Biometric Data Analysis for Identifying Features of the Structural and Spatial Organization of Hydrobiological Communities*

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Abstract. In the rivers of the Yenisei basin, benthic invertebrates play a major role in feeding most Siberian valuable fish species. This report presents advanced material on zoobenthos of the river Kan (one of the major tributaries of the Yenisei river in its middle course). Litho-psammo-rheophilic biocenosis of benthic invertebrates is most developed; 99 species and forms are recorded there. The total abundance of zoobenthos is formed by mayflies, caddisflies and chironomids, and biomass by caddisflies and mayflies. The correlation analysis reveals a consistent variation in the abundance of structure-forming insect orders (mayflies, stoneflies and caddisflies). The clustering of data on the abundance of families reveals the consistency with the geographical zoning of the river Kan and change in hydrological conditions. In the longitudinal profile of the river, there is a change of the dominant families among mayflies in Heptageniidae – Ephemerellidae – Ephemeridae; families of caddisflies – from Glossosomatidae to Hydropsychidae. The water temperature during the study period determined up to 30% of the variance in the number of stoneflies, dipterans, and the "other" group. For caddisflies, the influence of oxygen dissolved in water is more significant (20% of the explained dispersion).

Keywords: Rheophilic Zoobenthos, River Kan, Spatial Distribution, Correlation Graphs, Cluster Analysis.

1 Introduction

Nowadays, the worldwide interest in biometrics is growing and the need for biometric analysis of biological research results is increasing. Analysis of the species relationship in communities; identification of environmental factors affecting the formation of communities and viability of individual species as well as revealing patterns of the spatiotemporal distribution of species and communities – all these problems are related to the fundamental problems of ecology [1, 2] and cannot be solved without involving statistical data analysis [3].

Zoobenthos is one of the most important elements of the ecosystems of continental reservoirs and watercourses. Benthic invertebrates contribute to the natural self-purification of water and reflect the ongoing changes in the environment, including those anthropogenic in nature. In addition, zoobenthos is an important component of the food supply for most species of Siberian fish (sturgeon, whitefish, grayling, cyprinids, etc.), and the level of its development can be used to estimate the potential fish productivity of water bodies, depending on the amount of available food forbenthophage fish [4].

The purpose of the work is to analyze the spatial structure of the river zoobenthos communities with the help of mathematical and statistical methods of data processing using the example of the river Kan (tributary of the Yenisei in its midstream).

2 Materials and Methods

The Kan River is one of the largest tributaries of the Yenisei in its midstream, which extends from the mouth of the river Tuba to the mouth of the river Angara. The Kan originates on the northern slopes of the East Sayan, flows into the Yenisei from the right bank, 108 kilometers down the city Krasnoyarsk. The length of the channel is 630 kilometers, and the water intake is 37 thousand km^2. It is customary to subdivide the Kan into three large areas: in the upper reaches, the river flows to the north; in the middle - to the northwest, and in the lower - straight to the west. The midstream begins approximately at the mouth of the Peso River and ends in the area of the town Kansk. The width of the river in the upper reaches does not exceed 100 m, the most spacious place of the channel being near Kansk (390 m), while at the mouth the width of the river reaches 300 m. The depth of the Kan in the area from the mouth to Kansk is 2–6 m, in the upstream the depth decreases significantly. At a distance of 98 km from the mouth, the river is regulated by the dam of the low-pressure hydroelectric complex of the Krasnoyarsk Regional Hydroelectric Power Plant-2. The backwater extends upstream 15 km from the hydroelectric complex, the average depth of the reservoir being 3.0–4.5 m. The Kan is an industrial river, which is partially navigable; some of the nearby areas being densely populated and flooded. The largest settlements (the towns Kansk and Zheleznogorsk) are located in the lower reaches.

Zoobenthos samples were collected at 9 stations in the river Kan in September 2015, on a river area of about 450 km in the middle and lower reaches. For each station, water temperature, oxygen content, and soil type were recorded. The samples were taken in the watercourse by a circular Dulkeit scraper with a capture area of 1/9 m^2 and a benthometer with a capture area of 1/16 m^2. The samples were washed through a silk bolting cloth No. 28; in the field, water organisms were fixed with 80% ethanol. The Shannon index of the species diversity was calculated from the number of species. The analysis of biotic interactions within the benthic communities was carried out according to two indicators: the number of the main taxonomic groups and their share in the total number of zoobenthos. In this case, the Spearman rank correlation coefficient was used, which was considered significant at $p < 0.05$. To assess the degree of influence of the water temperature and oxygen content on the number of the main taxonomic zoobenthos groups, multivariate linear regression analysis was used. The determination coefficient was considered statistically significant at $p < 0.05$. To study the spatial structure of the bottom communities, clustering was made using the method of hierarchical agglomeration. The inside cluster distance (between the stations) was calculated in the Euclidean metric, and the intercluster distances (between the clusters) were calculated using the Ward's method. Clustering was performed according to two indicators: the share of the main taxa in the total number of zoobenthos and the logarithm number of each family. In order to avoid the appearance of a logarithm of zero, a unity was added to each number before taking the logarithm. Statistical data processing was performed in Python 3.7.2 using the `scipy` (https://scipy.org) and `scikit-learn` (https://scikit-learn.org/) libraries.

3 Results and Discussion

In the river Kan, stony-pebble and stony-sandy soils dominate; higher aquatic vegetation grows locally along the banks. The developmental advantage was obtained by the litho-psammo-rheophilic biocenosis of the bottom invertebrate animals, in which 99 species were recorded at the time of the study. Chironomids and caddis flies constituted the maximum number of species (27 and 23, respectively); the second place was occupied by mayflies (18). Small and rarely found benthos (mollusks, amphipods, leeches, dragonflies, water mites, bugs, beetles) were combined into the "other" group; the number of species in these taxa did not exceed 3. The richest species composition was recorded at stations 2 and 4 (40 and 44 species, respectively); at the other stations, 22–28 taxa were identified. The maximum Shannon index of the species diversity was identified at the station 2 (3.77 bit/ind.), the minimum values were recorded in the downstream of the Krasnoyarsk Regional Hydroelectric Power Plant-2 at stations 6 and 7 (2.74 and 2.77 bit/ind., respectively). In zoobenthos communities at other stations, the Shannon index varied insignificantly (3.11–3.24 bit/ind.). The total number of zoobenthos was formed due to insects: mayflies and caddis flies contributed 31% each, dipterans (mainly chironomids) – 23%. The largest share in the total biomass accounted for to caddis flies – 44%, followed by mayflies – 24% (Fig 1).

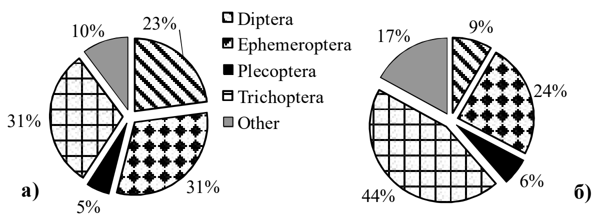

Fig. 1. The ratio of the main zoobenthos groups in the river Kan (a – by abundance; b – by biomass).

The quantitative characteristics of zoobenthos ranged from 0.3 to 3.5 thousand ind./m^2 and from 0.8 to 4.4 g/m^2. In the spatial dynamics of abundance and biomass (Fig. 2), two peaks can be distinguished: at stations 2 and 4. At station 2, the number of chironomids and caddis biomass increased; at station 4, mayflies and caddis flies formed for the basis of abundance and biomass. It should be noted that the bottom communities at stations 2 and 4 were characterized not only by high density, but also by high species diversity.

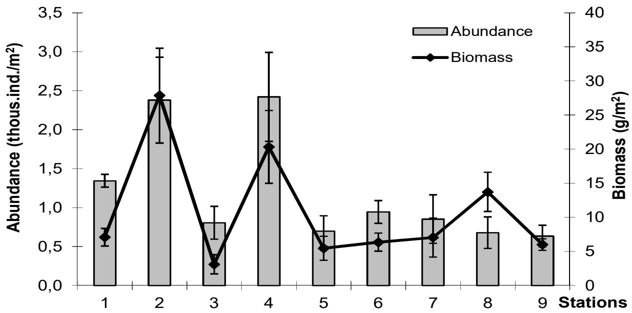

Fig. 2. The abundance and biomass of zoobenthos in the river Kan.

In the formation of the structural organization of communities, biotic interactions are undoubtedly of great importance. The analysis of the structure of benthic communities based on the ratio of the abundance numbers of the main large taxa revealed a number of statistically significant patterns. In particular, the numbers of structure-forming insect orders (mayflies, stoneflies and caddis flies) consistently varied; dipteran insects positively correlated only with stoneflies (Fig. 3). The maximum correlation coefficient R = 0.65 was found for a pair “mayflies – caddis flies”.

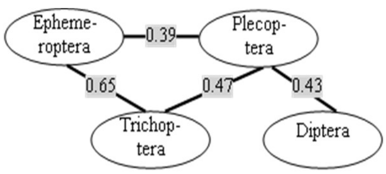

Fig. 3. Correlation graphs of the relationships between the abundance of the main zoobenthos taxonomic groups (gray color indicates the statistically significant Spearman correlation coefficients at $p<0.05$).

It is known that the species composition and abundance of benthos depend on many factors, including depth, flow velocity, water temperature, level fluctuations, soil, degree of vegetation development, and others [2, 5]. As a result of the linear regression analysis, the influence of the water temperature and oxygen content on the abundance of the main taxonomic groups of zoobenthos was determined (Table 1).

The maximum share of the data variation was explained by the water temperature: 23, 27, and 31% of the total number of stoneflies, dipterans, and other groups, respectively. Statistically significant coefficients of determination ($p < 0.05$) are marked in bold.

Table 1. Coefficients of multiple determination (R^2) of the abundance of the main taxonomic groups in zoobenthos in the river Kan and hydrological indicators.

Group of animals	Temperature		Oxygen		Temperature + Oxygen	
	R^2	p	R^2	p	R^2	p
Diptera	**0.31**	0.003	0.04	0.34	**0.34**	0.007
Ephemeroptera	0.08	0.15	0.12	0.07	0.20	0.07
Plecoptera	**0.23**	0.01	0.02	0.46	**0.25**	0.03
Trichoptera	0.05	0.29	**0.22**	0.01	**0.26**	0.03
Others	**0.27**	0.006	0.09	0.13	**0.37**	0.004

It is known that in rivers, as they move away from the headwater, regular changes in the hydrobionts habitat occur, which causes the heterogeneity of the species structure of communities along the longitudinal river profile [5, 6]. The nature of these changes has two characteristics – gradual and steplike; the latter is usually associated with a local influence of external factors.

The analysis of the bottom community structure in various parts of the river Kan by the agglomerative clustering method, based on the share of large taxa in the total zoobenthos abundance (Fig. 4a), revealed the presence of four clusters, each of them being characterized by the dominance of one or another group of invertebrates (mayflies, caddis flies, dipterans, or "others").

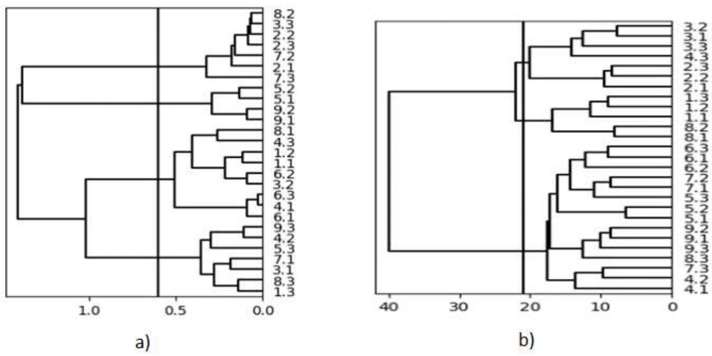

Fig. 4. The results of the cluster analysis by the Ward method of structural organization of zoobenthos communities at various stations in the Kan: a) – according to the portion of the major taxa in the total abundance of zoobenthos; b) – by the logarithmic abundance of families.

Clustering of data at the level of the prologarithmic number of families (Fig. 4b) revealed three clusters, to be consistent with the geographic zoning of the Kan river and change in hydrological conditions. In the first cluster there is station 1, located in the upper part of the middle reaches, where the river still has a pronounced mountain character. In zoobenthos, mayflies of the Heptageniidae family, as well as caddis flies of the Arctopsychidae and Glossosomatidae families, had an advantage. Station 8, located in the lower reaches in the area of the Great Kansk Lip, is in the same cluster. Here, under stormy conditions, as at station 1, the mayflies of the Heptageniidae family were leading. The second cluster combined stations 2 and 3, where the river enters the Kansk-Rybinsk basin and flows quietly along the wide valley of the Kansk forest steppe, and there are many islands in the channel. Among the mayflies, representatives of the Ephemerellidae family dominated there, among caddis flies – Hydropsychidae and Stenopsychidae. Other stations (4–7 and 9), located in the lower reaches of the river, formed the third cluster. At the same time, the Ephemeridae family, in particular *E. sachalinensis*, whose confinement to the lower reaches was also observed in the rivers of South Korea [7], had a clear advantage in the mayflies order. In the river Kan, this species spread from the Yenisei, where it often dominates in zoobenthos [8].

Thus, in the river Kan according to the longitudinal profile, a change in dominant families was observed among the mayflies in the series Heptageniidae – Ephemerellidae – Ephemeridae; caddis flies families – from Glossosomatidae to Hydropsychidae. A similar pattern was revealed in the spatial distribution of benthic communities in the watercourses of the river Ob basin [9].

4 Conclusions

The river Kan (a large tributary of the Yenisei in its middle course) in the studied area is inhabited by cold-loving reobiont organisms, among which amphibiotic insect larvae (stoneflies, mayflies, caddis flies, and dipterans) predominate qualitatively and quantitatively. The maximum number of species is represented by chironomids and caddis flies. Water temperature is one of the significant factors determining the number of stoneflies, dipterans, and "other" group (up to 30% of the explained variance). For caddis flies, a more significant influence of oxygen dissolved in water was noted (20% of the explained variance). Data clustering at the level of family numbers revealed the consistency with the geographic zoning of the river Kan and change in the hydrological conditions. In the longitudinal profile of the river from the upper reaches, a change in the dominant families was observed among mayflies in the series Heptageniidae – Ephemerellidae – Ephemeridae; caddis flies families – from Glossosomatidae to Hydropsychidae. Landscape-geomorphological features of the river Kan in the lower reaches, determine the leading position of the species characteristics for the upper reaches.

Acknowledgments. This work is supported by the Krasnoyarsk Mathematical Center and financed by the Ministry of Science and Higher Education of the Russian Federation in the framework of the establishment and development of regional Centers for Mathematics Research and Education (Agreement No. 075-02-2020-1631).

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