phytoplankton is dominated by true planktonic species (17.4% of species composition) with an admixture of benthic algae (11.7%) and epibionts (2.6%)—a structure characteristic of rivers. Species of undetermined ecological affiliation are 68.3%. The Anabar River has low dissolved solids, resulting in dominance of oligohalobic species (28.3%). The species typical of brackish waters *Cyclotella meneghiniana* Kütz and *Diatoma elongatum* (Lyngb.) Ag. are found only in the river mouth affected by the sea. The centric diatoms *Thalassiosira baltica* (Grun.) Ostf. and *Actinocyclus normanii* (Greg. ex. Grev.) Hust. primarily occuring in northern seas are also recorded only in the mouth of the Anabar. The river has neutral pH, hence it has high percentage (17.0%) of pH-indifferent species. Geographically, the floral aspect is dominated by boreal complex of species, which is typical of Northern Eurasian water bodies [12, 13].

Of the algal species revealed in the Anabar River, 80 species and subspecies (34.8% of the total number of taxa) are saprobity indicators. Concentrations of organic substances determined the following phytoplankton structure: saprobity indicators include 40% β-mesosaprobes and 31.3% species characteristic of β-mesosaprobic and oligosaprobic encironment. High-saprobity indicators amount to 16.4% and low-saprobity indicators account for 12.6%. Saprobity index varies from station to station from 1.11 to 1.98, averaging 1.56 (indicating oligo-β-mesosaprobic environment). According to Sladecek classification [15], the Anabar River is slightly polluted.

Morphometrically, the Anabar consists of 4 parts: the upper reaches, the middle reaches, the lower reaches, and the mouth.

The 578-km long upper reaches extend from the Anabar upper reaches to the mouth of the Ebelyakh River. This part of the Anabar is a mountain type, with stream velocity varying from 0.2 m/s in pools to 3.0 m/s on riffles. The river bed and banks are composed mainly of stone, the valley floor is waterlogged, and the upper part of the reaches crosses characteristic tundra landscape. The phytoplankton is the most diverse in this part of the river and counts 138 algal species (144 intraspecific taxa) in 7 phyla. The dominants are chlorophytes (37.7% of the total number of species), diatoms (29.0%), and cyanobacteria (21.0%). There are diverse xanthophyte members (8.7%). Crysophytes and dinophytes are represented by two species each. The only representative of rhodophytes—*Batrachospermum moniliforme* Roth—was recorded only in the upper reaches.

In the upper reaches phytoplankton abundance averages 23850 cells/l and biomass 0.0434 mg/l. In the upper Anabar the most abundant are chlorophytes (53.8% of the total number of species) and diatoms (38.3%) followed by xanthophytes with low percentage of other members. Highest biomass was recorded for diatoms (69.7% of the total biomass) and second highest for xanthophytes (27.7%). Interestingly, cyanobacteria were very low. Increased abundance of xanthophytes is a result of their ecology: the algae prefer clean standing waters with acidic pH, primarily sphagnum and peat bogs [16]. In the Anabar River xanthophytes are mainly stranger species that arrive from numerous tundra bogs in the upper and lower basin. Xanthophytes recorded from the Anabar are mainly large filaments that cause high cell abundance and biomass.

The Anabar dominant algae include the following diatoms: *Synedra tabulata* (Ag.) Kütz., *Tabellaria fenestrata* (Lyngb.) Kütz., *Tabellaria fenestrata* var. *intermedia* Grun., *Tabellaria flocculosa* (Roth.) Kütz., and *Eunotia lunaris* (Ehr.) Grun. The river phytoplankton has an average biodiversity index of 2.6.

The 96-km long middle reaches extending from the mouth of the Ebelyakh River to Mountain Bulka are a plain type with stream velocity varying from 0.3 to 1.2 m/s. The river valley is narrow and has steep walls; the river bed and banks are stony. Here we recorded 19 phytoplankton species (20 intraspecific taxa) in 5 phyla. Average phytoplankton abundance is 3230 cells/l, and biomass is 0.0150 mg/l. Diatoms have highest abundance (57.9% of the species composition), cell abundance (99.3% of the total abundance), and biomass (98.9% of total biomass). The dominant diatoms *Tabellaria flocculosa* and *Synedra ulna* (Nitzsch) Ehr. var. *amphirhynchus* (Ehr.) Grun. are joined by the chlorophyte *Cosmarium formosulum* Hoff. Biodiversity index is as high as 2.9.

The lower reaches 210 km long extend from Mountain Bulka to the Village of Yuryung-Khaya. The river bed and banks are composed of sand and the valley is much broader. Stream velocity is 0.05 to 1.0 m/s. In the lower reaches of the Anabar we revealed 102 species (103 intraspecific taxa) in 6 phyla. The most abundant are diatoms (41.2% of the total number of species), the second most abundant are chlorophytes (23.5%), and the third most abundant are cyanobacteria (12.7%). Less abundant are various crysophytes (10.8%) and xanthophytes (9.8%). In the lower reaches we recorded 2 dinophyte species. The phytoplankton abundance is 11180 cells/l and biomass is 0.0040 mg/l. Highest cell numbers were recorded for chlorophytes (35.6% of the total number of cells), second highest for cyanobacteria (24.9%), and third highest for diatoms (21.6%). A large percentage of crysophytes (14.3%) with a little portion of xanthophytes and dinophytes (3.6% together) is present. However, owing to large xanthophyte filaments, their biomass in the lower reaches is as high as 48.6% on the average. A considerable contribution (42.6%) to the biomass of the phytoplankton is made by chlorophytes.

Note that in the lower reaches crysophytes increase. A crysophyte species *Dinobryon sociale* Ehr. var. *americana* (Brun.) Bachm. together with diatoms *Nitzschia acicularis* W. Sm., *Cymbella silesiaca* Bleisch, *Synedria ulna*, and chlorophytes *Ankistrodesmus fusiformis* Corda ex Korsch., *Monoraphidium komarkovae* Nyg., is found among the edificators. Biodiversity index in the lower reaches has a value average for river phytoplankton, 2.8.

The mouth of the river—the Anabar Bay—has no current and is affected by tide effects. Ecology here is rather different from the other parts of the river because of tide backwater that causes accumulation of phytoplankton arriving from upriver to increase biomass and abundance values. The phytoplankton in the mouth is rich in species: a single sample revealed 51 species (52 intraspecific taxa) in 5 phyla. It is dominated by diatoms (49.0% of the total number of species), with various representatives of chlorophytes (25.5%) and crysophytes (11.8%). Cyanobacteria (9.8%) and (3.9%) are less represented. The phytoplankton counts 57250 cells/l, its biomass being 0.0277 mg/l. Diatoms have the highest number of cells (38.9% of the total number of cells) and biomass (60.8% of the phytoplankton biomass). The co-dominants are crysophytes accounting for 33.3% of the total number of species and 37.0% biomass. Cyanobacteria make up 22.2% of the total number of species but contribute little to biomass because of small cells. Chlorphytes amount to 5.6% of the total number of species and make minor contribution to biomass. Abundance and biomass of xanthophytes are low in the river mouth.

The abundance of crysophytes is increased in the mouth of the Anabar. The dominants are members of diatoms and crysophytes: *Asterionella formosa* Hass., *Nitzschia acicularis*, *Dinobryon sociale* var. *americana*, and *Cyclotella meneghiniana*. The mouth of the Anabar has the highest biodiversity index for the river, 3.1.

Different reaches of the river do not share many species because ecological conditions are different. The greatest similarity (0.37) is found for the lower reaches and mouth of the river as they are connected. Medium similarity (0.31) is found for the upper and lower reaches owing to a common factor: algae arriving from the tundra bogs located in the river valley. The lowest similarity is shown in pairwise comparisons of the upper reaches–mouth (0.17) and the middle reaches–

mouth (0.17) because of the remoteness of compared reaches and different ecologic conditions.

Thus, the greatest biodiversity characterizes the upper reaches of the Anabar River. Phytoplankton in this part of the river is largely augmented by stranger species owing to water turbidizing and additions from the benthos and periphyton stirred up into the water column. High abundance and biomass are caused by the presence of stranger large-cell filamentous species. In the plain part and lower reaches of the Anabar, the abundance of the stranger species is lower. The mouth of the river has backwater effects owing to which phytoplankton accumulates and abundance and biomass increase.

The abundance of xanthophytes is increased in the upper and lower reaches of the Anabar because of the flora of numerous tundra bogs situated in the river valley. The percentage of xanthophytes in species richness and quantity is low in the middle reaches where the valley is dry and narrow and has steep stony walls.

The percentages of crysophytes in the number of species and biomass increase in the lower reaches and the mouth of the river because the algae prefer cold clean water [16]. According to our data, water temperature in the mouth is the lowest in the river (8.0°C); average temperature in the lower reaches is 11.0°C, in the middle reaches 13.3°C, and in the upper reaches 11.3°C. Stream velocity and its limiting effect on phytoplankton development in the lower reaches is much lower compared to the upper and middle reaches. Lower temperature and slower stream velocity facilitate development of crysophytes.

Diatoms are among dominant species in all reaches; the upper reaches are dominated by diatoms only. In the middle reaches the dominants include a chlorophyte; the lower reaches and the mouth are also dominated by crysophytes.

Phytoplankton biodiversity index (Hb) is average for river plankton, increasing from the upper reaches to the mouth.

Hydrochemistry

Dissolved oxygen content varies from 6.00 to 8.20 mg/l, averaging 7.47 mg/l. It is sufficient in all reaches, favorable oxygen regime being characteristic of the river. The Anabar has neutral pH varying from 6.50 to 7.50 from station to station, all values within MAC.

According to the 1936 readings cited in Chistyakov et al [1], the Secchi disk is visible at a depth of 1.9 to 2.2 m. Our observations show that the Anabar River is transparent to a depth of 2.5 m from the headwater to the mouth of the Ebelyakh River. Downriver of the tributary, the water is highly turbid and the disk is visible only to a depth of 0.3 m. High water turbidity is caused by diamond mining in the area.

Concentrations of calcium and magnesium, determining water hardness, are ° meq/l and meet quality requirements. The river has low dissolved solids (15.98 to 147.87 mg/l), all values lower than MAC.

Hydrocarbonate concentrations vary from 4.27 to 84.82 mg/l, those of sulfates from 0.48 to 24.98, chlorides from 1.06 to 20.21, sodium from 0.05 to 16.00, calcium from 2.00 to 24.85, magnesium from 1.22 to 5.95, and potassium from 0.00 to 1.00 mg/l. Prevalent anions are hydrocarbonates (31.22% equiv.) and prevalent cations are calcium (23.01% equiv.) and magnesium (19.28% equiv.). They are followed by sulfate ions (13.28% equiv.). Chlorides are as low as 5.51% equiv.: sodium chloride is 7.03% equiv. and potassium chloride is 0.68% equiv. None of the main ionic concentrations is higher than MAC. Lowest water salinity, hardness, and main ionic concentrations characterize the upper reaches of the Anabar River. The values increase downstream of the mouth of the Malaya Kuonamka River and downriver the Anabar as the tributary crosses outcrops of limestone and other sedimentary rocks of the lower paleozoic era [1].

Ammonium nitrogen concentration is 1.3 to 2.6 times greater than MAC, increasing from the upper (0.24 to 0.78 mg/l) to lower reaches (0.56 to 1.00 mg/l). Nitrate concentrations are very low and increase from the upper (0.06 to 0.32 mg/l) to lower (up to 1.68 mg/l) reaches. Nitrite N concentrations (0.00 to 0.02 mg/l) and silicon (1.64 to 3.20 mg/l) are low and within the limits of MAC.

In the upper reaches we registered high iron concentrations of 0.02 to 0.26 mg/l (1.5 to 2.0 times greater than MAC). In the lower reaches iron concentrations are higher, 0.10 to 1.08 mg/l (2.6 to 10.8 times higher than MAC). Mineral phosphates (0.0 to 0.06 mg/l) and total phosphorus (0.0 to 0.14 mg/l) are normal. Lowest water color values are recorded in the upper reaches (33 to 73°) (1.6 to 3.6 times higher than MAC) and highest in the lower reaches (52 to 81°) (2.6 to 4.0 times higher than MAC). High inoxidable organic matter is recorded in the upper reaches, 15.65 to 44.35 (1.0 to 2.9 times higher than MAC), and lower reaches, 28.65 to 60.15 mg/l (1.9 to 4.0 times higher than MAC).

Phenol concentrations vary from station to station from 0.0001 to 0.0003 mg/l, those of anionic surfactants from 0.01 to 0.02, and oil from 0.006 to 0.008 mg/l. None of the concentrations of the chemicals exceeds MAC.

All in all, the Anabar River has neutral pH and low dissolved solids, is hydrocarbonate class, calcium-magnesium group, type II, very soft, with favorable oxygen regime. All the main ionic concentrations are lower than MAC. The Anabar waters are characterized by low concentrations of most biogenic and organic substances. Relatively high concentrations are recorded for ammonium nitrogen, total iron, inoxizable organic substances, and color of water. Distributions of different organic and biogenic elements vary along the river and are higher in the reaches that neighbor mining sites.

Primary pollutants are ammonium nitrogen, total iron, inoxizable organic substances, and contributors to water color. As the concentrations of inoxizable organic matter, total iron, and high color of water are characteristic of boreal water bodies [17], the river is mainly affected by natural factors with insignificant contribution from anthropogenic ones. According to water quality parameters, the upper reaches are clean, quality class I to II, and the lower reaches are slightly polluted, quality class I to III.

CONCLUSIONS

The Anabar phytoplankton is quite species-rich; from floristic and ecologic-and-geographic perspective it retains characteristic traits of an algal community of an undisturbed boreal water body. Many species and genera new to the regional flora that are found in the Anabar River are revealed for the first time. Quantitatively, the Anabar River is an oligotrophic boreal water body. The phytoplankton development is affected by mainly natural factors. According to Sladecek classification, the river water is slightly polluted. Physicochemical values indicate that the upper reaches of the river are clean, water quality class I to II; the lower reaches are slightly polluted, quality class I to III. Decreased water quality is caused by mineral resources industry.

The data on phytoplankton structure and physicochemical characterization of the upper reaches can be used as reference for monitoring of the river during future commercial development of the neighboring mineral resources.

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