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ECOLOGY

Consortia in Aquatic Ecosystems of the Transbaikalia

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Abstract—A survey in the basin of the Khilok River (a right tributary of the Selenga River) in 1999–2002 allowed us to reveal and describe the consortia of cyanobacteria *Stratonostoc linckia* f. *linckia* and *Stratonostoc verrucosum*, green alga *Cladophora aegagropila*, stonewort *Nitella opaca*, water moss *Fontinalis* sp., and duckweed *Lemna trisulca.* The relationship between the consort organisms and edificator plants can become the limiting factor in these communities. The long-term studies of the benthic communities of the Arakhlei Lake demonstrate the significance of the consortium approach in the long-term prediction of changes in the lake ecosystem.

INTRODUCTION

Integrated studies of the structural and functional organization of ecosystems substantiate recognition of elementary biocenosis on the basis of key species. In modern biocenology, key species is among the most important problems (Skoptsov, 2000; *Vostochno-Evropeiskie…*, 2004); however, it is developed largely for land ecosystems.

Vegetation and colonial animals are known to play the key role in aquatic ecosystems (Okuneva, 1974; Shtina, 1997; Skal'skaya, 2002). Their populations often serve as the core of elementary biocenoses and govern development of associated organisms, which are consequently associated with the edificator population by their common fate. In this study, we referred to such biocenoses as consortia. This term was introduced to biocenology by Beklemishev (1951) and Ramenskii (1952). Although the volume and content of the notion of consortia remain controversial (Arnol'di *et al.*, 1969; Rabotnov, 1969, 1973, 1974; Nosova, 1973; Voronov, 1974; Kamaltynov *et al.*, 1993), we believe that it fits best for elementary biocenosis which includes interacting populations of the edificator and consort species. As for aquatic ecosystems, we consider the viewpoint of Kharchenko and Protasov (1981) as the most convincing.

Nevertheless, the volume of available publications remains the problem of using consortia for long-term monitoring open. We tried to illustrate the consortium approach and to demonstrate the significance of key consortia recognition in the monitoring and long-term prediction of aquatic ecosystem status by the study of water bodies in the Transbaikalia.

MATERIALS AND METHODS

The principal study was carried out in the basin of the Khilok River (a right tributary of the Selenga River), which covered the Khilok River, its tributaries, and the system of Ivano-Arakhleisk Lakes in the upper reaches of this river. Some data are also given for the Nikishikha River, a left tributary of the Ingoda River (Amur River Basin). Lake and river samples were collected in 1999–2000 and 1999–2001, respectively.

Samples of the Arakhlei Lake were collected near the southeastern lakeside in the region of Gryaznukha River using a Petersen grab (S = 0.025 m^2) (Fig. 1). Along the profile Preobrazhenka Settlement–lake center (the deepest zone), samples were taken from June to October 2000 once in three weeks at depths of 0, 0.5, and 1.0 m with the grab and at depths of 2.0, 3.0, 4.0, 5.0, 9.0, and 14–16 m with a grab for amphipod taking (GAT; S = 0.25 m^2) proposed by Shapovalova and Vologdin (1973). Stations were spaced by at least 50 m. At each station, soil and vegetation were described, surface and bottom water temperatures were recorded, and oxygen dissolved in water was determined using the Winkler method. Arakhlean sand sculpin *Cottus kessleri arachlensis* was counted using a GAT. All samples were washed through a mill screen N24-33 and fixed in 4% formalin. Samples were weighed on a torsion balance accurate to 0.5 mg.

River samples were collected along the profiles perpendicular to the riverside. Since the growth band width rarely exceeded 20 m (commonly 5–10 m), three to five sample plots were established along profiles. Collected algae were fixed in 4% formalin.

Obtained data were processed using statistical software Microsoft Excel 97 and Statistica 5.5.

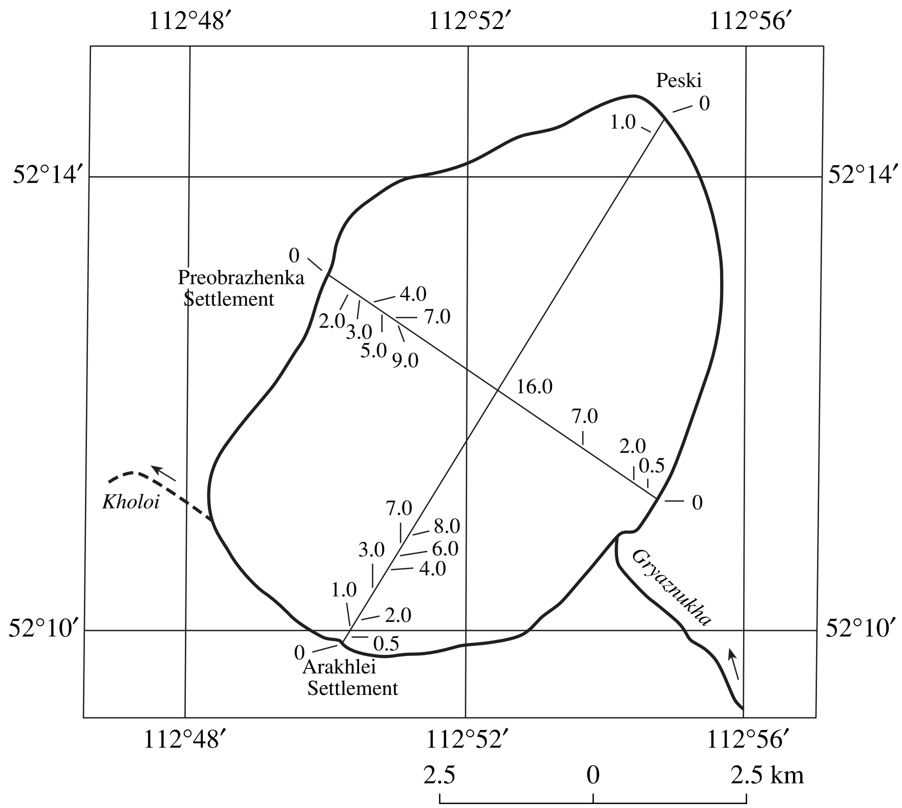

Fig. 1. Map of sampling stations in the Arakhlei Lake in 1996–1997. Numbers indicate depths at the sampling stations (m).

RESULTS

In order to determine the place and role of consortia in aquatic ecosystems in the Khilok River basin, we have chosen several communities with the following edificator species: cyanobacteria *Stratonostoc linckia* f. *linckia* and *S. verrucosum*, green alga *Cladophora aegagropila*, stonewort *Nitella opaca*, water moss *Fontinalis* sp., and duckweed *Lemna trisulca* (Matafonov *et al.*, 2003).

The consortia of cyanobacteria *S. linckia* f. *linckia* and *S. verrucosum* had the simplest structure with a direct topic and trophic relationships. These species are among permanent dominants of communities in Transbaikalia river systems (Kuklin *et al.*, 2002; Kuklin, 2002). Their colonies include slimy thallus with a strong periderm; they are spherical or spread over substrate; the colonies can completely overgrow rock substrates and moss branches. Animal organisms are represented by chironomid larvae *Cricotopus (Nostococladius) nostocicola*, which occupy the first concenter in this community. According to our observations, the abundance of *N. nostocicola* larvae directly increased with the abundance of cyanobacterial colonies. For instance, in the Nikishikha River, the chironomid abundance and biomass equaled 5400 ind./m^2 and 3.23 g/m^2, respectively, while the air-dry phytomass equaled 10.9 g/m^2. Since chironomid larvae are parasites that live in and feed on the colonies, the infested colonies have clearly distinct morphology with a flattened deformed shape. Importantly, *N. nostocicola* finds a shelter in cyanobacterial colonies which protects it from predators and water-level variations. In general, the data obtained for this consortium correspond to the relationship revealed by Brock (1960) for *Nostoc parmeloides* and two midge species living on this cyanobacteria, *Cricotopus nostocicola* and *C. fuscatus.*

Communities of water mosses remain poorly explored although they, together with cyanobacteria, are among the major cenosis-forming species in many river systems of Siberia. Larvae of midge *Phalacrocera replicata* were found in the Khilok River basin in 2001 (Matafonov *et al.*, 2002). They were collected in the growth of moss *Fontinalis* sp. and the body size and weight ranged from 1.5 to 2.0 cm and from 30 to 100 mg, respectively. Specific morphological structure of *P. replicata* larvae indicate a long-term coevolution with mosses. Hence, this midge species can be assigned to the consorts of the first concenter. Note that the previous eastern boundary of *P. replicata* range went through the European Russia (*Opredelitel'…*, 1999). One cannot exclude finding other *Phalacrocera* species after specific investigation of water mosses in Transbaikalia water bodies (Matafonov *et al.*, 2002).

Both communities described above have simple structure and include an edificator species and a consort

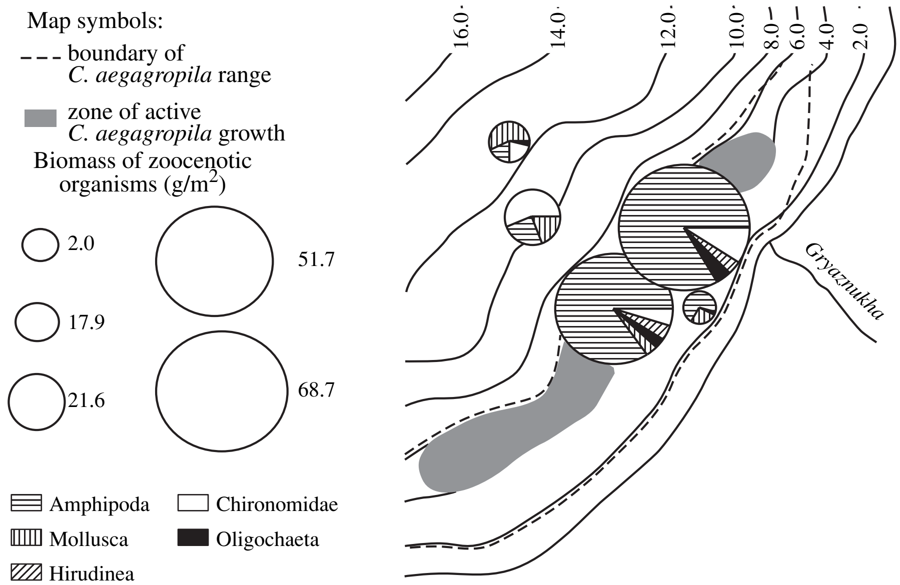

Fig. 2. Structure of communities of benthic invertebrates and of consortium of alga *Cladophora aegagropila* near the southeastern Arakhlei lakeside.

species occupying the first concenter. A more complex structure was revealed in the consortium of green alga *Cladophora aegagropila* (Fig. 2). According to our observations, this alga was represented by small spherical or pincushion-shaped bunches including thick-brunched dark green filaments. Individual bunches could reach 5 cm in size. Mass *C. aegagropila* assemblages completely covering the bottom were observed near the southeastern Arakhlei lakeside in the region of Gryaznukha River at depths of 4 to 6 m. Colonization of this layer by *C. aegagropila* is favored by the presence of coarse gravel which is overgrown by the alga at the initial stages of growth. The algal air-dry phytomass was highest in this habitat reaching 1000 g/m^2 (Kuklin, 2002). Specific structure of bunches, spatial distribution, and phytomass accumulation provided for the environment-forming role of *C. aegagropila* for many benthic organisms. In this case, the first concenter included epiphytic diatoms living on *C. aegagropila* filaments. Larvae of chironomids of the family Orthocladiinae and oligochaetes *Nais barbata, N. communis*, and Enchytraeidae gen. sp. constitute the second concenter: they use the space provided by *Cladophora* but largely feed on epiphytic diatoms and a thin fraction of sedimenting detritus. Total abundance of chironomid larvae and oligochaetes in the consortium amounted to 31 000 and 21 000 ind./m^2, respectively. Similarly, *Cladophora* determined the distribution of amphipod *Gammarus lacustris* in the lake (Matafonov, 2003). The community of this alga provides best for the vital requirements of the amphipod: here it finds optimal conditions for feeding, reproduction, and protection from unfavorable environmental factors. The occurrence of *G. lacustris* in this consortium was 100% and its population density was also high there, up to 7500 ind./m^2.

Note that the *C. aegagropila* community was not described in the Arakhlei Lake until 1999 (Matafonov *et al.*, 2000). *Cladophora* proved to replace water mosses lived in this part of the lake, which eventually affected the composition of animal inhabitants (Matafonov *et al.*, 2000).

Near the western Arakhlei lakeside at depths of about 3 m, mat of *Lemna trisulca* is a substantial environment-forming factor for benthic organisms. A pure formation of this duckweed was observed over silty sand at these depths with ovendry phytomass ranging from 7 to 550 g/m^2. The abundance of *G. lacustris* proved to increase with the phytomass of *L. trisulca* (Table 1). Apparently, the structures of the duckweed and *Cladophora* communities are similar, which determined high abundance of the amphipod in both of them. In addition, the amphipod abundance depended on the physiological status of *L. trisulca.* For instance, in June 2000, *G. lacustris* was found in one out of three samples with living duckweed, while two other samples contained dead *L. trisulca.* In addition to the amphipod, this community largely included gastropods of the genera *Physa, Acroloxus*, and *Polypylis*.

The structure of the consortium of stonewort *Nitella opaca* is equally complex. In 2000, individual *N. opaca* beds were found near the western Arakhlei lakeside over silty soil at depths around 4 m. Its ovendry phytomass ranged from 200 to 500 g/m^2 there. This stonewort determined the distribution of gastropods of the genera *Bithinia, Valvata*, and *Armiger* and its filaments carried numerous egg masses of these mollusks. The obtained data indicate that this stonewort determined

Table 1. Load of variables on the coefficients of correlation of the major component illustrating the dependence of *G. lacustris* abundance on the parameters of the biotope along the profile Preobrazhenka Settlement–lake center

Variables	Date				
	6.06.00	27.06.00	22.07.00	10.08.00	16.09.00
Depth	–0.019	0.036	0.050	0.183	0.013
Lake area (littoral, sublittoral, and profundal)	–0.08	0.018	0.070	0.132	0.284
Soil	0.049	0.045	–0.075	0.139	–0.455
Benthic temperature	–0.02	–0.086	–0.117	–0.178	0.720
Benthic oxygen	–0.136	–0.657	–0.178	0.223	–
Gmelinoides fasciatus abundance	0.024	–0.227	–0.038	–0.260	–0.749
Gammarus lacustris abundance	0.996	0.873	0.778	0.910	–0.786
Lemna trisulca	0.995	0.868	0.858	0.937	–0.584
Potamogeton perfoliatus		0.009	0.053	–0.130	–0.146
Ceratophillum demersum	–0.005	0.119	–0.181	–0.131	–0.324
Chara sp.	–0.099	–0.117	–0.033	–	–0.166
Potamogeton praelongus	–	–0.077	–0.459	–0.136	–0.220
Nitella opaca	–0.045	–0.389	–0.177	–0.053	–0.227
Potamogeton compressus	–	–	–0.478	–	–
Expl.Var	2.023	2.194	1.909	1.982	2.580
Prp. Totl	0.184	0.169	0.136	0.165	0.215

Note: Dash sign indicates that no data were available for this variable and were omitted from analysis.

the distribution of *Cottus kessleri arachlensis* (Table 2), which often carried fish leech *Piscicola geometra.* In August and September 2000, the density of *C. kessleri arachlensis* in the *N. opaca* consortium reached 20 ind./m^2 (Table 2).

DISCUSSION

Analysis of the structure and dynamics of aquatic ecosystems in terms of consortium approach makes it possible to use consortia as complex markers of the status of aquatic ecosystems and, in prospect, to predict changes in the ecosystem. For instance, accounting for the pattern of relationships in the consortium and considering the presence of the edificator as the limiting factor in the consortium, one can propose that disappearance of such species can eliminate consorts of the first concenter or significantly decrease the abundance of consorts of the subsequent concenters. *Vice versa*, extension of the area occupied by the edificator can increase the abundance of the consorts. Hence, it is advisable to recognize and monitor the key consortia. The knowledge about the changes in their structure and distribution make it possible to predict changes in the whole aquatic ecosystem.

First two considered consortia have simple structure based on direct trophic and topic relationships between animals and edificator species. However, the consortia with a more complex structure and often equally strong bonds are also of interest, since the disappearance of the edificator can considerably reduce of the abundance of a set of species. In this case, the common fate of the edificator and the consorts is clearly manifested.

Table 2. Abundance of Arakhlean sand sculpin in the Arakhlei Lake in 2000 (*N*, ind/m^2)

Month	Depth, m	Biotope	*N*
June	2.05	Sand, *Chara* sp., *L. trisulca*	4
	3.0	Sand, *L. trisulca*	4
	4.0	Silt, *N. opaca*	4
	4.05	Silt, *N. opaca*	4
	3.95	Silt, *C. demersum*, detritus	4
	4.5	Silt, *C. demersum*	8
	9.0	Silt	4
July	3.0	Sand, *L. trisulca*, *P. perfoliatus*	4
	4.1	Silt, *N. opaca*	4
	4.85	Silt, *L. trisulca*, *P. perfoliatus*	4
	9.1	Silt	4
August	4.05	Silt, *N. opaca*	20
September	4.1	Silt, *N. opaca*	20
	4.1	Silt, *N. opaca*, *C. demersum*	16
October	3.9	Silt, *N. opaca*	12
	4.15	Silt, *N. opaca*, *P. perfoliatus*, *C. demersum*	4

In terms of the consortium approach, we considered the consequences of reducing the areas inhabited by *Nitella* in the Arakhlei Lake. The data on the present-day status of this ecosystem demonstrated that a considerable reduction of the area inhabited by the stonewort in 1970s (Bazarova, 2002, 2003) reduced the area occupied by phytophilic invertebrates (Matafonov and Matafonov, 2002). In contrast to the situation observed in 1960s, nearly all gastropods, caddis flies *Mystacides* sp. and *Oxyethira* sp., and mayfly *Caenis horaria* disappeared from the sublittoral zone. We believe that the reduction of stonewort abundance in this region is responsible for the reduced abundance of amphipod *G. lacustris.*

The effect of reduced abundance of *N. opaca* on *C. kessleri arachlensis* population was equally significant. For instance, we observed 70% of *C. kessleri arachlensis* in the stonewort samples, which amounted to around 5% of their total number. Hence, the reduction of stonewort growth from 23% of total aquatic vegetation area to individual beds (Bazarova, 2002, 2003) had a catastrophic effect on the population of *C. kessleri arachlensis* in the Arakhlei Lake. For the relatively low mobile benthic sculpin, the presence of *N. opaca* is one of the main factors for the colonization of silty depth layers. The reduced proportion of the *C. kessleri arachlensis* in the diet of perch within recent years (Gorlacheva and Afonin, 2000) is clearly due to this reason.

The data obtained for benthic cenoses of the Arakhlei Lake demonstrate that the considerable changes associated with the reduced area of *N. opaca* growth are similar to the model of the year-two-year changes in the status of the Ivano-Arakhleisk Lakes described by Shishkin (1972). This model serves for long-term predictions of the lake status from cyclic variations in water level and the corresponding changes in the biocenoses (mediated by the illuminance). It had much in common with the processes going in the ecosystems of lakes and sors later described by Bekman (1977). Our studies demonstrated that decline of the above-mentioned groups of organisms from the benthic communities of the Arakhlei Lake corresponds to the transition from the phytoplankton–hydrophyte stage to the phytoplankton stage of lake development (Matafonov and Matafonov, 2002). However, a combined impact of an increasing anthropogenic load and sharp rise of water level in early 1980s is a more probable cause of these changes. For instance, the transition from a low-water to high-water period was relatively fast: water level increased by 2 m and reached the top level from 1982 to 1986 (Obyazov *et al.*, 2002). A 2.5-fold increase in phytoplankton production, transition to the dominance of cyanobacteria, and decrease in water clarity to 5 m were observed in 1988 (Ogly, 1993). These factors could reduce the area of *N. opaca* and moss growth near the southeastern lakeside.

Hence, the knowledge about the phase of lake water level (descending or ascending), anthropogenic load, and the impact of these conditions on the edificator plants of the key consortia mediated by indirect factors (water clarity, biogens, competition with phytoplankton, etc.) makes it possible to predict changes in the lake ecosystem. At the same time, current predictions should take into account possible lake colonization by an invader. For instance, invasion of canadian waterweed *Elodea canadensis* is among the most probable factors of considerable structural changes of phyto- and zoocenoses of the Ivano-Arakhleisk Lakes similar to the catastrophic changes induced by this species in the ecosystem of the Kotokel' Lake (Sokolova, 2001; Maistrenko and Neronov, 2002). Recently *E. canadensis* was found in the Eravninsk Lake system (Maistrenko and Neronov, 2002).

Studies on consortia can be successfully used to elucidate the mechanisms of concerted evolution of plant and animal organisms and to predict changes induced by biological invasions. Monitoring the organisms of the key consortia as complex indicator of ecosystem status can be more informative than monitoring individual indicator species.

The nearest targets for studies on the Ivano-Arakhleisk Lake system and Khilok River for further prediction include revealing new consortia and monitoring those we already know.

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