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Article

Features of structural changes in communities of aquatic macroinvertebrates in low-mountain watercourses of Altai under the influence of residential areas

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Abstract. The features of the structural characteristics of benthic communities were analyzed in five low-mountain watercourses of Altai in the areas located upstream and downstream populated areas. In some watercourses, a decrease of the frequency of occurrence of the most sensitive species, of the species richness of EPT taxa, and of the Shannon diversity index was noted in areas located downstream of populated areas compared to those upstream. A deterioration in the water quality of the Saidys River downstream the Sredniy Saidys village (down to the class of "moderately polluted") and that of the Ulaushka River within the city of Gorno-Altaisk (down to the class of "polluted") was revealed. It is recommended to use the EPT and BMWP indices to assess the ecological state of low-mountain watercourses of Altai based on macroinvertebrates.

Keywords: zoobenthos, small rivers, urbanization, taxonomic diversity, water quality

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Научная статья

Особенности структурных перестроек сообществ водных макробеспозвоночных низкогорных водотоков Алтая под влиянием селитебных территорий

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Аннотация. Проанализированы особенности структурных характеристик донных сообществ пяти низкогорных водотоков Алтая на участках, расположенных выше и ниже населенных пунктов. Для некоторых водотоков отмечено снижение частоты встречаемости наиболее чувствительных видов, видового богатства EPT таксонов и индекса видового разнообразия Шеннона на участках, расположенных ниже населенных пунктов по сравнению с вышерасположенными. Выявлено ухудшение качества воды р. Сайдыс ниже п. Средний Сайдыс до класса «умеренно загрязненные» и р. Улалушка в черте г. Горно-Алтайска до класса «загрязненные» воды. Для оценки экологического состояния низкогорных водотоков Алтая по макробеспозвоночным рекомендовано использовать индексы EPT и BMWP.

Ключевые слова: зообентос, малые реки, урбанизация, таксономическое разнообразие, качество воды

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Introduction

Over the past decades, diverse ecosystems are under increasing pressure from human activities worldwide (Søndergaard and Jeppesen, 2007). Urbanization and the growth of industrial and agricultural production are among the main factors of anthropogenic transformation both of terrestrial and aquatic ecosystems. Unlike point sources of pollution, which can be relatively easily identified and controlled, the impacts of diffuse changes in river catchments on the water quality are more difficult to predict due to the complex interactions of water flow and landscapes (Crooks et al., 2021). Studying the impact of different land uses on water quality is receiving special attention worldwide (Cheng et al., 2022; de Mello et al., 2020; Giri and Qiu, 2016; Shi et al., 2017). Urbanization and agricultural land use are leading factors in water quality degradation (Crooks et al., 2021). At the same time, agricultural use of the catchment area increases the concentration of nitrates and phosphorus in the water, urbanization, the content of ammonium and suspended solids (Crooks et al. 2021).

Structure changes in macroinvertebrate communities are a generally accepted indicator of transformation of aquatic ecosystems caused by various types of anthropogenic impact. The taxonomic richness and diversity of macroinvertebrates decreases and the population density of pollution-resistant taxa increases in the watercourses of urbanized areas (Meyer et al., 2005). However, the response of zoobenthos to the changes in living conditions may vary depending on the natural conditions of the region, the strength of the impact, the structural and functional characteristics of aquatic ecosystems, and the regional characteristics of the fauna. In this regard, studying the response of benthic communities to the transformation of the drainage area in various regions are necessary to develop the conservation measures for aquatic ecosystems and for sustainable management of water resources.

The most active studies of regularities of the structural changes in macroinvertebrate communities affected by urbanization of river catchment areas were carried out in the USA, Canada, Australia, and China (Bazinet et al., 2010; Davies et al., 2010; Voelz et al., 2005; Zhang et al., 2014). Such studies are still few for small rivers of Altai, so they do not provide an idea of the regional characteristics of the community response to the changes in land use at the catchment area. At the same time, the urbanization degree of the Altai River catchment area is steadily growing, the population of the Altai Republic is increasing, and the development of the region as a touristic and recreational center contributes to increasing tourist activity, currently exceeding 2 million people per year. All this increases residential areas and, therefore, the need to analyze their impact on the aquatic ecosystems of the region.

The study aims to assess the influence of residential areas on the structural characteristics of benthic communities of low-mountain watercourses in Altai.

Materials and methods

The samples were collected in April–May 2022 in five small watercourses of the Upper Ob River basin (Fig. 1): the Paspaul River (upstream and downstream the village of Paspaul), the Karasuk River (upstream and downstream the village of Karasuk), the Saidys River (upstream and downstream the village of Sredniy Saidys), the Biryulya River (upstream and downstream the village of Biryulya and at the mouth), and the Ulaushka River (upstream the city of Gorno-Altaisk and at the mouth). Macroinvertebrates were collected using a grab with a capture area of 0.04 sm^2. The samples were washed through nylon mesh (mesh size of 220×220 µm) and fixed with 95% ethyl alcohol. The species composition was analyzed, the animals were counted individually and weighed on a VT-500 torsion scales (Russia). A total of 38 zoobenthos samples were analyzed. The water temperature, pH, saturation level and oxygen concentration, turbidity, and depth were measured with a multi-parameter probe YSI 6600 V2-03 (YSI Incorporated, USA) simultaneously with the macroinvertebrate sampling at sampling sites (Table 1). The content of biogenic compounds (ammonium, nitrates, nitrites) and COD in water samples was analyzed at the Chemical Analytical Center of the Institute of Water and Environmental Problems, Siberian Branch of Russian Academy of Sciences.

In order to assess the ecological state of watercourses, several biotic indices were calculated for each site in terms of macroinvertebrates: Woodiwiss index, or the Trent River Biotic Index (TBI), Biological Monitoring Working Party Index (BMWP); Average Score Per Taxon Index (ASPT); EPT index, which is a total number of EPT (Ephemeroida, Plecoptera, Trichoptera) species (Semenchenko and Razlutsky, 2010). Structural rearrangements of macroinvertebrate communities were assessed by changes in the taxonomic composition and in EPT taxa diversity. Water quality class for each indicator was determined

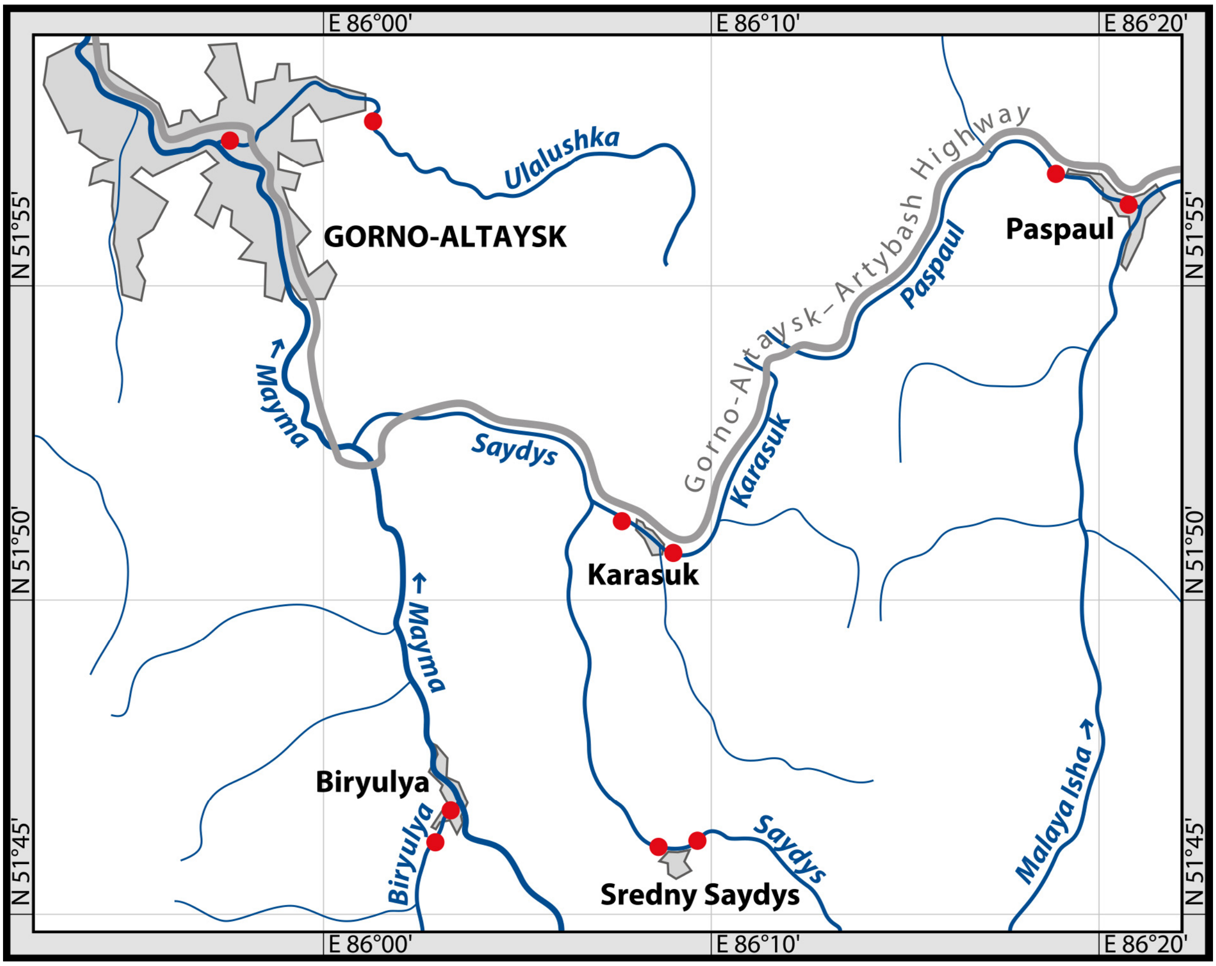

Fig. 1. Sampling sites map.

using the EQI (Environmental Quality Index) by comparing it with background values (Semenchenko and Razlutsky, 2010). The indices of the sampling site located upstream the corresponding settlement were taken as background values for each watercourse. At the same time, values deviating from the background by no more than 20% were classified as quality class I ("very pure"); 20–40%, as class II ("pure"); 40–60%, as class III ("moderately polluted"); 60–80%, as class IV ("polluted"); more than 80%, as class V ("dirty") (Semenchenko and Razlutsky, 2010).

Statistical analysis of the data was performed using the Statistica 6.0 software package. All indicators are presented as means with standard errors. The values of species richness (S), Shannon's index of species diversity (H), abundance (N) and biomass (B) of EPT macroinvertebrate taxa in different sections of the studied rivers were used as dependent variables in the analysis of variance; the concentration of nutrients (ammonium, nitrites, nitrates), COD, turbidity, location of the site (upstream or downstream of the populated areas), as independent. The joint influence of these factors on the dependent variables was assessed using generalized linear models (GLM analysis). When comparing samples, the nonparametric Kruskal–Wallis method was applied. The nonparametric Mann–Whitney method was used for pairwise comparisons of samples to assess the difference of studied indicators between the sampling sites located upstream and downstream. The null hypothesis of no differences between samples was rejected at $p > 0.05$.

Table 1. Characteristics of watercourses in the Upper Ob basin. UP – upstream the settlement, DWN – downstream the settlement.

Parameter	Water stream									
	Paspaul River		Biryulya River		Saidys River		Karasuk River		Ulaushka River	
Length, km	16		16		26		12		20	
Sampling site	B	H	B	H	B	H	B	H	B	H
Temperature,°C	1.9	5.1	4.0	3.3	0.1	0.7	3.5	4.8	–	–
Average depth, m	0.2	0.15	0.1	0.25	0.1	0.1	0.2	0.2	0.1	0.15
Width, m	5	45	2	4	2	25	10	12	4	5
Shading, %	20	0	10	15	40	30	10	0	15	10
Projective cover of mosses, %	10	0	0	40	15	5	10	0	0	30
pH	8.19	8.39	8.35	8.32	7.68	7.66	8.24	8.19	8.39	8.46
O_2, mg/dm^3	12.74	13.56	12.3	11.99	12.55	11.9	11.9	11.85	9.3	14.36
Turbidity, NTU	38.01	18.45	33.72	42.95	17.35	172.17	130.51	55.35	10.47	12.36
NH_4, mg/dm^3	0.19	0.29	0.14	0.28	0.26	1.6	0.18	0.28	–	–
NO_2, mg/dm^3	0.004	0.022	0.005	0.008	0.009	0.14	0.008	0.015	–	–
NO_3, mg/dm^3	2.0	2.5	1.9	2.1	1.0	3.4	1.4	2.8	–	–
COD, mgO/dm^3	27	23	13	15	10	129	54	10	17	17

Results

Gravel and pebble sediments predominated in the studied river sections, located both upstream and downstream the populated areas. The watercourses at the sampling sites were characterized by a favorable oxygen regime, a low level of shading (except for the Saidys River), and a low projective cover of mosses (except for the lower section of the Biryulya River). During the sampling period, the water temperature mainly did not exceed 5.1 °C, but the temperature was usually higher in the areas located downstream. For all studied rivers, general increasing trends in the concentrations of ammonium, nitrates, and nitrites were noted in the sampling areas located downstream (Table 1). Particularly significant differences were noted for Saidys River, where nitrite concentration was 15 times higher downstream the settlement, COD, 10 times higher. In addition, in the downstream section of the Saidys River, maximum values of all analyzed indicators were noted, which exceeded threefold the maximum permissible concentration (MPC)[1] for ammonium and twofold, MPC for nitrites.

In most of the studied watercourses (Biryulya River, Saidys River, and Ulaushka River) pronounced decline of the water transparency was noted downstream the settlements; maximum water turbidity was observed on the downstream section of the Saidys River. During the study period, the upper section of the Karasuk River influenced by the road works, which predetermined a significant decrease in water transparency. In the area downstream the Karasuk village, water turbidity decreased by more than a

[1] Order of the Ministry of Agriculture of the Russian Federation dated December 13, 2016 No. 552 (as amended on June 16, 2020) “On approval of water quality standards for water bodies of fishery importance, including standards for maximum permissible concentrations of harmful substances in the waters of water bodies of fishery importance.”

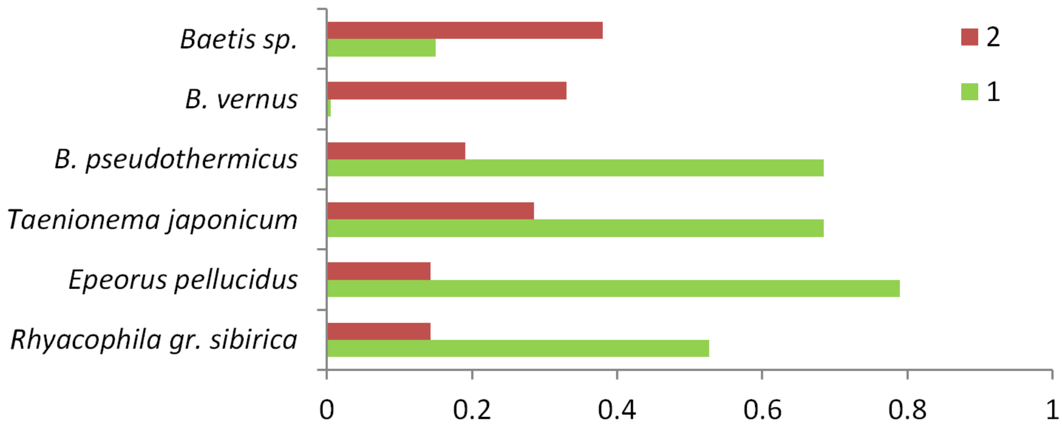

Fig. 2. Occurrence of indicator species in the areas upstream (1) and downstream (2) populated areas.

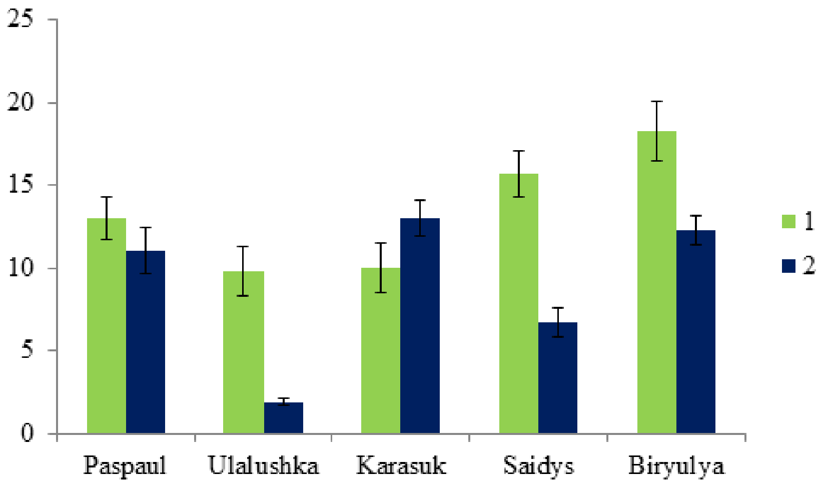

Fig. 3. Species richness (average number of species per sample) of EPT taxa of macroinvertebrates (1 – upstream the settlement, 2 – downstream).

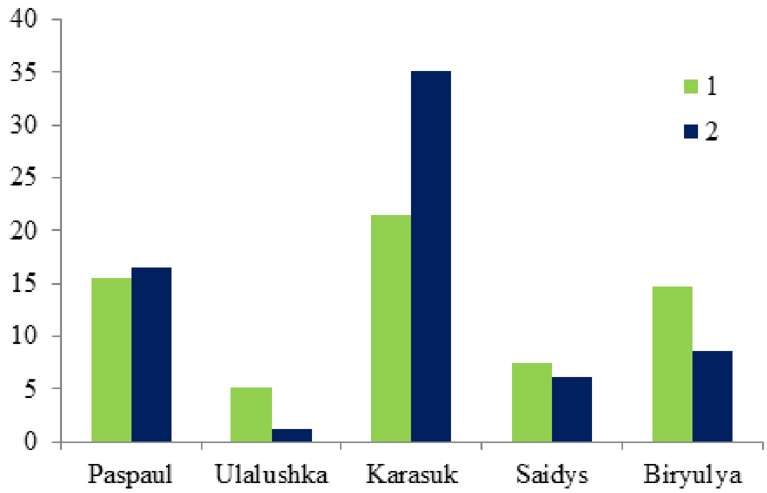

Fig. 4. Biomass (g/m^2) of macroinvertebrate communities at the sites located upstream (1) and downstream (2) of populated areas.

half, but its values still remained significantly higher than those in other rivers (except for the downstream section of Saidys River). High water turbidity values were also noted in the upstream section of the Paspaul River, which was likely due to the supply of suspended substances from the highway running along the river.

In total, 64 taxa of macroinvertebrates were found in the benthic communities of the studied rivers, including 27 species of mayflies, 20 species of caddisflies, and 17 species of stoneflies. The complex of the most common species was represented by *Amphinemura borealis* (Morton, 1894) noted in 60% of samples, *Ceratopsyche newae* (Kolenati, 1858), 60%; *Epeorus pellucidus* (Brodsky, 1930), 52%; and *Neoleptophlebia japonica* (Matsumura, 1931), 50%. At the same time, the frequency of occurrence of some species decreased significantly at the downstream sampling sites, including such species as *Rhyacophila* gr. *sibirica, E. pellucidus, Baetis pseudothermicus* Kluge, 1983, and *Taenionema japonicum* Okamota, 1922, which can be classified as the species most sensitive to water pollution. The frequency of occurrence of only some species of the genus *Baetis,* known as the most pollutant-tolerant mayfly taxa (Suhaila et al., 2017), has increased (Fig. 2).

The studied rivers differed significantly in the species richness of the EPT taxa: the maximum number of species (34) was noted in the Biryulya River, the minimum, in the Ulaushka River (21). At the same time, a statistically significant decrease in the species richness of macrozoobenthos was noted in areas downstream residential zone for the Saidys, Biryulya and Ulaushka rivers (Fig. 3). The largest drop in this indicator has been noted for the Ulaushka River, which flows through the largest populated area (the city of Gorno-Altaisk), and for the Saidys River, where settlement and a timber processing enterprise are located on its banks. The opposite trend – an increase in the species richness of macroinvertebrates downstream the settlement – is found only for the Karasuk River, due to the maximum turbidity caused by the road works in the upstream area.

Bottom communities of the background river sections were characterized by a relatively high abundance and biomass of EPT taxa. Downstream settlements, the abundance of aquatic macroinvertebrates generally declined with only exception of the Karasuk River, in which the biomass of benthic organisms downstream the settlement was 1.5 times higher than the values of the upper section similar to that of species richness (Fig. 4).

The analysis of variance was performed to assess the factors determining the variability of the structural characteristics of the bottom communities of the studied rivers. The variability of species richness, abundance, and Shannon diversity index was largely determined by the location of the site (upstream or downstream of the settlement), water turbidity, and COD (Table 2). Combining the factors increased the share of explained variance up to 67%, 53%, and 64%, respectively.

The EPT index values in the areas upstream the settlements varied slightly (mainly 19–27 species) and indicated generally a high diversity of insect orders most sensitive to pollution (Table 3). At most of the sampling sites located downstream, the richness of EPT taxa decreased; however, the EQI index for Biryulya River and Paspaul River evidenced that these changes did not break the boundaries of quality class I–II (“very clean” and “clean” waters, respectively). The most significant decrease in the EPT index was noted for the Saidys River (from 24 to 10 species) and the Ulaushka River (from 21 to 6 species). EQI values for these rivers indicated a decrease in water quality to class III (“moderately polluted”) for the Saidys River and quality class IV (“polluted”) for the Ulaushka River.

The Woodiwiss index reached maximum values (10 points) and corresponded to class I water quality in most of the studied watercourses. A decrease in index values to class II was noted only for the Ulaushka River. ASPT index values also indicated high water quality at all sites.

Changes in the BMWP index in various sections of the studied rivers generally corresponded to the dynamics of the EPT index and indicated a decrease in water quality in the Saidys River to class III, and in the Ulaushka River, to class IV. When comparing the EQI index values upstream and downstream the settlements, the ecological condition of these rivers may be stated as deteriorating.

Discussion

Residential areas significantly influence the state of aquatic ecosystems of low-mountain watercourses of Altai.

The content of organic substances in the water was the most significant factor in the formation of bottom communities of the studied low-mountain streams. An increase in COD downstream human

Table 2. Results of GLM analysis of variability in species richness (S), Shannon species diversity index (H), abundance (N), and biomass (B) of EPT macroinvertebrate taxa in low-mountain streams of Altai. Statistically significant values (p < 0.05) are highlighted in bold.

Factor	Parameter	R^2	F	p
Location	S	**0.29**	**15.59**	**0.0003**
	N	**0.13**	**5.81**	**0.0209**
	B	0.01	0.27	0.6092
	H	**0.27**	**13.99**	**0.0006**
COD	**S**	**0.37**	**22.46**	**<0.0001**
	N	**0.23**	**11.29**	**0.0018**
	B	0.07	2.93	0.0948
	H	0.23	11.58	0.0016
Nitrates	S	0.14	3.95	0.0579
	N	0.01	0.34	0.5645
	B	0.00	0.12	0.7298
	H	**0.16**	**4.78**	**0.0384**
Nitrites	S	0.03	0.75	0.3934
	N	0.02	0.43	0.5182
	B	0.00	0.06	0.8025
	H	**0.16**	**4.60**	**0.0418**
Ammonium	S	0.14	3.95	0.0579
	N	0.01	0.34	0.5645
	B	0.00	0.12	0.7298
	H	**0.16**	**4.78**	**0.0384**
Water turbidity	**S**	**0.15**	**6.84**	**0.0127**
	N	0.00	0.05	0.8321
	B	**0.15**	**6.89**	**0.0124**
	H	**0.24**	**12.15**	**0.0013**
Water turbidity × location	**S**	**0.46**	**10.11**	**0.0001**
	N	0.14	1.92	0.1438
	B	0.16	2.23	0.1014
	H	**0.54**	**13.92**	**< 0.0001**
Water turbidity × COD	**S**	**0.48**	**10.97**	**< 0.0001**
	N	**0.36**	**6.73**	**0.0010**
	B	0.18	2.67	0.0619
	H	**0.41**	**8.42**	**0.0002**
Water turbidity × location× COD	**S**	**0.67**	**10.98**	**< 0.0001**
	N	**0.53**	**6.25**	**0.0002**
	B	0.24	1.71	0.1501
	H	**0.64**	**9.76**	**< 0.0001**

settlements, concomitant with changes in the structure of benthic communities, has been noted in other studies of small rivers, likely due to intensive agricultural use of catchment areas (Wang, 2012).

Water turbidity is another factor affecting the distribution of macroinvertebrates in the studied rivers. In contrast to a number of studies demonstrating an increase in turbidity in the rivers of urbanized areas (Crooks et al. 2021; Mena-Rivera et al., 2017; Zhang et al., 2017), a decrease in water turbidity was noted in the area downstream the villages in some studied rivers (Karasuk River and Paspaul River). This was due to the construction of a road in the study area and the washing of soil particles from disturbed lands into watercourses. In the remaining studied areas, turbidity values were low, which was probably due to sampling before the onset of active snowmelt.

Despite the slight deterioration in water quality in most of the studied rivers in residential areas in terms of hydrochemical indicators, bottom communities demonstrated significant changes in their structural characteristics. This may be due to the early spring sampling period, when most of the catchment area is covered with snow, which prevents pollutants from being washed away from the catchment area. The life cycle of most EPT taxa is at least a year in the mountain rivers. Therefore, the structural characteristics of benthic communities reflect the dynamics of water quality over this period and may not fully correspond to the water quality in terms of hydrochemical indicators at the sampling period.

The most sensitive biological indicators of water quality in the studied rivers were the EPT and BMWP indices. The Woodiwiss biotic index (TBI), included in the state environmental monitoring system in Russia[2], has demonstrated low effectiveness in assessing the ecological status of low-mountain watercourses in Altai. This is probably due to significant differences in the indicator significance of the western and eastern Palaearctic families of macroinvertebrates belonging to the same order.

Table 3. Biotic indices in the studied rivers of the Upper Ob River basin.

Sampling site	EPT	TBI	BMWP	ASPT
Paspaul River, upstream the settlement	23	10	117	8.4
Paspaul River, downstream the settlement	18	10	90	8.2
EQI	**0.78**	**1.00**	**0.77**	**0.98**
Biryulya River, upstream the settlement	27	10	120	8.6
Biryulya River, downstream the settlement	23	10	100	8.3
EQI	**0.85**	**1.00**	**0.83**	**0.97**
Saidys River, upstream the settlement	24	10	113	9.4
Saidys River, downstream the settlement	10	8	72	9.0
EQI	**0.42**	**0.80**	**0.64**	**0.96**
Karasuk River, upstream the settlement	19	10	103	8.6
Karasuk River, downstream the settlement	22	10	93	8.5
EQI	**1.16**	**1.00**	**0.90**	**0.98**
Ulaushka River, upstream the settlement	21	10	74	8.2
Ulaushka River, delta	6	6	29	7.3
EQI	**0.29**	**0.60**	**0.39**	**0.88**

[2] GOST 17.1.3.07–82. Protection of nature. Hydrosphere. Rules for monitoring the water quality of reservoirs and streams.

Conclusions

Residential areas have a significant impact on the aquatic ecosystems of low-mountain watercourses in Altai. In the studied sections of rivers downstream the villages, increasing trends were noted in water temperature and concentrations of ammonium, nitrates and nitrites. The structural characteristics of benthic macroinvertebrate communities are a sensitive indicator of changes in the ecological state of rivers affected by residential areas. It is recommended to use the EPT and BMWP indices (in terms of macroinvertebrates) to assess the ecological state of low-mountain watercourses of Altai. These indices allowed to identify a significant deterioration in the living conditions of aquatic organisms in the Saidys River downstream the village of Sredny Saidys (to the class of "moderately polluted") and at the mouth of the Ulaushka River within the city of Gorno-Altaisk (to the class of "polluted" waters).

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