

Biotic Indices and Metrics of Zoobenthos in the Assessment of the Ecological State of a Large Mixed-Type River

A. V. Andrianova^a, * and Yu. V. Shan'ko^a

^a Institute of Computational Modeling, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia

*e-mail: AndrAV@icm.krasn.ru

Received June 3, 2021; revised September 15, 2021; accepted September 23, 2021

Abstract—The current state of zoobenthos communities has been studied in a large Siberian river, namely, the Chulym River. Bioindication indices have been calculated to determine the water quality. The use of the integral indicator has made it possible to assess the water quality in a single system in compliance with the Russian standards. The high water quality (“conventionally clean”) has been recorded in the middle reaches, where the river is semi-mountainous, as well as in the zone of its transformation from the semi-mountain type to the lowland type. Deterioration of the water quality (“dirty” water) has been recorded in the lowland reaches. It is shown that the assessment of the ecological state of water bodies using bioindication methods should take into account natural environmental factors, in particular, the type of bottom sediments.

Keywords: macrozoobenthos, biotic indices, principal component analysis, integral indicator, water quality class, type of ground

DOI: 10.1134/S1067413622020035

The strengthening of anthropogenic impact on water bodies over the past 50 years has made it necessary to enhance monitoring of the quality of surface waters, develop methods of water quality assessment, and search for objective criteria and integral indicators of water quality. It is known that monitoring of the aquatic environment quality using chemical methods does not make it possible to fully characterize the harmful impact of anthropogenic factors on biological communities. In many foreign countries, the chemical monitoring of water quality is less common than the biological one, since the priority of assessing the state of ecosystems by biological indicators has become obvious [1–3]. Russian hydrobiologists [4–6] pay increasingly more attention to methods and approaches proposed by the European Water Framework Directive (WFD), which recommends the biological monitoring of the state of water bodies.

It is known that zoobenthos organisms are widely used as promising indicators for assessing the state of river ecosystems both in domestic [6–8] and foreign studies [2, 9–11]. There are various methods for assessing the ecological state of water bodies by the structural and functional characteristics of zoobenthos; however, all of them are based on the general approach that does not take into account such factors as the differentiation between the natural dynamics of communities and anthropogenic transformation and between the regional and local features of aquatic ecosystems and certain river basins [3, 6].

The Chulym River is a large river in Siberia and the largest right-bank tributary of the Middle Ob River. The Chulym basin is one of the most populated areas of Krasnoyarsk krai, which includes five cities with large industrial enterprises. The intensive use of water bodies for industrial purposes has caused irreparable damage to ecosystems in the Chulym basin, in particular, in the second half of the 20th century during the development of the state district power plant of the Kansk–Achinsk fuel and energy complex. The diluting natural capacity of the river has actually been exhausted to date [12].

The purpose of this study is to assess the ecological state of a model watercourse of mixed type (with clearly defined mountain, semi-mountain, and lowland areas) by the composition and structure of bottom communities using an integral bioindication index and statistical data analysis.

MATERIAL AND METHODS

The study material included zoobenthos samples collected in the spring and autumn of 2016 from the Chulym River; the length of the sampling area was 800 km from the source of the river within the Republic of Khakassia and Krasnoyarsk krai. The surface relief is rugged; the mountain, hilly, and lowland parts of the basin are well defined. In spring, samples were taken from seven stations located in a mountain hilly area; in autumn, the study area was expanded (18 sta-

Table 1. Characteristics of zoobenthos sampling stations in the Chulyum River

Station no.	Sampling site	Coordinates, N/E	Type of ground	Number of samples
1	Village of Kopyevo	55°02′/89°51′	MSP	6
2	Village of Berezovyi Log	55°08′/90°40′	Sand and silt; M	8
3	Village of Balakhtha	55°22′/91°36′	MSP and silt; M	8
4	Village of Kurbatovo	55°35′/91°10′	MSP	10
5	Village of Podsosnoe	55°49′/91°01′	MSP and silt; M	8
6	Village of Krasnyi Yar	55°59′/91°01′	MSP; M	8
7	Village of Bolshoi Serezh	56°00′/90°41′	MSP and silt	8
8	Town of Nazarovo, above the HPP dam	56°03′/90°20′	Silt	5
9	Town of Nazarovo, below the HPP dam	56°02′/90°14′	MSP and silt	3
10	Village of Ershovo	55°56′/89°21′	MSP	5
11	Town of Bogotol	56°10′/89°34′	MSP; M	5
12	Village of Krasnovka	56°26′/90°25′	MSP; M	5
13	Village of Novobirilyussy	56°58′/90°39′	MSP and silt	5
14	Village of Prombor	57°19′/90°22′	MSP; M	5
15	Oxbow Lake Bolshaya Ladozhskaya	57°26′/90°03′	Silt and sand	5
16	The beginning of the Chulyum Nature Reserve	57°28′/89°51′	MSP and silt	4
17	The middle of the Chulyum Nature Reserve	57°29′/89°35′	Sand	4
18	The end of the Chulyum Nature Reserve	57°28′/89°14′	Sand	4

MSP, mixed sand and pebble; M, with macrophytes.

tions) to the border with Tomsk oblast, where the river is typically lowland. The length of the Chulyum River is 1733 km; the basin area is 134 thousand km². The river channel is divided into areas with the upper, middle, and lower reaches. The river width varies from 90 to 500 m and current velocity is 0.3–0.5 m/s [12, 13].

Benthic invertebrate samples were collected, fixed, and treated according to generally accepted methods [14]. Ground was sampled from an accessible shore area (ripal zone) using a Dulkeit circular scraper (the capture area is 1/9 m²). The sampling depth varied from 0.4 to 0.8 m. The coordinates of the sampling stations, types of ground, and amount of collected material are given in Table 1. A total of 106 quantitative zoobenthos samples were studied.

Assessment of the water quality by benthic communities was based on an integrated analysis of 11 bioindication indices, including those traditionally used in Russian hydrobiological studies: number of species in the community (n); Shannon diversity index (H) [15]; and Balushkina chironomid index (K). The other indices and metrics are recommended by the European Water Framework Directive: EPT index (total species number (EPT_n) or total relative abundance (EPT_N) of mayflies, stoneflies, and caddis flies), BMWP (biological monitoring working party index) and its derivative (ASPT (average score per taxon index)), and FBI (family biotic index). Methods of calculating the indices and their correspondence to

the water quality categories have been discussed in detail in many foreign and domestic works [2, 3, 5, 10]. In addition, indicators based on the ratio of macrozoobenthos species that are highly sensitive and insensitive to pollution have been used: EPT/Ch (the ratio of the total abundance (EPT_N) and number of mayfly, stonefly, and caddis fly species (EPT_n) to the abundance and species number of chironomids.

The data were statistically analyzed using the R software [16]. An analysis of variance (at a significance level of 0.05) was performed for each of the 11 indices separately for spring and autumn, which made it possible to determine the degree of influence of types of ground on the bioindication indices. To construct the integral index and divide the stations into groups by water quality, we used the k-means method (which makes it possible to minimize the sum of squares of distances from the points of clusters to their centers) and principal component analysis for revealing hidden factors influencing the data.

RESULTS

The structure, species composition, and quantitative development of benthic communities in the Chulyum River were previously described in detail in [17]. In our study, we recorded 170 macroinvertebrate species and higher grade taxa, which are widespread in the Palearctic and Holarctic and characteristic of

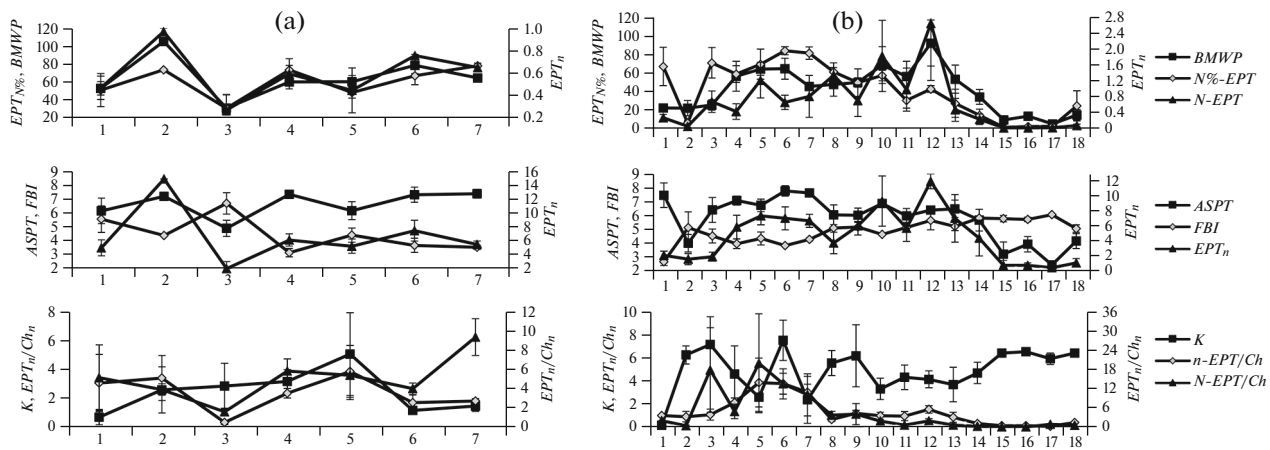


Fig. 1. Values of the biotic indices and metrics at the studied stations in the Chulym River in spring (a) and autumn (b).

mountain and foothill watercourses in different regions [18]. The species composition was represented by 95 taxa in spring and increased to 134 taxa in autumn. The zoobenthos included mainly larvae of amphiotic insects: chironomids, stoneflies, mayflies, and caddis flies. The largest number of species (54) was recorded among chironomids. The EPT indicator group is represented by 67 species; 34 of them are caddis flies, 25 of them are mayflies, and eight of them are stoneflies. The most significant among the indicator taxa in the Chulym River zoobenthos are the mayfly families Ephemeridae, Ephemerellidae, Caenidae, and Heptageniidae, caddis fly families Hydropsychidae, Lepidostomatidae, Sericostomatidae, and Leptoceridae, and stonefly families Perlodidae and Chloroperlidae.

The studied area of the Chulym River covers the zone of its transformation from the semi-mountain to the lowland type, which determines a slowdown of the current and an increase in the volume of silt deposits in the channel. This naturally resulted in the transformation of the taxonomic structure of zoobenthos: the proportion of chironomids increased in the total abundance from the upper to the lower reaches, while the proportion of the EPT group decreased [17].

Changes in the bioindication indices along the river profile and in different seasons. The Shannon diversity index (H) reached 4.5 bit/ind.; its average value was 2.8 ± 0.2 bit/ind. in spring and decreased to 2.4 ± 0.1 bit/ind. in autumn. The highest values (species number, 22–30, and H values, over 3 bit/ind.) were recorded in the upper reaches (station 2) in spring and middle reaches (stations 9–14) (in transitional communities reflecting the natural transformation of the river from the semi-mountain type to the lowland type) in autumn. Additional supply of biogens from the headwater of the Nazarovo HPP, located between stations 8 and 9, also contributes to an increase in the species diversity of zoobenthos.

In spring, the EPT index reached its maximum values in the upper reaches (station 2, Fig. 1). In autumn, the peaks of the species richness and abundance of the EPT group were recorded at station 12, where the river has features of transformation to the lowland type. In the lower reaches of the river, the proportion of EPT longitudinally decreased to 1% in the total abundance of zoobenthos (see Fig. 1). The highest EPT/Ch values were recorded in the upper area of the river, where the number of species (EPT_n) was 3–4 times higher than that of chironomids. It is known that the EPT/Ch value decreases with increase in the pollution level [5, 19].

The water quality was assessed from “clean” to “polluted” using the Balushkina index. The best water quality was recorded at station 1. It should be noted that the assessment by the K index is inconsistent with the other indices and metrics; for instance, stations 3 and 6 were assessed as “polluted” in autumn, while the other indices showed a higher water quality.

According to the FBI index, the highest level of pollution was recorded in the upper reaches (stations 1 and 3) in spring and lower reaches of the studied area (stations 12 and 14–17) in autumn. The water quality was assessed as “excellent” only at stations 4 (in spring) and 1 (in autumn).

According to the BMWP index, the worst water quality was recorded at station 3 in spring (“low” water quality); in autumn, the “poor” condition of the water was recorded in the upper reaches of the river (stations 1–3) and in the lower reaches of the studied area (stations 15–18).

The ASPT index exceeded 6 at most of the stations, which indicates “good” and “very good” water quality according to [3, 11].

Most of the biotic indices demonstrated that the water quality tended to deteriorate towards the lower reaches of the studied area (stations 15–18).

Table 2. Values of bioindication indices in different types of ground in the Chulyum River

Type of ground	n	H	EPT_n	EPT_n/Ch_n	EPT_N	$EPT_{N\%}$	EPT_N/Ch_N	FBI	BMWP	ASPT	K
Spring											
MSP	12 ± 2	2.9 ± 0.2	7 ± 1	3.4 ± 0.6	0.54 ± 0.11	71 ± 5	6.4 ± 1.1	3.4 ± 0.3	63 ± 7	7.4 ± 0.1	2.3 ± 0.7
Silt	14 ± 1	2.8 ± 0.2	5 ± 1	1.4 ± 0.2	0.60 ± 0.10	54 ± 6	4.1 ± 0.9	4.7 ± 0.5	57 ± 8	6.3 ± 0.4	3.6 ± 1.0
Macrophytes	14 ± 2	2.8 ± 0.3	3 ± 1	0.6 ± 0.2	0.46 ± 0.2	34 ± 7	1.5 ± 0.2	6.0 ± 0.5	38 ± 9	5.0 ± 0.2	6.5 ± 2.2
Autumn											
MSP	12 ± 1	2.7 ± 0.2	5 ± 1	2.1 ± 0.3	0.53 ± 0.1	57 ± 5	5.2 ± 1.8	4.3 ± 0.2	45 ± 4	6.8 ± 0.2	4.5 ± 0.7
Silt	11 ± 2	2.2 ± 0.2	3 ± 1	0.8 ± 0.2	0.48 ± 0.18	27 ± 8	3.1 ± 1.6	5.3 ± 0.5	30 ± 6	4.7 ± 0.5	6.3 ± 0.5
Sand	7 ± 1	1.9 ± 0.3	1 ± 0	0.3 ± 0.1	0.03 ± 0.01	9 ± 7	0.5 ± 0.3	5.5 ± 0.2	8 ± 2	3.2 ± 0.3	6.3 ± 0.2
Macrophytes	14 ± 1	2.4 ± 0.3	5 ± 1	1.5 ± 0.3	0.94 ± 0.29	38 ± 9	8.4 ± 3.4	5.0 ± 0.4	49 ± 9	5.6 ± 0.5	5.4 ± 0.6

MSP, mixed sand and pebble.

Changes in the bioindication indices depending on the type of substrate. The studied area of the river was formed mainly from mixed sand and pebble (MSP) and silted grounds, with sandy ground appearing in the lower reaches. Macrophyte thickets with the development of a phytophilic benthos community locally occurred in some places. The bioindication indices varied depending on the type of ground (Table 2): in spring, the water quality in the zone of biotope transformation consistently deteriorated in the MSP–Silt–Macrophyte series with respect to most of the indicators (except the species number (n), species diversity index (H), and abundance of the EPT_N group). This trend continued to be observed in autumn; i.e., the biotic indices and metrics in sandy-pebble biotopes showed the best water quality during this season. At

the same time, the water quality in macrophyte communities was better with respect to all indicators (except n and H) in autumn than in spring as a result of the appearance of mayfly and caddis fly indicator species. The worst indicators were recorded in sandy biotopes. Therefore, the water quality in the zone of biotope transformation deteriorated in the MSP–Macrophytes–Silt–Sand sequence in autumn.

An analysis of variance of the 11 indicators was carried out for each of the seasons. The null hypothesis was that the value of a certain indicator did not depend on the type of ground. The analysis of variance (Table 3) of the bioindication indices revealed that the type of ground described 30–60% of the data variation in spring and 13–45% in autumn: in spring, the null hypothesis can be rejected for five metrics (EPT_n/Ch_n , $EPT_{N\%}$, FBI, ASPT, and K), while their number increased to eight in autumn. At the same time, the Balushkina index was not included in these indicators; however, n , EPT_n , EPT_N , and BMWP were added.

Table 3. Determination coefficients (R^2) in the analysis of variance of the bioindication indices depending on types of ground in different study seasons in the Chulyum River

Indices	Spring		Autumn	
	R^2	p	R^2	p
n	0.024	0.725	0.128	0.038
H	0.004	0.950	0.073	0.200
EPT_n	0.183	0.072	0.242	0.001
EPT_n/Ch_n	0.302	0.013	0.188	0.010
EPT_N	0.030	0.671	0.249	0.001
$EPT_{N\%}$	0.310	0.008	0.262	0.000
EPT_N/Ch_N	0.173	0.103	0.111	0.094
FBI	0.351	0.004	0.152	0.017
BMWP	0.117	0.200	0.276	0.000
ASPT	0.597	0.000	0.454	0.000
K	0.251	0.031	0.066	0.292

The determination coefficients (the percentage of the explained variance), for which the corresponding indices significantly depend ($p < 0.05$) on the type of soil, are in bold.

Assessment of the ecological state of the watercourse by the bioindication indices. To group the stations by the water quality, we tested a statistical approach using the k-means clustering method. The integral indicator was constructed using the principal component method. The average values of all 11 bioindication indices for the stations during both seasons were selected as the initial data. The results of the analysis of the principal component analysis are given in Table 4. It is obvious that the first factor corresponds to the water quality itself. Therefore, the projection of the corresponding point of the 11-dimensional space onto the axis of the first principal component was chosen as an integral indicator of water quality [20]. According to the Kaiser rule, components with an eigenvalue greater than 1 are left for further analysis; in our case, there are two of them.

Factor loads for the first two principal components are given in Table 5. It should be noted that the first principal component has a negative correlation coefficient only with the FBI and K indices, which are

Table 4. Eigenvalues and percentages of the explained variance in the principal component analysis

Indices	Components										
	1	2	3	4	5	6	7	8	9	10	11
Eigenvalue	6.1	2.5	0.98	0.53	0.48	0.17	0.13	0.08	0.04	0.02	0.01
Percentage in the total variance	55.2	22.8	8.9	4.8	4.4	1.5	1.2	0.7	0.4	0.2	0.1
Percentage of the accumulated variance	55.2	77.9	86.8	91.6	96.0	97.5	98.6	99.3	99.7	99.9	100

Table 5. Factor loads for the first two principal components (PC1 and PC2)

Factor	<i>n</i>	<i>H</i>	EPT _{<i>n</i>}	EPT _{<i>n</i>} /Ch _{<i>n</i>}	EPT _{<i>N</i>}	EPT _{<i>N</i>} %	EPT _{<i>N</i>} /Ch _{<i>N</i>}	FBI	BMWP	ASPT	<i>K</i>
PC1	0.62	0.61	0.88	0.75	0.89	0.83	0.47	-0.57	0.93	0.91	-0.52
PC2	0.76	0.71	0.39	-0.28	0.02	-0.50	-0.64	0.61	0.31	-0.26	0.06

inversely related to water quality. The clustering results are satisfactory when all the stations are divided into four clusters (Fig. 2). As a result, the more to the right the center of the cluster in the figure, the better the water quality at the corresponding stations.

The integral indicator (Table 6), which includes the set of all calculated indices and metrics, makes it possible to assess the water quality in a single system, in which the differentiated clusters can be roughly compared to the division into water quality classes in accordance with the applicable Russian standards [21]. Therefore, the best water quality (“conventionally clean”) was recorded at station 2 (near the village of Novomaryasovo) and station 6 (near the Arga ridge) in spring and at stations 10 (the village of Ershovo, Nazarovo Loop) and 12 (the village of Krasnovka) in autumn. The minimum values of the integral indicator and, accordingly, worst water quality (“dirty”) were recorded in autumn in the lower reaches of the studied area near the Chulym reserve (stations 15–18).

DISCUSSION

It is known that the habitat conditions for hydrobiota consistently change in rivers with distance from the source, which entails a heterogeneity of the taxonomic structure of communities along the longitudinal profile of the river [22–24]. At the same time, the species richness may increase with distance from the upper river reaches [6, 18, 19], which is determined by the heterogeneity of habitat conditions, accumulation of organic matter, and invertebrate drift. A similar picture was observed in the Chulym River—a decrease in the proportion of representatives of the EPT group, an increase in the proportion of chironomids in zoobenthos, and an increase in the species diversity index in the zone of river transformation from the semi-mountain type to the lowland type. Although biological monitoring is currently widely used in assessing water quality, the bioindication indices used in biological

monitoring have some drawbacks and it is recommended to use them together.

It is known that the species diversity decreases with increase in the level of pollution or eutrophication of the water body [9, 19]. However, the decrease in the species diversity can be caused not only by anthropogenic but also by natural specific factors, e.g., by the uniformity of biotopes under oligotrophic conditions in a fairly clean environment [7] or by the typical poor composition of sandy grounds. Under certain conditions, the index of species diversity can be even higher

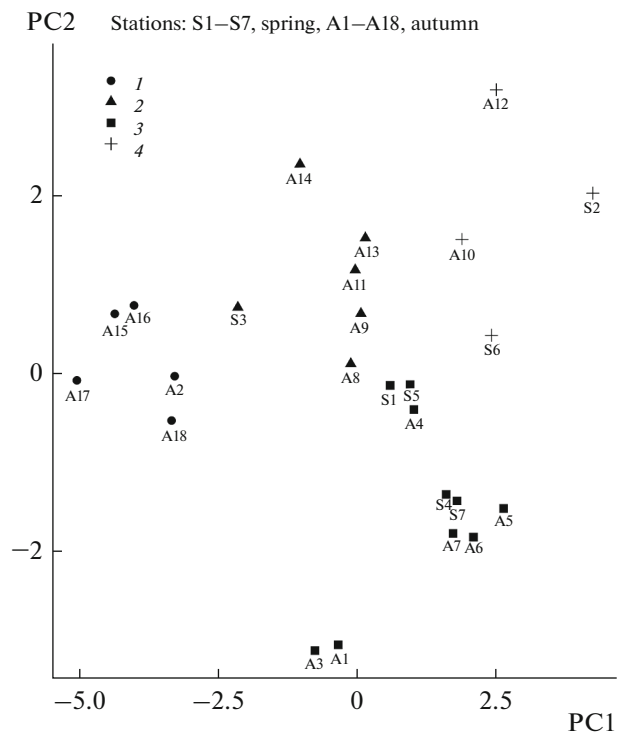


Fig. 2. Classification of the studied stations in the Chulym River by water quality using the k-means method: (1) dirty, (2) polluted, (3) weakly polluted, (4) conventionally clean.

Table 6. Integral indicator and classes of water quality in the Chulym River

Season	Station no.																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Spring	0.6	4.3	-2.1	1.6	1.0	2.5	1.8	—	—	—	—	—	—	—	—	—	—	—
	WP	WP	P	WP	WP	CC	WP											
Autumn	-0.31	-3.3	-0.7	1.1	2.7	2.2	1.8	-0.1	0.1	1.9	-0.004	2.5	0.2	-1.0	-4.3	-4.0	-5.0	-3.3
	WP	P	WP	WP	WP	WP	WP	P	P	CC	P	CC	P	P	D	D	D	D

CC, conventionally clean; WP, weakly polluted; P, polluted; D, dirty; dash, no data.

in anthropogenically stressed areas of rivers than in background ones [25], since the food flow to bottom cenoses increases with growth in the trophic level, which can lead to a decrease in competition and an increase in species richness and, accordingly, species diversity (up to 3.5–4 bit) [1, 26]. It is often difficult to differentiate the effects of natural and anthropogenic factors on the species diversity of zoobenthos communities. Therefore, the use of the species diversity index in the assessment of water quality requires careful interpretation; it is reasonable to consider this index in combination with other indices and metrics, rather than as an independent value.

The EPT biotic index is widely used in foreign systems for ecological monitoring of lotic waters. The index can be based on the total or relative abundance, as well as on the number of species of the orders Ephemeroptera, Plecoptera, and Trichoptera, which are least tolerant to different types of pollution. However, the EPT index is not normalized for water quality classes and largely depends on the natural features of the watercourse. Some researchers randomly divide the relative abundance of the EPT group ($EPT_{N\%}$) into five classes, where the best water quality corresponds to the value above 40% and worst water quality to the value below 10% [27].

One of the disadvantages of the EPT/Ch index is that chironomids include both tolerant and highly sensitive species to environmental pollution. It is known that the ratio between the main subfamilies of chironomid larvae (Chironominae, Tanypodinae, and Orthocladinae) changes under the effect of environmental conditions. This pattern is taken into account by the Balushkina index (K), which is widely used in Russian monitoring systems. However, there are also conflicting opinions about the use of chironomids (in particular, the Balushkina index) for bioindication [4, 7].

The BMWP index is widely used in environmental monitoring systems throughout the world; however, the gradations determined for index values differ in different countries [2, 8, 10, 27], which decreases the reliability of its interpretation. In our study, we assumed the gradation according to [5]: the BMWP value of over 150 scores corresponds to the “excellent” water quality and its value of less than 25 scores means the “poor” water quality.

There are data indicating a low sensitivity of the ASPT and its trend to overestimate [5, 8, 25] or, on the contrary, underestimate the water quality in sandy biotopes of weakly polluted rivers [28]. At the same time, other authors have shown the successful use of this index in bioindication [3, 11].

The use of the bioindication method in assessing the ecological state of water bodies should take into account not only anthropogenic impact but also natural environmental factors. A number of researchers have pointed out the relationship between the type of substrate and values of bioindication indices [8, 10, 28]. In one of the river basins of Ecuador, it was revealed that the satisfactory water quality was determined by solid stony-pebble substrates prevailing in mountain and semi-mountain river areas [10]. A similar picture was observed in the Chulym River: most of the bioindication indices showed the best water quality in sandy-pebble biotopes compared to silty and sandy ones.

The absence of a single generally accepted ranking system for water quality classes decreased the sensitivity of the indicators in the pollution gradient, which leads to a distortion of the resulting values of water quality categories. Some indices can be unified according to gradations by water quality classes [8, 27]. However, each of the indices selects a certain feature of a biotic community, thereby underestimating its other features, which results in differences between assessments of the quality of ecosystems by different indicators.

To solve this problem, it is proposed to use a comparative approach reflected in the principles of the European Water Framework Directive. According to the WFD requirements, the ecological status of a river or a river basin is determined in relation to certain reference model systems [5]. The effectiveness of this approach is reflected in many works [4–6, 18]; however, the diversity and heterogeneity of different aquatic ecosystems, determined not only by anthropogenic but also by natural conditions, makes it difficult to select reference communities. Lack of domestic hydrobiological studies in background areas that are far from anthropogenic impact in different climatic zones also makes it difficult to use this approach. The hydrological network of Roshydromet (Federal Ser-

vice for Hydrometeorology and Environmental Monitoring) in Krasnoyarsk krai includes only 137 stations; its density is 6 thousand km² per one hydrological station, which is clearly insufficient, in particular, under study conditions in the northern areas of Krasnoyarsk krai [29].

During the assessment of the ecological status of the Chulym River, it is very difficult to choose the reference site due to an active anthropogenic exploitation of the basin and hydromorphological features of the river in the zone of its transformation from the mountain type to the lowland type. Therefore, different statistical methods, in particular, clustering of data on a set of several bioindication indices, can be used as a way to determine the water quality in mixed-type rivers that have areas with different hydromorphological conditions.

Therefore, the integrated assessment of the ecological state of the Chulym River with the hydromorphological transformation from the upper to the lower reaches revealed that the bioindication indices for the composition and structure of benthic communities had a nonuniform distribution along the studied area. Most of the metrics and biotic indices were inconsistent with each other. A natural environmental factor influencing the assessment of the ecological state of a watercourse is the type of bottom sediments. For instance, the water quality in the zone of biotope transformation deteriorated in the Sandy-pebble–Macrophytes–Silt–Sand series; here, up to 60% of data variation was explained by the type of ground. The integral indicator, calculated from the set of biotic indices and metrics using the statistical analysis, made it possible to rank the control stations by categories corresponding to the Russian State Standard. The best water quality (“conventionally clean”) was recorded in the middle reaches of the river, where it is semi-mountainous, and in the area of its transition from the semi-mountain to the lowland type. The deterioration of water quality (“dirty”) was recorded in the lowland reaches.

ACKNOWLEDGMENTS

The authors are grateful to members of the Krasnoyarsk branch of the Russian Federal Research Institute of Fishery and Oceanography (Research Institute of Ecology of Fishery Reservoirs), who participated in the expeditions.

FUNDING

This study was performed within the framework of state budgetary topic no. 0287-2021-0004 of the Ministry of Science and Higher Education of the Russian Federation.

CONFLICT OF INTERESTS

The authors confirm that they have no conflict of interests.

COMPLIANCE WITH ETHICAL STANDARDS

This study involved animals as objects of research in compliance with the applicable ethical standards.

REFERENCES

- Balushkina, E.V. and Golubkov, S.M., Biodiversity of benthic animal communities and water quality in the Neva River under anthropogenic stress, *Tr. Zool. inst. Ross Akad. Nauk*, 2015, vol. 319, no. 2, pp. 229–243.
- Sharifinia, M., Mahmoudifard, A., Namin, J.I., et al., Pollution evaluation in the Shahrood River: Do physico-chemical and macroinvertebrate-based indices indicate same responses to anthropogenic activities?, *Chemosphere*, 2016, vol. 159, pp. 584–594. <https://doi.org/10.1016/j.chemosphere.2016.06.064>
- Banagar, G., Riaz, B., Rahmani, H., and Jolodar, M.N., Monitoring and assessment of water quality in the Haraz River of Iran, using benthic macroinvertebrates indices, *Biologia*, 2018, vol. 73, pp. 965–975. <https://doi.org/10.2478/s11756-018-0107-5>
- Golovatyuk L.V. and Zinchenko, T.D. Biotic indices and metrics in the assessment of water quality in small rivers of the Lower Volga basin (the Baitugan, Kamyshla, and Sosnovka), in *Osobennosti presnovodnykh ekosistem malykh rek Volzhskogo basseina* (Specific Features of Freshwater Ecosystems in Small Rivers of the Volga Basin) Rozenberg, G.S., Zinchenko, T.D., Eds., Tolyatti: Cassandra, 2011, pp. 160–169.
- Semenchenko, V.P., and Razlutskiy, V.I., *Ekologicheskoe kachestvo presnykh vod* (Ecological Quality of Fresh Waters), 2nd ed., Minsk: Belaruskaya Navuka, 2011.
- Yanygina, L.V., Macrozoobenthos as an indicator of the ecological state of mountain watercourses, *Russ. J. Ecol.*, 2017, vol. 48, no. 2, pp. 185–190. <https://doi.org/10.1134/S1067413617020114>
- Bezmaternykh, D.M., Zoobenthos as an indicator of ecological state of aquatic ecosystems in Western Siberia: An analytical review, *GPNTB SO RAN, Inst. Vodn. Ekol. Probl., Ser. Ecol., Gos. publich. nauch.-tekhn. b-ka SO RAN, In-t vod. i ekol. problem. Ser. Ekologiya*, Novosibirsk, 2007, no. 85.
- Yanygina, L.V., Benthic communities in assessing the ecological state of the small Izdrevaya River, *Izv. AO RGO*, 2017, no. 4 (47), pp. 93–100.
- Mehari, A.K., Wondie, A., Mingist, M., and Vijverberg, J., Spatial and seasonal variation in the macroinvertebrates and physico-chemical parameters of the Enfranz River, Lake Tana sub-basin (Ethiopia), *Ecohydrol. Hydrobiol.*, 2014, vol. 14, pp. 304–312. <https://doi.org/10.1016/j.ecohyd.2014.07.004>
- Damanik-Ambarita, M.N., Lock, K., Boets, P., et al., Ecological water quality analysis of the Guayas River basin (Ecuador) based on macroinvertebrates indices, *Limnologica*, 2016, vol. 57, pp. 27–59. <https://doi.org/10.1016/j.limno.2016.01.001>
- Mangadze, T., Bere, T., and Mwedzi, T., Choice of biota in stream assessment and monitoring programs in tropical streams: A comparison of diatoms, macroinvertebrates and fish, *Ecol. Indic.*, 2016, vol. 63, pp. 128–

143.
<https://doi.org/10.1016/j.ecolind.2015.11.029>
12. Korytnyi, L.M., *Reki Krasnoyarskogo kraja* (Rivers of Krasnoyarsk Krai), Krasnoyarsk: Knizhn Izd., 1991.
 13. Glazyrina, E.I., Gundrizer, A.N., Zalognyi, N.A., et al. *Biologicheskie resursy vodoemov basseina reki Chulyma* (Biological Resources of the Chulym River Basin), Tomsk: Izd. Tomsk. Gos. Univ., 1980.
 14. *Metodicheskie rekomendatsii po sboru i opredeleniyu zoolentosa pri gidrobiologicheskikh issledovaniyakh vodotokov Dal'nego Vostoka Rossii* (Methodological Guidelines for Collection and Identification of Zoobenthos in Hydrobiological Studies on Streams of the Russian Far East), Moscow: Izd. VNIRO, 2003.
 15. Rukovodstvo po gidrobiologicheskomu monitoringu presnovodnykh ekosistem (TRANSLATION) Abakumov, V.A., Ed., St Petersburg: Godrometeoizdat, 1992.
 16. R Core Team, R: A Language and Environment for Statistical Computing, Vienna, Austria, 2020. www.R-project.org/
 17. Andrianova, A.V., Current Data on zoobenthos from the Chulym River, *Mezhd. Zh. Pekl. Fundament. Issled.*, 2017. no. 6 (2), pp. 257–261.
 18. Andrianova, A.V., Biotic indices and metrics in assessment of the water quality of small rivers on the territory of Ergaki Nature Park (south of Krasnoyarsk krai), *Contemp. Probl. Ecol.*, 2015, vol. 8, no. 3, pp. 358–367. <https://doi.org/10.1134/S1995425515030038>
 19. Menbohan, S., Tchakonte, S., Ajeagah, G.A., et al., Water quality assessment using benthic macroinvertebrates in a periurban stream (Cameroon), *Int. J. Biotechnol.*, 2013, vol. 2, no. 5, pp. 91–104.
 20. Strijov, V., Granic, G., Juric, Z., et al., Integral indicator of ecological impact of the Croatian thermal power plants, *Energy*, 2011, vol. 36, no. 7, pp. 4144–4149. <https://doi.org/10.1016/j.energy.2011.04.030>
 21. RD 52.24.309-2016. *Rukovodyashchii dokument. "Organizatsiya i provedenie rezhimnykh nablyudenii za sostoyaniem i zagryazneniem poverkhnostnykh vod sushi"* (utv. Rosgidrometom 8.12.2016) (Regulatory Document RD 52.24.309-2016: Organization and Performance of Scheduled Observations on the State and Pollution of Land Surface Waters. Approved by Rosgidromet on December 8, 2016), Moscow, 2016.
 22. Webster, J.R., Spiraling down the river continuum: Stream ecology and the U-shaped curve, *J. North Am. Benthol. Soc.*, 2007, vol. 26, pp. 375–389. <https://doi.org/10.1899/06-095.1>
 23. Masikini, R., Kaaya, L.T., and Chicharo, L., Evaluation of ecohydrological variables in relation to spatial and temporal variability of macroinvertebrate assemblages along the Zigi River, Tanzania, *Ecohydrol. Hydrobiol.*, 2018, vol. 2, pp. 130–141. <https://doi.org/10.1016/j.ecohyd.2018.03.004>
 24. Scotti, A., Jacobsen, D., Tappeiner, U., and Bottarin, R., Spatial and temporal variation of benthic macroinvertebrate assemblages during the glacial melt season in an Italian glacier-fed stream, *Hydrobiologia*, 2019, vol. 827, pp. 123–139. <https://doi.org/10.1007/s10750-018-3731-8>
 25. Gorzel, M. and Kornijów, R., The response of zoobenthos to “natural channelization” of a small river, *Ecohydrol. Hydrobiol.*, 2007, vol. 7, no. 1, pp. 59–70. [https://doi.org/10.1016/S1642-3593\(07\)70189-1](https://doi.org/10.1016/S1642-3593(07)70189-1)
 26. Belyakov, V.P. and Bazhora, A.I., Structural and functional characteristics of zoobenthos in lakes located in natural and urbanized landscapes of the Northwestern region of Russia, *Zh. Sib. Fed. univ., Ser. Biol.*, 2016, vol. 9, no. 4, pp. 484–498. <https://doi.org/10.17516/1997-1389-2016-9-4-484-498>
 27. Galas, J., Dumnicka, E., and Galus-Barchan, A., A comparison of various indices based on benthic macrofauna for the assessment of the ecological status of selected Carpathian streams, *Oceanol. Hydrobiol. Stud.*, 2014, vol. 43, no. 2, pp. 123–130. <https://doi.org/10.2478/s13545-014-0124-0>
 28. Dickens, C.W.S. and Graham, P.M., The South African scoring system (SASS), version 5: Rapid bioassessment method for rivers, *Afr. J. Aquat. Sci.*, 2002, vol. 27, pp. 1–10. <https://doi.org/10.2989/16085914.2002.9626569>
 29. Shaparev, N.Ya. and Andrianova, A.V., The Yenisei River in terms of sustainable water management, *Geogr. Nat. Resources*, 2018, vol. 39, no. (4), pp. 307–315. <https://doi.org/10.1134/S1875372818040030>

Translated by D. Zabolotny