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# Use of Algae for Monitoring Rivers in the Monsoon Climate Areas (Russian Part of Asian Pacific Region)

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**(Abstract)** The climate of the coastal Russian Far East is monsoon type. Rain precipitations with summer-autumnal typhoons and floods prevail and bring up to 90 % annual precipitation. The algal communities of rivers located in protected territories (Kedrovaya River, Serebryanka River) or undeveloped areas (Samarga River), and polluted Rudnaya River were chosen as models of clean and impacted rivers. Pennate diatoms prevail in the periphyton of fast flowing rivers of the Russian Far East. In clean natural rivers the complex of diatoms *Hannaea arcus, Meridion circulare, Diatoma mesodon, Encyonema silesiacum, Ulnaria ulna, U. inaequalis, Achnanthidium minutissimum, Didymosphenia geminata, Gomphoneis olivaceum*, cyanoprokaryote *Homoeothrix janthina*, chrysophyte *Hydrurus foetidus* usually are dominant. Diatom alga *Didymosphenia geminata* is a typical native species and indicator of clean water. Saprobic indices varied from 0.67 to 2.23 in different sites and corresponded to oligo- and beta-mesosaprobic zones (II-III classes of water quality). Thus, three investigated rivers of protected and undeveloped areas are characterized by high quality water with insignificant grade of natural organic pollution. On the contrary, the Rudnaya River having similar hydrology but long time impacted by atmospheric acidification and industrial and domestic waste water has different community structures. Its algae assemblages contain more species tolerated to pollution. They include also many aberrant forms of diatoms.

**Keywords:** Asian Pacific Region; Russian Far East; Algal community; Organic pollution; Saprobic indice; Diatom; Indicator species; *Didymosphenia.*

## 1. INTRODUCTION

Lately the territory of the Russian Far East Region (RFER) is under great human pressure; especially connected with constructions of oil and gas pipelines. Therefore; the bioassessment of the current status of aquatic ecosystems is very important.

The climate of the RFER is monsoon mainly formed under the influence of interaction between continent and ocean. Up to 95% of precipitation falls in the warm part of the year and only about 5% of falls in the winter. Rains in the Far East cover large areas and have high intensity; the storms are very often. More intense rainstorms occur in Primorsky Region (southern part of Russian Far East Region): annual rainfall reaches 800-900 mm. Sometimes 150-250 mm falls in one day. During the warm part of the year floods follow each other; and may reach 10-12 per season. The most significant monsoon rains (July-August) can cause disastrous floods; when water level may be increase 5-6 meters per day [1; 2]. Owing to; rivers of Primorsky Region have many specific hydrological characters.

Algae as water quality indicators are used in the Russian government monitoring and the only saprobity index (S) included in standard methodic. The Russian Far Eastern rivers were biologically monitored from 80th of the last century.

The algal diversity of the RFER was studied by the team of algologists since 1914. Simultaneously the species composition and community structure changes in natural and polluted conditions were investigated. These results were used for establishing the regional bio-indication methodology. The purpose of our work is to study the species composition of periphyton communities in different rivers under the monsoon climate influence; and to test effectiveness of bioindicational and statistical methods.

Four hydrologically similar rivers typical for Primorsky Region were chosen for the current comparative analysis (Kedrovaya River; Serebryanka River; Samarga River and Rudnaya River).

## 2. MATERIALS AND METHODS

Rivers of Primorsky Region flow from eastern slopes of Sikhote-Alin Ridge fall into Japan Sea. They are usually not large with narrow valleys; high slopes and rapid current. Rivers are fed by atmospheric precipitation and have circumneutral pH: Kedrovaya River and Serebryanka River located in corresponding nature reserves; and not polluted

Samarga River are examples of non-disturbed algal communities (**Figure 1**). On the contrary; the long time impacted Rudnaya River having similar hydrology but influenced during many years by atmospheric acidification as well as industrial and domestic waste water. The main hydrological characteristics of studied rivers are in **Table 1.**

For our study we used samples from many river sites. The samples were obtained by scratching for periphyton and were fixed in 3% formaldehyde. Algae were studied with Amplival microscope under magnifications of 400–1200 X. The diatoms were prepared with the peroxide technique modified for glass slides [3; 4]. To identify algae we used following guides and manuals [5-15]. Some species names were checked according to on-line databases [16-18].

Density scores were calculated using 6-score scale [19]. Saprobity indices (S) were obtained for each algal community [20; 21]. Ecological characteristics of the species are summed up in our database [22]. Ordination methods the Canonical Correspondence Analysis (CCA) have been chosen for statistics. We obtained quantitative information on the relationship between species and environmental variables using CCA with the CANOCO for Windows 4.5 package.


**Figure 1.** Territory of the Primorsky Region (part of the Russian Far East) with studied rivers.

**Table 1.** Hydrological characteristics of studied rivers.

| Characteristic \ River | Kedrovaya | Serebryanka | Samarga | Rudnaya |
|---|---|---|---|---|
| Length (km) | 28 | 72 | 220 | 73 |
| Width (m) | 0.5-10 (estuary 30) | 3-100 (estuary 400) | 20-100 (estuary 150) | 3-10 (estuary 40) |
| Depth (m) | 0.05-0.7 | 0.1-2 | 0.1-2 | 0.3-0.6 |
| Current rate (m $s^{-1}$) | 0.1-2 (in flood 2.5) | 0.2-2 (in flood 3.5) | 0.3-2 (in flood 3.5) | 1-2 (in flood 2.5) |
| Bottom | rocks; stones; pebbles | stones; pebbles | stones; pebbles | stones; pebbles |
| Temperature ($^{0}$C) | 0.2-18 | 0.2-20 | 0.2-16 | 0.2-16 |
| pH | 6.9-7.0 | 7.0-7.1 | 7.0-7.1 | 7.5-8.3 |
| Number of samples | 113 | 247 | 88 | 368 |

## 3. RIVER

The river and whole its basin are situated on the territory of biosphere reserve «Kedrovaya Pad» and never were under any anthropogenic stress; because the nature reserve was established in 1915 before exploration of the region by humans.

The algal flora of the Kedrovaya River includes 137 species (162 including subspecific taxa) from 6 taxonomical divisions **(Table 2)** [23]. Long-term monitoring of algal communities of Kedrovaya River (from 1964 to 2002) revealed practically continual and similar algal communities both in the riffles and pools. Diatoms display the high species and subspecies diversity and comprise 102 species (127 including subspecific taxa). Reophilic diatoms were the most various and numerous: *Hannaea arcus*; *Cocconeis placentula*; *Achnanthidium minutissimum;* *Gomphoneis olivaceum*; *Gomphonema angustatum*; *Encyonema minutum*; *E. silesiacum*; *Cymbella turgidula*. Other dominants were cyanoprokaryote *Homoeothrix janthina*; chrysophyte *Hydrurus foetidus* and green alga *Ulothrix zonata*.

102 found taxa (63 %) are organic pollution indicators. The oligosaprobic group consists of 45 species (44.2 %); beta-mesosaprobic group – 30 species (28.8 %); xenosaprobic group – 20 species (19.6 %). Most dominate belong to oligosaprobic and xenosaprobic groups. Saprobity indices of organic pollution (S) in the Kedrovaya River fluctuated from 0.67 to 1.36 in different sites and corresponded to oligosaprobic zone of self-purification (II class of water quality).

**Table 2.** Taxon number of different algal divisions (including infraspecific taxa).

| Division \ River | Kedrovaya | Serebryanka | Samarga | Rudnaya |
|---|---|---|---|---|
| Cyanoprokaryota | 9 | 23 | 4 | 14 |
| Euglenophyta | - | 3 | - | 3 |
| Dinophyta | - | 1 | - | - |
| Chrysophyta | 1 | 2 | - | 1 |
| Bacillariophyta | 102 (127) | 200 (226) | 135 (146) | 130 (139) |
| Xanthophyta | 1 | 5 | 1 | 5 |
| Rhodophyta | 1 | 1 | 1 | - |
| Chlorophyta | 23 | 48 (51) | 10 | 18 (21) |
| | | | | |
| Total | 137 (162) | 283 (312) | 151 (162) | 171 83) |

### 3.1 Serebryanka River

Serebryanka River is the main river of Sikhote-Alin Biosphere Reserve. Near Terney village it flows into the Japan Sea. Four river reaches were sampled: upper (about 1-13 km from the source); middle (40-50 km from the source); lower (with many backwaters – about 5 km) and the estuary (about 2 km from the mouth). Numerous tributaries of the river are small submontane streams. The greater part of the river is protected and clean; except its estuary. The species composition and community structure of Serebryanka River is studied longer and more carefully therefore data are more complete [24; 25]. The algal flora of the Serebryanka River (except tributaries) includes 283 species (312 with subspecific taxa) from 8 divisions (Table 2). The species composition of Serebryanka River is the most diverse and the diatoms have higher species richness and abundance in comparison with other studied rivers: 200 species (226 subspecific taxa).

The upper part of the river is characterized poor species composition. There are 46 species of algae: Cyanoprokaryota – 3; Chrysophyta – 1; Bacillariophyta – 36; Rhodophyta – 1; Chlorophyta – 5. Algal communities on the stony bottom surfaces were formed by rheophilic diatoms: *Ulnaria inaequalis; U. ulna; Hannaea arcus*; *Diatoma mesodon; Cocconeis placentula; Achnanthidium minutissimum; Encyonema minutum; Gomphonema angustatum; Gomphoneis olivaceum; G. quadripunctatum*. Occasionally cyanoprokaryotes *Phormidium autumnale; Ph. uncinatum*; *Homoeothrix janthina* and chrysophyte *Hydrurus foetidus* dominated.

The middle river section of the Serebryanka River is approximately 50 km long. Due to homogenous environmental conditions (pebble bottom; high oxygen concentration; absence of biogenic pollution) the species composition of algal communities is not varied. In comparison with the upper river section the species composition of diatoms increased twice and three *Ulothrix* species were found. Totally 76 species of algae were found. The most abundant species were some cyanoprokaryotes; chrysophytes and the diatoms.

Lower part of the Serebryanka River is located in the coastal plane where the valley expands; water velocity decreases; bottom is silted; river channel forms many branch and backwaters. We found 241 algal species (including subspecific taxa – 282) from 7 divisions: Cyanoprokaryota – 16 (17); Euglenophyta – 3; Dinophyta – 1; Chrysophyta – 2; Bacillariophyta – 146 (179); Xanthophyta – 5; Chlorophyta – 68 (75). The algal community of the river section is dramatically different from the upstream section. There were abundant accumulations of diverse diatom algae in the periphyton and metaphyton: Melosira lineata; M. varians; Fragilaria capucina; F. vaucheriae; Ulnaria acus; U. inaequalis; U. ulna; Tabularia fasciculata; Hannaea arcus; Diatoma mesodon; D. tenue; Tabellaria fenestrata; T. flocculosa; Navicula cryptocephala; N. gregaria; N. rhynchocephala; Cocconeis placentula; Planothidium lanceolatum; Achnanthidium minutissimum; Eunotia bilunaris; Cymbella cistula; Encyonema minutum; E. silesiacum; Gomphonema acuminatum; G. angustatum; G. parvulum; Epithemia adnata; Rhopalodia gibba; Nitzschia palea. The composition of algae from other divisions also changed: cyanoprokaryotes Nostoc linckia; Anabaena cylindrica f. intermedia; Tolypothrix distorta f. penicillata; T. tenuis f. lanata; Phormidium limosum; green algae Mougeotia sp.; Zygnema sp.; Spirogyra sp.; Scenedesmus species; Dictyosphaerium pulchellum; Ankistrodesmus fusiformis were found. Desmids algae were also plentiful: Closterium tumidulum; Staurodesmus dejectus; Staurastrum polymorphum..

Serebryanka River estuary is influenced by two factors: anthropogenic pollution and salt water from the Japan Sea. Therefore some halophilic and mesohalobic species algae appear as well as indicators of pollution. The estuarine algal community of the Serebryanka River includes 135 species (with varieties and forms – 143) from 4 divisions: Cyanoprokaryota – 3; Bacillariophyta – 122 (130); Xanthophyta – 2; Rhodophyta – 1; Chlorophyta – 7. Cyanoprokaryotes Anabaena laxa and Calothrix parietina grew in mass. As usually diatoms were the most various and predominate algae: Stephanodiscus hantzchii; Melosira lineata; Fragilariforma bicapitata; Staurosirella pinnata; Tabularia fasciculata; Diatoma tenue; Hippodonta hungarica; Sellaphora laevissima; Navicula rhynchocephala; N. slesvicensis; Stauroneis phoenicenteron; Pinnularia subgibba; Caloneis silicula; Neidium iridis; Cocconeis placentula; Planothidium delicatulum; Pl. lanceolatum; Rhoicosphenia abbreviata; Encyonema silesiacum; Cymbopleura naviculiformis; Gomphoneis olivaceum; Gomphonema clavatum; G. parvulum; G. productum; G. truncatum; Rhopalodia gibba; Nitzschia frustulum; Surirella brebissonii. Chlorophytes belonging to Ulva; Cladophora and Spirogyra genera were dominated. Desmids completely disappeared.

In estuary 208 (53.4 %) were organic pollution indicators. Oligosaprobic and beta-mesosaprobic groups were nearly equal and consisted accordingly 21.3% and 20.3% **(Table 3).**

**Table 3.** Summarized saprobiological characteristics of algal communities of the Serebryanka River; (%).

| Saprobity group | Upper part | Middle part | Lower part | Estuary | Total for river |
|---|---|---|---|---|---|
| Taxon number | 46 | 76 | 241 (282) | 135 (143) | 283 (312) |
| Xenosaprobic ($\chi$) | 11.1 | 19.0 | 6.4 | 3.5 | 7.0 |
| Oligosaprobic (o) | 28.9 | 31.0 | 23.7 | 25.9 | 21.3 |
| Beta-mesosaprobic ($\beta$) | 24.5 | 22.6 | 24.4 | 22.4 | 20.3 |
| Alpha-mesosaprobic ($\alpha$) | 4.4 | 2.4 | 5.0 | 7.7 | 4.6 |
| Polysaprobic ($\rho$) | - | - | 0.4 | - | 0.2 |
| Data are absent | 31.1 | 25.0 | 40.1 | 40.5 | 46.6 |
| Saprobity index (S) | 0.67-1.3 | 0.98-1.66 | 1.3-2.02 | 1.85-2.04 | |

In upper and middle sections xenosaprobic and oligosaprobic indicators dominated (11.1%-19.0% and 28.9%-31.0%); but amount of alpha-mesosaprobic indicators were increased in estuary – 7.7%. Beta-mesosaprobic group often occupied the second place after oligosaprobic indicators; except in the lower section were they consisted of 24.4%. The obtained data shows reflect good water quality. Indices of organic pollution in different sites of Serebryanka River fluctuated within the different limits (Table 3). The minimal S indices were in the upper and middle sections (0.67-1.66). In lower section and estuary the indices increased up to 1.30-2.02 and 1.85-2.04. The data corresponded to xeno-beta-mesosaprobic zones of self-purification (I-III classes of water quality).

## 3.2 Samarga River

Samarga River is large northern river of Primorsky region. There are only two villages on this river; so the river has no heavy anthropogenic pollution. The first algological data for the river basin and its estuary during was obtained only in the last decade [26]. The middle river part approximately 120 km long was observed by river rafting from the Pukhi River mouth to Samarga River estuary.

The algae community of the Samarga River is comprised of 151 species (162 including subspecific taxa) from 4 divisions (Table 2). Usually; diatoms showed the highest species richness and abundance with 135 species (146 subspecific taxa). Mass periphytonic diatom species were: *Didymosphenia geminata; Hannaea arcus; Meridion circulare; Encyonema minutum; E. silesiacum; Ulnaria ulna; U. inaequalis; Achnanthidium minutissimum;* and *Planothidium lanceolatum*. The periphyton communities of the main river channel were very constant and stable unchanging. The dominant species was *Didymosphenia geminata*; other diatoms were subdominants. This algal community does not change along the 100 km of studied part of the river channel [27]. In river backwaters filamentous green algae and cyanoprokaryotes formed large metaphyton mass: *Spirogyra*; *Mougeotia*; *Oedogonium*; *Ulothrix; Phormidium*. Diatom algae were subdominants: *Diatoma tenue; Planothidium lanceolatum; Meridion circulare; Ulnaria ulna; Melosira varians; Tabellaria flocculosa;* and *T. fenestrata.*

102 organic pollution indicators were found in this part of the river. Beta-mesosaprobic and oligosaprobic indicator groups were numerous: 42 and 36 species accordingly. Xenosaprobic indicator group contained 14 species. Algae dominating in the periphyton in most part of the river channel were related to this group. Mass vegetation xeno- and oligosaprobic algal species evidenced the high water quality on 120 km section of the river. Indices of organic pollution (S) on Samarga River sites were fluctuated within narrow limits from 1.0 to 1.32; in the estuary up to 1.4. All sites of the river are corresponded to oligosaprobic zone of self-purification; (II class of water quality).

### 3.3 Rudnaya River

The Rudnaya River is one of the most polluted rivers in Primorsky region; whose residents suffer from serious lead poisoning from an old smelter and the unsafe transport of lead concentrate from the local lead mines. Lower section the river especially polluted with arsenic; sulfates; fluorides and borates; whereas all river by silver and zinc.

There are some papers devoted to the algal flora and ecological situation of this river [28-30].

In spite of the situation the relative diversity of algal communities in this polluted river consist of 171 algae and cyanoprokaryotes represented by 183 subspecific taxa from 6 divisions (Table 2).

Monitoring of Rudnaya River algae registered different algal communities on clean and polluted parts of the river. Diatoms were more the diverse group (130 species; 139 including subspecific taxa). On unpolluted upper river section the reophilic diatoms *Hannaea arcus; Diatoma mesodon; Meridion circulare;* chrysophyte *Hydrurus foetidus*; and red alga *Audouinella chalybaea* dominated during 1978-1982. Saprobity indices fluctuated from 1.22 to 1.45 (oligosaprobic zone).

The composition of the algal communities on polluted river section dramatically changed: in algal community of the lower section *Nitzschia palea*; *Gomphoneis olivaceum*; *Encyonema minutum*; *Surirella brebissonii* var. *kuetzingii*; cyanoprokaryotes *Phormidium autumnale*; *Ph. uncinatum*; and green algae *Stigeoclonium; Ulothrix zonata* were dominants. Different sections of the river had different saprobity indices which varied from 1.75 to 3.0 (beta- and alpha-mesosaprobic zones). The large amount of teratologic forms of diatoms and green algae were found here. The anthropogenic (mainly industrial) impact on the Rudnaya River algal communities increases to downstream.

## 4. DISCUSSION

Pennates dominate in the periphyton of fast flowing mountain and foothill rivers of the Russian Far East. Community structures of undisturbed rivers in Primorsky region usually are formed under monsoon climate influence. Main character species of algal assemblages in clear natural rivers are Hannaea arcus; Meridion circulare; Diatoma mesodon; Encyonema silesiacum; Ulnaria ulna; U. inaequalis; Achnanthidium minutissimum; Didymosphenia geminata; Planothidium lanceolatum; Gomphoneis olivaceum; Gomphonema angustatum; Cocconeis placentula; cyanoprokaryote Homoeothrix janthina; and chrysophyte Hydrurus foetidus. All these species have specific morphological adaptations to existence in the running water. We regard that the diatom species Didymosphenia geminata is a typical indicator species of clean; unpolluted water in the rivers of Russian part of the Asian Pacific Region. It dominates in periphyton along the 100 km length of the Samarga River and form natural algal communities. As noted by numerous authors; this species prefers low-nutrient; low-temperature and low anthropogenic impacted habitats but often is a reason of the problems with water supply [31; 32]. In monsoon climate of RFER with frequent summer-autumnal typhoons and floods this species does not cause any disturbance for fish and insects. On the contrary; in condition of rapid water velocity; gelatinous stalks of *Didymosphenia geminata* create microenvironment for colonization by other diatoms and refuges for mayfly; stonefly and chironomid larvae.

As regards organic pollution; the oligosaprobic; xenosaprobic; and beta-mesosaprobic species groups usually were most representative. Saprobic indices (S) in undisturbed rivers varied from 0.67 to 2.23 and corresponded to oligo- and beta-mesosaprobic zones of self-purification (II-III classes of water quality). Thus; studied clean and unpolluted water with insignificant grade of natural organic pollution possess high ecological status.

On the contrary; the heavily polluted Rudnaya River having similar hydrology; possess different algal species composition and community structures. Algal community of this river included many teratologic forms of diatom species; such as *Nitzschia palea* and *Encyonema silesiacum*. The green alga *Ulothrix zonata* changed its specific morphological characteristics and formed very large slims. Thus; we can mark that appearance of teratologic forms reflect the deterioration of ecological conditions of the environment.

Results of CCA show the main factors influencing on algal species abundance; diversity and structure in the Rudnaya River [30; Fig. 13). They are borate salts; fluorides; copper; lead and their associated arsenic. All these substances appeared in the water as a result of anthropogenic activivities. It seems that concentration of these elements is related to the pH fluctuations. So the species of polluted waters are fairly tolerant to individual pollutants; which are in contrast to the group of the neutral pH clear-water species. A biosensor species group sensitive to borates and fluorides includes the green algae *Monoraphidium irregulare*; *M. griffithii*; *Scenedesmus acuminatus*; cyanoprokaryote *Heteroleibleinia kuetzingii* and the diatoms *Neidium ampliatum* and *Sellaphora rectangularis*.

## 5. CONCLUSION

In four studied rivers we revealed algal diversity as follows: 137 algal and cyanoprokaryotes species in Kedrovaya River; 283 in Serebryanka River; 151 in Samarga River; and 171 in Rudnaya River. The species abundance was especially high in the Serebryanka River; but taxonomic representativity of divisions is very similar.

Results of bioindicational analysis show that communities of studied reference rivers contain similar proportion of indicator species. It reflects the regional peculiarity of the North-Pacific climatic region.

The indices of saprobity (S) in Kedrovaya River: 0.67-1.36; in Serebryanka River: 0.67-2.04; in Samarga River: 1.0-1.32; in Rudnaya River: 1.22-1; 45 (unpolluted part) and 1.75-3.0 (polluted part). Thus; all rivers on protected and unpolluted territories have practically clean water with insignificant grade of natural organic pollution so these rivers have high ecological status. Algal communities of polluted Rudnaya River have some peculiarities and include numerous teratologic forms. The CCA helped to reveal biosensor species group sensitive to borates and fluorides.

Therefore; the combination of bioindicational methods and CCA confirmed the effectiveness of these approaches for determination of the main factors influencing on algal diversity; abundance and community structures; and allowed to define indicators or bio-sensing species.

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