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THE ECOSYSTEM OF A SMALL SALMON RIVER IN THE FAR EAST OF RUSSIA

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Abstract — Three main stages of complex study of stream ecosystems are allocated on the basis of existing methodologies and concepts. Material has been collected within 1960 - 1994 on the small model salmon river Kedrovaya, located in the Far East of Russia. Data on aquatic insect species diversity, abundance and biomass were obtained at the first stage of the investigations. The fundamental differences of three structural characteristics in stream ecosystems of three subregions: the Northern Far East, Kamchatka and Southern Far East have been established as well. The quantitative relationships between different parts of the stream ecosystems were investigated at the second stage. A balance approach was used to explane the relationships between structural and functional characteristics in the aquatic organism communities. The goal of the third stage of the investigations was the elucidation of the mechanisms, responsible for individual properties of stream ecosystems. State-of-the-art of the small salmon river ecosystem investigations is also considered.

INTRODUCTION

There are several approaches in the investigations of river ecosystems, reflecting spatial scale researchers focus upon. In order to throw light on a river ecosystem in a way comparable with that of other rivers, we propose a set of three approaches as follows (Gutelmakher, 1987). In the first stage the river system concerned will be classified according to the regional categories by the external characteristics of biota such as species composition, abundance and biomass, and of abiotic environmental factors such as thermal regimes, water chemistry, and flow regimes (Levanidov, 1979; 1981). The second stage is concerned with the inner structure of biological communities in the river system based on the balance approach (Rossolimo, 1934; Winberg, 1934; Alimov, 1982). This stage requires a set of quantitative data on feeding, growth, production and metabolic expenditures, etc. of community members in an energetic base in order to clarify their functions in the system. The third stage is investigations of the local processes of the river ecosystem by means of monitoring of the distribution, abundance and production of inhabitants in relation to geomorphological settings of the habitat (Takemon & Tanida, 1993). This stage aims at clarifying the spatio-temporal structure of river habitats and its interrelations with the structure and function of the biological community in local scales.

In this paper we present a series of results on a small salmon river, Kedrovaya River, located west of Vladivostok in the Far East, as an example of the above three approaches to the river ecosystems. Kedrovaya River is a typical small salmon stream characterized by a cold or moderately warm water, a watercourse with swift current, and stony and rocky substrates, which provide the conditions essential for spawning and development of the fry and fingerings of salmonids (Levanidova et al., 1989). Since research on river ecosystems in the Far East began on this river, information on the ecosystem has been accumulated. Moreover, the river flows through Kedrovaya Pad' reserve territory and thus is free from artificial impact on the system.

THE FIRST STAGE OF THE ECOSYSTEM INVESTIGATION

There are numerous small salmon rivers in the Russian Far East regions, which are up to ca. fifty five thousands only in Primorye territory. As a result of great efforts for collecting data from these rivers, information on flora, fauna, abundance and biomass of hydrobiont, annual regime of water temperature, and some other abiotic environmental factors have been obtained. Levanidov (1979; 1981) reported on the fundamental differences among salmon stream ecosystems all over the Far East Russia based on those data, and categorized them into three subregions: i.e., Southern Far East Subregion, Kamchatka Peninsula Subregion, and Far Northeast Subregion.

Southern Far East Subregion: composed of the Ussuri River basin, lower and middle Amur, the west coast of the Japan Sea, southern Sakhalin, and the Southern Kuril Islands. Macrobenthic communities of this subregion are bearing high species diversity up to 300 species or more. Average annual biomass in the rhithron is 30 ± 10 g/m^2.

Kamchatka Peninsula Subregion: composed of rivers in the peninsula. Macrobenthic communities of this subregion have a lower species diversity less than 100 species. The mean biomass of the rhithron is 25 ± 10 g/m^2.

Northern Far East Subregion: composed of rivers of the Chukotskyi Peninsula and western coast of the Sea of Okhotsk, Anadyr' and Penzhina rivers. Macrobenthic communities of this subregion characterized by very lower species diversity and mean biomass of the rhithron 5.0 ± 2.5 g/m^2.

Kedrovaya River belongs to the first subregion. Research on the river began in 1960s including experimental investigations on the production of each hydrobiont. Floristic studies on algae in Kedrovaya River started in 1964 and have continued (Kukharenko, 1964; 1972; Zhurkina & Kukharenko, 1974; Medvedeva, 1995). A total of 243 taxa of algae recorded is composed of Cyanophyta (25 taxa), Bacillariophyta (141), Chlorophyta (69), Chrysophyta (1), Xanthophyta (4), Dinophyta (1), Euglenophyta (1) and Rhodophyta (1). Although diatoms dominate on the surface of stones and mosses throughout a year, *Hydrurus foetidus* Kirchn., *Phormidium autumnale* (Ag.) Gom., *P. uncinatum* (Ag.) Gom., *Ulothrix zonata* (Web. et Mohr) Kutz. and *Spirogyra* sp. are also abundant on stones in some sections of the river bed.

A total of ca. 100 species of macrobenthos has been registered in Kedrovaya River during two series of year-around quantitative collections in 1972-1973 and 1979-1980 (Levanidov, 1977; Kocharina et al., 1988). Macroinvertebrate fauna is composed of 28 species of mayflies, 13 stoneflies, 30 caddisflies, 1 gammarid, 26 chironomids and a few species of other Diptera and Oligochaeta. Mean annual biomass of the macrobenthos is 34.3 ± 6.2 g/m^2 in the middle reaches of the river (Kocharina et al., 1988). Larvae of caddisflies predominate in the biomass sharing 45.5% of the total and nymphs of mayflies 19.9% in the second place. The roles of amphipods and stoneflies are noticeable, whereas the significance of chironomid larvae is not so great (3.2%). Mean annual abundance of the macrobenthos is 15306 ± 1677 individuals/m^2. Main quota in terms of density is shared by mayfly nymphs (47%) and chironomid larvae (38%).

Consequently, as a result of the first stage of ecosystem investigation in Kedrovaya River, the floral and faunal composition and quantitative characteristics of major components of the community have been given.

THE SECOND STAGE OF ECOSYSTEM INVESTIGATION

The second stage is concerned with the inner structure of biological communities in the river system. We have adopted balance approach which was offered by Rossolimo (1934) and established with an energetic base by Winberg (1934). In this approach, quantitative data on feeding, growth, production and metabolism of the community components will be balanced after transformation into energy values. This approach will make it possible to find relationships between structure and function of biological communities (Alimov, 1982). Although a vast amount of empirical data on biological productivity has been accumulated in lakes and reservoir ecosystems from this approach, investigations of running water ecosystems have fallen behind in this respect.

In case of Kedrovaya River, patterns of growth rate, energy metabolism, and productivity have been revealed for both individuals and populations of the main species of mayflies, stoneflies, caddisflies, chironomids and gammarids, based on a set of experimental studies (Kocharina, 1990; Teslenko, 1992; Tiunova, 1993). The results of productivity research on those major benthic animals have been allowed to determine energy interrelations within the community of the river (Table 1). Among non-predatory insects, nymphs of mayflies dominated (ca. 61%) over the total amount of organic matter produced secondarily. The production values of non-predatory caddisflies, chironomids, stoneflies and gammarids shared only ca. 14, 11, 6 and 5%, respectively. The biggest quota (ca. 53%) of the secondary production flew into stoneflies through predation.

Table 1. Energy balance of the invertebrate community in the Kedrovaya River in the season of vegetation.

Taxa	Pnp	Rnp	Cnp	P	R	C
Ephemeroptera	243.4	191.3	769.3			
Trichoptera	56.9	139.1	327.5	34.8	59.5	117.8
Chironomidae	42.5	34.1	128.1	4.8	3.8	11.0
Plecoptera	23.9	19.0	53.9	67.8	161.6	198.2
Gammaridae	21.4	23.1	74.1	21.4	23.1	55.6
Total	402.1	406.7	1352.9	128.8	247.9	382.6

P, R and C represent production, metabolic expenditure, and ration of predatory (p) and non-predatory (np) invertebrates, respectively.

Estimation of a total production of the invertebrate metarhithral community in Kedrovaya River resulted in 148.3 KJ/m^2 during the season of vegetation (Table 2). This value represents a realized community production corresponding to a part of the production utilized by predators mainly composed of fishes. The total energy for metabolic expenditures (654.6 KJ/m^2) was more than four times greater than the community production. A proportion of the production (P) to the metabolic expenditures (R), efficiency of productivity (K_2) and P/B coefficient were all low in values, derivied from great energy expenditures on the metabolic processes.

Table 2. Energy balance components of the invertebrate community in the Kedrovaya River in the season of vegetation in 1979-1980. Values are in KJ/m_2.

P	R	P/R	C/Pnp	Pp/P	K_2	P/B
148.3	654.6	0.23	0.95	0.87	0.18	1.03

P, R and C represent production, metabolic expenditure, and ration of predatory (p) and non-predatory (np) invertebrates, respectively. K_2 and B show the efficiency of productivity and biomass, respectively.

A considerable amount of energy (382.6 KJ/m^2) produced by non-predators was consumed by predators in Kedrovaya River (Table 1). The assimilation efficiency exceeded 93% for the predators. High value of the ratio of the predatory ration to the production of the non-predators (Cp/Pnp) indicates a high food requirement and a strong impact of predators in the community. The ration for predatory stoneflies shared more than a half of the total values for predatory animals. This indicates that predatory stoneflies are a key component which limits the production of non-predators in the system.

More detailed pictures of the substance and energy transformation within the community are necessary to reveal the mechanisms producing characteristics of Kedrovaya River described above. In order to elucidate the mechanisms in functional interactions among community members, however, it is essential to consider a spatio-temporal heterogeneity of the community structure by means of the third approach as mentioned below.

THE THIRD STAGE OF ECOSYSTEM INVESTIGATION

The third stage will focus on local processes of the community parameters in relation to geomorphological settings of the habitat. This stage aims at clarifying the spatio-temporal structure of river habitats and its interrelations with the structure and function of the biological community in local scales. We followed a mapping method of Takemon & Tanida (1993) for surveying geomorphology of the river and the distributional patterns of organisms. Study area including a pool-riffle structure with length of 60m was established along Kedrovaya River in 1993-1994. An environmental map of the area was made twice a month using measurements on geomorphology, water depth, current velocity, water temperature, illumination and substrate types. A total of 896 samples of macrobenthos was collected using a benthometer with an area of 0.0625 m^2. At each sampling site periphyton and fishes were also collected. The samples were sorted and identified at the species level. Distribution of each species or species complex of aquatic insects and that of algae were correlated with the set of environmental factors. Seasonal changes in the community structure and production will be also examined based on the 16-month series of survey. Primary production and destruction of periphyton at each sampling site was estimated by means of an oxygen bottle method. The amount of chlorophyll 'a' was also measured to calculate algal biomass at each site. Primary production was also estimated, based on a close connection of photosynthesis to the amount of chlorophyll 'a' considering a ratio of common carotinoids to chlorophyll 'a' which was used as an index of physiological state of periphyton cells. The diversity of algal communities was estimated using the Margaleff's Index (Margaleff, 1964). Feeding habits of mayflies, stoneflies, caddisflies, gammarids and fishes were examined for each sample and changes in their functions in the community according to their developmental stages were revealed.

Kedrovaya River is located in a monsoon climate zone, where a seasonal fluctuation of the water level is conspicuous compared with other regions in the Far East of Russia. In spite of extreme environmental conditions such as drought, spate and freezing of the river bed within a year, the species diversity and species composition of benthic communities were very stable throughout a long period. Table 3 shows a comparison of the faunal data of the river in 1972 - 1973 and in 1979 - 1980. Larvae of the caddisfly, *Stenopsyche marmorata* Navas dominated and *Gammarus koreanus* Ueno and *Drunella aculea* Allen belonged to the subdominants in both years, although biomass of other species was changed through the years.

Table 3. Species composition of the macrobenthos (in %) in the Kedrovaya River in 1972 -1973 and in 1979 - 1980.

Dominants	Subdominants	Secondary species
	Data by Levanidov, 1977	
Stenopsyche marmorata (28)	*Gammarus koreanus* (13.2)	*Arctopsyshe palpata* (3.7)
	Drunella aculea (10.5)	*Cincticostella tshernovae* Baik. (2.1)
	Kamimuria luteicauda (9.5)	*Allonarcus sachalina* (1.5)
	Cinygmula grandifolia Tshern. (9.0)	*Epeorus* species (1.3)
	Stavsolus japonicus (Pkamoto) (5.7)	*Diamesa gr.insignipes* (1.3)
	Data by Kocharina et al., 1988	
Stenopsyche marmorata (35.1)	*Gammarus koreanus* (12.9)	*Megarcys ochracea* Klap. (3.4)
	Drunella aculea (8.8)	*Stavsolus japonicus* (2.4)
	Arctopsyche palpata Mart. (5.3)	*Kamimuria luteicauda* (2.4)
		Cinygmula grandifolia (2.3)
		Allonarcus sachalina (2.0)
		Epeorus species (2.0)

These results indicate that the community of Kedrovaya River is in a stable condition even under the fluctuation of environmental conditions. There might be such a mechanism that will bring back the system to a primary condition even after energy and organic matter accumulated as biomass in macrobenthos were swept away by spates. We expect that influence of such environmental impacts on populations and community will be detected by further examination on the seasonal changes in the community structure of the river during 16 months. It is also noted that organisms might detect an alarm signal before extreme conditions occur. For example, we have observed an upstream migration by mass individuals of gammarids along the river, which continued for some hours (Tiunova, pers. comm.). Water level of the river rose up to 260 cm in the next day. And we also observed that subimagines of mayflies emerged frequently before the rise of water level.

Organisms inhabiting rivers located in a monsoon climatic zone, in general, may be adapted to seasonal and annual fluctuations of environmental conditions. If this is true, they might require fluctuated environmental conditions for their life and on the contrary, the community structure might be altered under non-fluctuated conditions. Based on this hypothesis, the next step of our investigation will be focused on a comparison among natural and regulated rivers. Comparative approaches between natural rivers with a stable water regime and those with a fluctuated one may be also important for revealing mechanisms in structural and functional stability of river ecosystems found in Kedrovaya River.

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