ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 12: 1447–1469 (2026)
doi: 10.5281/zenodo.23978111
http://journal.asu.ru

RESEARCH ARTICLE

Diversity and status of the ichthyofauna of small rivers on the southern slope of the Shu-Ile Mountains (Shu River Basin, Kazakhstan)

Sayat E. Sharakhmetov[1], Yerbol T. Sansyzbayev[1], Fariza T. Amirbekova[1], Nadir Sh. Mamilov[1], Nazym S. Sapargaliyeva[1], Gulnar B. Kegenova[1], Nurlan B. Baimurzayev[1], Rasul K. Zhanzakov[1]

1 *Department of Zoology, histology and cytology, Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan*

Corresponding authors: Nazym S. Sapargaliyeva (sapargalyeva.nazym@gmail.com)

Academic editor: R. Yakovlev | Received 5 September 2026 | Accepted 20 October 2026 | Published 7 November 2026

http://zoobank.org/94ADEB83-046F-45BB-A5A1-8E91E978F904

Citation: Sharakhmetov SE, Sansyzbayev YT, Amirbekova FT, Mamilov Nsh, Sapargaliyeva NS, Kegenova GB, Baimurzayev NB, Zhanzakov RK (2026) Diversity and status of the ichthyofauna of small rivers on the southern slope of the Shu-Ile Mountains (Shu River Basin, Kazakhstan). Acta Biologica Sibirica 12: 1447–1469. https://doi.org/10.5281/zenodo.23978111

Abstract

The article presents an analysis of the ichthyofauna of 23 small rivers located on the southern slope of the Shu-Ile Mountains, based on data collected in 2024. Among the 23 rivers studied, fish were recorded in 16 rivers, where a total of 16 species were identified, belonging to 15 genera, 9 families, and 4 orders, with a predominance of Cypriniformes. The ratio of native to alien species was approximately 1:1; however, native species prevailed in terms of abundance. Species richness of the rivers ranged from 1 to 6 species. Native species such as *Gobio lepidolaemus* and *Rutilus lacustris* demonstrated high ecological plasticity, whereas alien species *Pseudorasbora parva* and *Micropercops cinctus* often formed the core of simplified communities. The highest diversity of species was observed in the Karakonyz, Karasu, and Turan rivers, whereas in several rivers only one or two species were recorded. Analysis of community structure revealed substantial spatial variation, driven by hydrological regime, orographic isolation, and the impact of irrigation. Simpson and Shannon diversity indices, Sorensen similarity coefficients, cluster analysis, and principal component analysis (PCA) indicated differences among communities, ranging from simplified systems dominated by a single species to relatively balanced ecosystems. The data obtained highlights the importance of comprehensive monitoring of small rivers for assessing the stability of native species, controlling introduced species, and conserving the biodiversity of riverine ecosystems in the region.

Copyright Sayat E. Sharakhmetov et al. This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Keywords
Alien, native species, fish communities, structure, similarity, ecological plasticity

Introduction

The Shu-Ile Mountains, extending for approximately 200 km northwestward from the Ile Alatau, represent a continuation and terminal segment of the Northern Tien Shan, with which they share a common geological history of formation. These are highly eroded ancient mountain massifs composed of sedimentary and igneous rocks. The axial part of the Shu-Ile Mountains forms the watershed between the Shu and Ile rivers (Clottes 2011). The Shu-Ile Mountains are in southern Kazakhstan, predominantly within the Zhambyl Region and partially extending into the Almaty Region. They belong to the category of deserted low mountains and are characterized by a hummocky upland relief alternating with broad valleys. The mountain system comprises a series of ridges separated by intermontane tectonic depressions. The maximum width of the massif in its central part reaches approximately 50 km (Trip to the Chu-Ile Mountains). The elevation amplitude of the Shu-Ile Mountains is significantly lower than that of the Ile Alatau (approximately 5000 m). The highest points of the massif are the Anyrakay Mountains (1183 m), Kulzhabasy (1178 m), and Khantau (1024 m) (Clottes 2011).

The main spurs of the Shu-Ile Mountains include Aytau, Zheltau, Kindiktas, and Zhetyzhol. In the southwest, the system gradually transitions into the low mountains of Khantau and Maizharlygan, which form the terminal segments of the mountain massif (Zhakyp 2011).

Rivers such as Ashchysu, Kopalysai, Zhingeldy, Tesik, Kakpaktas, and several other watercourses originate on the mountain slopes. They flow along numerous gullies predominantly during the spring season; however, by summer they either completely dry up or persist as isolated pools sustained by groundwater input (Chu-Ile Mountains).

Climatically, the region is characterized by insufficient moisture. The annual precipitation ranges from 200 to 400 mm. River feeding is of a mixed type (Duysebaeva 2020).

Small rivers are key components of freshwater biodiversity, particularly of ichthyofauna (Biggs 2017). Ichthyofauna serves as an indicator of water quality and the overall condition of ecosystems. Despite their relatively small size and often remote location, small rivers provide valuable ecosystem services, including sustaining larger rivers, serving as sources of drinking water, and supporting biodiversity, all of which are important for human well-being. However, these rivers are highly vulnerable to pollution, flow regulation, climate change, and habitat degradation (Ferreira et al. 2023). It should be noted that small rivers often function as refugia, ensuring the preservation of rare, endemic, and vulnerable fish species. The conser-

vation of fish genetic diversity is essential for maintaining the resilience and stability of ecosystems under changing environmental conditions (Tkachev, Bulatov 2002).

Climate change affects the thermal regime, water levels, and hydrological characteristics of small rivers (Zyryanov 2015), which may lead to alterations in composition of ichthyofauna. The study of ichthyofauna in small rivers contributes to fundamental knowledge of freshwater ecosystems and their functioning. Research on the ichthyofauna of the Shu River basin began in the mid-19th century with N.A. Severtsov (1873). G.V. Nikolsky (1931) provided data on the fishes of the middle and lower reaches of the river. Detailed information on species composition was obtained by P.A. Dryagin (1936) during the comprehensive Kyrgyz expedition of the USSR Academy of Sciences. Subsequent studies were carried out by F.A. Turdakov (1963) and I.A. Pivnev (1985).

Between 1990 and 2010, the ichthyofauna of the Shu River basin was the subject of research by several domestic scientists, including G.N. Dukravets et al. (1994, 2001) and F.V. Klimov (2005). According to monitoring studies by N.Sh. Mamilov (2011), 35 fish species were recorded in the Kazakhstan section of the Shu River basin, of which 16 were non-native. In subsequent years, the composition of the ichthyofauna in the middle section of the river (Bekkozhaeva, Mamilov 2014) was found to be considerably variable. The ichthyofauna of small rivers flowing from the southern slopes of the Shu-Ile Mountains remains virtually unstudied to date, due to their remoteness from settlements, difficult accessibility, and hydrological instability. The lack of data on fish populations hinders effective biodiversity conservation, sustainable use of natural resources, and ecosystem management. In this context, the aim of our study is to assess the diversity of the species and status of the ichthyofauna of small rivers on the southern slopes of the Shu-Ile Mountains within the Shu River basin.

Materials and methods

All ichthyological and hydrochemical data (Table 1) were collected from small rivers flowing from the southern slopes of the Shu-Ile Mountains between 17 and 24 July 2024 at the specified river sites (Fig. 1).

Table 1. Coordinates and number of fish sampled in small rivers on the Southern slopes of the Shu-Ile Mountains from 17 to 24 July 2024

No	Sampling sites	Catch date	Coordinates WGS	Altitude BS	Quantity, pcs	Taxa
1	Kalguty river*	17.07.2024	43°13.568'N; 74°50.887'E	824	21	2
2	Yrgaity river		43°7.383'N; 74°42.449'E	638	16	3
3	Maibulak river		43°00.186'N; 75°3.031'E	819	39	1
4	Oriktisai river		42°59.292'N; 75°8.368'E	941	No fish	

5	Kyzylsai river*	18.07.2024	42°59.707'N; 75°12.506'E	1016	5	1
6	Batys Zhinishke river		42°58.301'N; 75°14.113'E	971		No fish
7	Shygys Zhinishke*		42°58.387'N; 75°17.264'E	1061	7	1
8	Karakonyz river*		42°57.433'N; 75°20.728'E	979	114	6
9	Kishi Kemin river		42°49.650'N; 75°41.439'E	1105		No fish
10	Karasu river		42°59.669'N; 74°52.398'E	665	31	6
11	Ungirli river*	21.07.2024	43°31.692'N; 74°0.618'E	558	42	4
12	Shatyrkol river*		43°34.446'N; 74°2.289'E	585	27	2
13	Bayguta river		43°39.993'N; 73°59.993'E	543	42	2
14	Turan river*	22.07.2024	43°49.178'N; 73°49.816'E	444	301	6
15	Terekti river*		43°49.516'N; 73°58.915'E	493	136	5
16	Shokpar river*		43°48.539'N; 74°23.105'E	761	86	3
17	Kerbulak river*		43°44.961'N; 74° 23.357'E	837	25	2
18	Kulakshynsay river*		43°55.201'N; 74°6.738'E	565	5	1
19	Ushkyzyl river*		43°57.080'N; 74°3.817'E	538	23	4
20	Shaladyr river		43°58.245'N; 74°1.786'E	518		No fish
21	Sarybulak river	23.07.2024	44°20.904'N; 73°51.886'E	619		Dry
22	Karashygaly river		44°55.759'N; 72°49.837'E	417		Dry
23	Tarylgan river	24.07.2024	43°25.046'N; 74°19.621'E	678		Dry
			Total number of specimens and taxa		**931**	**16**

Note: * indicates rivers where hydrochemical water analysis was conducted.

To ensure a comprehensive assessment of the ichthyofauna, a range of habitat types at the sampling sites was surveyed. Fish sampling was conducted using hand nets with a frame size of 0.5–1 m, a net bag length of 1–1.5 m, and a mesh size of 3–6 mm, as well as a juvenile seine 6 m in length with a mesh size of 3 mm (Hill et al. 2005). Following capture, fish were subjected to preliminary visual identification to species level, and the frequency of occurrence of each species was recorded. Specimens were fixed in 4% formaldehyde. Detailed examination was subsequently carried out under laboratory conditions. Morphological identification of fish was performed using standard taxonomic keys (Baimbet, Temirkhan 2005; Koblitskaya 1981; Veselov 1977).

Valid fish nomenclature was verified using the online database Eschmeyer's Catalog of Fishes (2025). Biological parameters of fish (total length, TL; standard length, SL; body weight, Q) were determined according to Pravdin (1966). Statistical analysis of the data (min, max, mean, standard deviation, and coefficient of variation was performed following Lakin (1990) using MS Excel 2019.

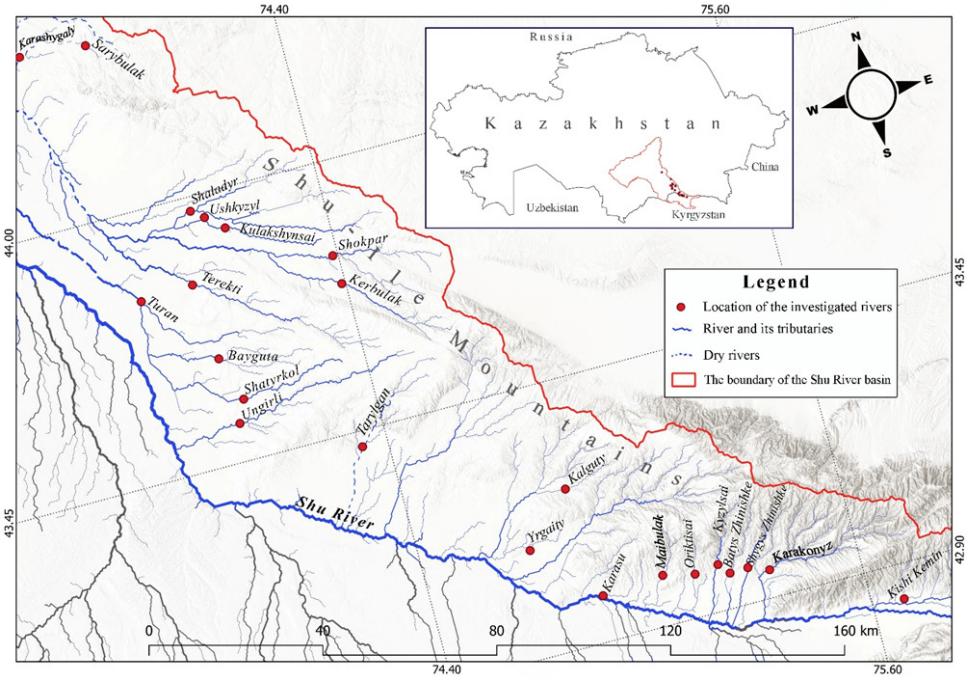


Figure 1. Schematic Map of the studied rivers on the southern slope of the Shu-Ile Mountains, July 2024.

Relative species abundance was calculated according to Artaev and Ruchin (2017), with the following categories distinguished: rare (<0.1%), scarce (0.1–1%), common (1–5%), abundant (5–10%), dominant (10–50%), and superdominant (50–100%). The similarity of ichthyofauna among rivers was assessed using the Sørensen similarity coefficient.

$$K = \frac{2 \cdot c}{a + b}$$

Here, a and b represent the number of species recorded in each of the two water bodies compared, and c denotes the number of species common to both. The resulting coefficients ranged from 0 to 1, where 1 indicates maximum similarity. The ichthyofaunal diversity index and cluster analysis were calculated using the statistical software package PAST 4.17 (2001). Dendrograms were constructed using the unweighted pair-group method with arithmetic means (UPGMA).

Shannon diversity index:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Simpson diversity index:

$$1 - D = 1 - \frac{\sum_{i=1}^{s} n_i\,(n_i - 1)}{N(N-1)}$$

where H' is the Shannon diversity index; D is Simpson's dominance index; n_i is the number of individuals of species i; N is the total number of individuals of all species in the sample; S is the total number of species recorded; $p_i = n_i/N$ is the relative abundance of species i; and ln denotes the natural logarithm.

The main hydrochemical parameters – pH, dissolved oxygen (O_2), concentrations of nutrients and major ions, and the level of mineralization – were determined in hydroanalytical laboratory of the Research and Production Center for Fisheries LLP. The classification of river waters was carried out according to the scheme proposed by O.A. Alekin (1990).

The survey map of the small rivers on the southern slopes of the Shu-Ile Mountains was visualized using the free cross-platform software QGIS 3.34 (2025). The Shu River basin boundary and the vectorized river network were obtained from open digital layers of the HydroSHEDS database (2024).

Results

Hydrochemical analysis of the small rivers on the southern slopes of the Shu-Ile Mountains showed that pH values in all surveyed rivers ranged from 8.29 to 8.91, indicating a slightly alkaline environment. Dissolved oxygen concentrations varied from 8.12 to 10.76 mg/dm³, reflecting a good oxygen regime. The total water mineralization ranged from 282.2 to 592.2 mg/dm³, which, according to Alekin's classification, classifies the studied waters as freshwater. The highest mineralization levels were recorded in the Shygys Zhinishke (592.2 mg/dm³), Kalguta (564.1 mg/dm³), and Shatyrkol (524.4 mg/dm³) rivers.

Ammonium (NH_4^+) concentrations in most watercourses did not exceed regulatory limits; however, elevated levels were observed in the Terekti (0.6 mg/dm³) and Ungirli (0.3 mg/dm³) rivers, which may indicate localized agricultural impact. Nitrite, nitrate, and phosphate concentrations did not exceed permissible limits. Major ions in the studied rivers showed moderate variation among the watercourses, remaining within established maximum allowable concentrations (MAC).

The hydrochemical parameters of the studied rivers (Table 2) comply with ecological standards and fall within a range favorable for the survival and normal functioning of aquatic organisms.

A total of 23 rivers were surveyed, three of which were dry (Sarybulak, Karashyghaly, and Tarlygan rivers), and no fish were found in four rivers (Oriktisay, Zapadnaya Zhinishke, Kishi Kemin, and Shaladyr rivers). In the remaining 16 rivers, fish

species richness ranged from 1 to 6 species. The total number of recorded taxa was 16, belonging to 15 genera, 9 families, and 4 orders: Cypriniformes, Gobiiformes, Beloniformes, and Scorpaeniformes.

Table 2. Hydrochemical parameters of selected small rivers on the southern slopes of the Shu-Ile Mountains, 2024

River name	pH	Biogenic compounds, mg/ dm^3					Major ions, mg/dm^3					Mineralization, mg/dm^3
		O_2, mg/ dm^3	NH_4	NO_2	NO_3	PO_4^{3-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	$Na^+ + K^+$	
Kalguty	8.76	8.79	0.05	0.004	0.7	0.18	372.1	19.9	35.0	22.4	74.75	564.1
Karakonyz	8.44	9.94	0.02	0.008	0.7	0.2	225.7	5.0	7.5	28.1	33.8	314.9
Kerbulak	8.65	10.01	0.01	0.007	0.7	0.18	207.4	5.7	11.2	36.1	40.8	305.5
Kulakshynsay	8.31	9.65	0.08	0.008	0.4	0.1	280.6	14.2	26.1	36.9	61.5	434.4
Kyzylsai	8.29	8.71	0.05	0.004	1.3	0.21	305.0	9.2	17.4	37.7	62.5	446.9
Shatyrkol	8.79	8.14	0.02	0.019	2.4	0.2	366.0	6.4	12.1	13.6	109.8	524.4
Shokpar	8.61	9.16	0.11	0.004	0.8	0.23	201.3	11.3	20.2	31.3	38.0	313.8
Shygys Zhinishke	8.45	10.04	0.01	0.009	1.3	0.19	414.8	7.1	13.0	13.6	123.8	592.2
Terekti	8.91	10.76	0.6	0.011	1.7	0.21	311.1	6.4	11.6	17.6	78.0	443.2
Turan	8.34	8.12	0.02	0.005	0.6	0.2	189.1	6.4	10.8	28.9	42.8	282.2
Ungirli	8.37	8.96	0.3	0.010	2.1	0.19	414.8	3.6	6.4	12.0	121.8	577.5
Ushkyzyl	8.64	9.14	0.02	0.005	1.1	0.21	317.2	7.1	13.0	13.3	63.8	451.2
Quality standards *	6.0-9.0	≥4	≤1.0	≤3.30	≤45.0	≤0.70	-	-	-	-	-	≤1300

In terms of the number of taxa, Cypriniformes were dominant, represented by 12 species, accounting for 75% of the total species diversity. The remaining orders were represented by one or two species each (Table 3).

Of the 16 recorded fish species (Table 4), half are non-native to this basin (bitterling, goby, Prussian carp, common carp, stone moroko, Chinese false gudgeon, Japanese rice fish, and Chinese sleeper). Their presence is likely associated with previously conducted acclimatization efforts.

Among the rivers analyzed, the highest species diversity was recorded in the Karakonyz, Karasu, and Turan rivers, each supporting six fish species. The ichthyofauna of the Karakonyz river consisted entirely of native species. In the Karasu river, two non-native species – goby and bitterling – were recorded, while the remaining species were native. In contrast, the Turan river was dominated by non-native species: of the six species recorded, two were native and the remaining four were introduced. Notably, Southern ninespine, Chinese sleeper, and Japanese rice fish were not observed in any of the other surveyed rivers.

Table 3. List of fish species occurring in the small rivers of the Shu-Ile mountains, with their taxonomic classification

Order	Family	Latin name	English name
Cypriniformes	Acheilognathidae	*Rhodeus sericeus* (Pallas, 1776)	Bitterling
	Cyprinidae	*Carassius gibelio* (Bloch 1782)	Prussian carp
		Cyprinus carpio (Linnaeus, 1758)	Common carp
		Schizothorax argentatus Kessler, 1874	Balkhash marinka
		Gymnodiptychus dybowskii (Kessler, 1874)	Naked osman
	Gobionidae	*Gobio lepidolaemus* Kessler 1872	Turkestan Gudgeon
		Pseudorasbora parva (Temminck & Schlegel, 1846)	Stone moroko
		Abbottina rivularis (Basilewsky 1855)	Chinese false gudgeon
	Leuciscidae	*Rutilus lacustris* (Pallas, 1814)	Siberian roach
		Leuciscus baicalensis (Dybowski 1874)	Siberian dace
	NemacheIledae	*Triplophysa strauchi* (Kessler, 1874)	Spotted thicklip loach
		Triplophysa stoliczkai (Steindachner, 1866)	Tibetan stone loach
Gobiiformes	Gobiidae	*Rhinogobius* sp.	Goby
	Gobiidae	*Micropercops cinctus* (Dabry de Thiersant, 1872)	Chinese sleeper
Beloniformes	Adrianichthyidae	*Oryzias latipes* (Temminck et Schlegel, 1846)	Japanese rice fish
Scorpaeniformes	Gasterosteidae	*Pungitius platygaster* (Kessler, 1859)	Southern ninespine stickleback

The Terekti river ranked second in species diversity, with five fish species recorded, the spotted thicklip loach being the dominant species. The Ungirli and Ushkyzyl rivers illustrate the influence of local factors, such as the availability of food resources and interspecific competition, and are characterized by moderate species richness (four species each). Among native species, both rivers share Siberian roach and Turkestan gudgeon, while the Amur goby represents the shared non-native species.

Table 4. The diversity of the ichthyofauna of small rivers on the southern slopes Shu-Ile Mountains, 2024

Species	Rivers																
	Kalguty	Maibulak	Kyzylsai	Shygys Zhinishke	Karakonyz	Karasu	Ungirli	Shatyrkol	Bayguta	Turan	Terekti	Shokpar	Kerbulak	Kulakshynsay	Ushkyzyl	Yrgaity	Species abundance, n
Rhodeus sericeus	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Carassius gibelio	-	-	-	-	-	-	-	-	-	-	-	7	6	-	3	-	3
Cyprinus carpio	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
**Schizothorax argentatus*	11	-	-	-	15	2	-	-	-	-	-	-	-	-	-	-	3
**Gymnodiptychus dybowskii*	-	-	7	7	33	-	-	-	-	-	-	-	-	-	-	-	3
**Gobio lepidolaemus*	21	-	-	-	3	-	6	18	10	-	26	59	19	1	2	-	10
Pseudorasbora parva	-	-	-	-	-	-	6	-	-	41	25	-	-	-	1	3	5
Abbottina rivularis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
**Rutilus lacustris*	-	-	-	-	32	7	23	-	34	72	12	-	-	-	17	-	7
**Leuciscus baicalensis*	-	-	-	-	-	-	-	9	-	-	-	20	-	-	-	11	3
**Triplophysa strauchi*	-	39	-	-	24	18	7	-	-	-	66	-	-	-	-	-	5
**Triplophysa stoliczkai*	-	-	-	-	7	1	-	-	-	-	-	-	-	-	-	-	2
Rhinogobius sp.	-	-	-	-	-	2	-	-	-	-	7	-	-	-	-	-	2
Micropercops cinctus	-	-	-	-	-	-	-	-	-	171	-	-	-	-	-	-	1
Oryzias latipes	-	-	-	-	-	-	-	-	-	9	-	-	-	-	-	-	1
**Pungitius platygaster*	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	1
Number of fish caught, pcs.	32	39	7	7	114	31	42	27	44	301	136	86	25	1	23	16	931
Number of taxa in rivers	2	1	1	1	6	6	4	2	2	6	5	3	2	1	4	3	16

Note: * – native species.

Diversity of low fish species was observed in the Shokpar and Yrgaity rivers (three species in each river), and in the Kalguty, Shatyrkol, Bayguta, and Kerbulak rivers (two species in each river). In four rivers – Maibulak (Spotted thicklip loach), Kyzylsay, Shygys Zhinishke (naked osman), and Kulakshynsay (Turkestan gudgeon) - the ichthyofauna was represented by a single species. The ichthyofauna of these rivers, except for the Yrgaity river, consisted exclusively of native species.

Analysis of the obtained data indicates that certain species exhibit high ecological plasticity. Among the rivers studied, some native species were recorded most frequently, including the Turkestan gudgeon (found in 10 rivers), Siberian roach (in 7 rivers), and spotted thicklip loach (in 5 rivers), reflecting their adaptive capacity to a range of environmental conditions.

The Stone moroko was recorded in five rivers. In the Terekti (18.4%) and Turan (13.6%) rivers, it was the dominant species, whereas its abundance in the Ungirli, Yrgaity, and Ushkyzyl rivers was low. At the same time, species such as the naked osman, Balkhash marinka, Prussian carp, Siberian dace, Tibetan stone loach, goby, Bitterling, common carp, Chinese false gudgeon, Chinese sleeper, Japanese rice fish, and Southern ninespine exhibited a restricted distribution, which may indicate their dependence on specific ecological factors.

The spatial distribution of key fish species in the small rivers of the Shu-Ile Mountains was as follows:

The Turkestan gudgeon *Gobio lepidolaemus* was represented by 165 individuals and emerged as the most widely distributed species, occurring in 10 of the surveyed rivers. In several systems, the species attained a pronounced superdominant status, accounting for the entirety of the ichthyofaunal assemblage in the Kulakshynsai river (100%) and constituting a substantial proportion of total abundance in the Kerbulak (76%), Shokpar (69%), Shatyrkol (67%), and Kalguty (66%) rivers.

The Siberian roach *Rutilus lacustris* total 197 specimens, representing 21% of the overall catch, and was recorded in seven rivers. Its highest abundances were observed in the Bayguta (77.3%), Ushkyzyl (73.9%), and Ungirli (54.8%) rivers, where it functioned as a superdominant species. In the Karakonyz and Karasu rivers, Siberian roach was a dominant species, comprising 28.1–22.6% of the total catch, whereas in the Terekti River it was classified as an abundant species (8.8%).

The Spotted thicklip loach *Triplophysa strauchi* was represented by 154 specimens, comprising 16.5% of the total catch, and was recorded in five of the surveyed rivers. The species was superdominant in the Maibulak River (39 specimens, 100%) and the Karasu River (18 specimens, 58.1%). In the Terekti (48.5%), Karakonyz (21.1%), and Ungirli (16.7%) rivers, it functioned as a dominant component of the fish assemblage.

Chinese sleeper *Micropercops cinctus* was represented by 171 specimens and was recorded exclusively in the Turan River, where it functioned as a superdominant, comprising 56.8% of the total fish abundance in the river.

According to the calculations, species diversity was low in the Maibulak, Kyzylsai, Shygys Zhinishke, and Kulakshynsai rivers, where only a single taxon was re-

corded, with abundances ranging from 39 to 1 specimen, respectively. In these water bodies, complete dominance by a single species was observed, as reflected by zero values of the Simpson and Shannon indices. This indicates extreme environmental instability associated with pollution or high levels of anthropogenic impact.

In the group of rivers characterized by high species richness (six taxa) – Karakonyz, Karasu, and Turan – the lowest values of the dominance index (D = 0.222–0.398) were recorded, indicating a more even distribution of abundance among taxa and the absence of a clearly pronounced dominant species. At the same time, the highest values of the Simpson diversity index (1–D) and the Shannon index (H) were observed in the Karakonyz, Terekti, and Karasu rivers, reflecting high community stability and considerable structural complexity. Evenness indices based on Simpson and Shannon (E and J) in most rivers ranged from 0.60 to 0.93, suggesting a relatively uniform distribution of abundance among taxa.

Table 5 presents the values of species diversity indices and community evenness metrics of the ichthyofauna calculated for 16 rivers of the Shu-Ile Mountains.

Table 5. Main structural characteristics of fish communities in the rivers of the Shu-Ile Mountains

Rivers	Taxa	Quantity	D	1-D	H'	E	J
Kalguty	2	32	0.534	0.466	0.659	0.967	0.928
Maibulak	1	39	1	0	0	1	-
Kyzylsai	1	7	1	0	0	1	-
Shygys Zhinishke	1	7	1	0	0	1	-
Karakonyz	6	114	0.222	0.778	1.599	0.825	0.880
Karasu	6	31	0.379	0.622	1.308	0.616	0.685
Ungirli	4	42	0.353	0.647	1.220	0.847	0.584
Shatyrkol	2	27	0.539	0.462	0.655	0.963	0.918
Bayguta	2	44	0.641	0.359	0.547	0.864	0.773
Turan	6	301	0.398	0.602	1.155	0.529	0.640
Terekti	5	136	0.311	0.689	1.360	0.779	0.836
Shokpar	3	86	0.526	0.474	0.814	0.752	0.730
Kerbulak	2	25	0.620	0.380	0.571	0.885	0.795
Kulakshynsai	1	1	-	-	-	1	-
Ushkyzyl	4	23	0.553	0.447	0.903	0.617	0.604
Yrgaity	3	16	0.492	0.508	0.894	0.815	0.757

Notes: D – Simpson's dominance index; 1-D – Simpson's diversity index; H' – Shannon diversity index; E – Simpson's evenness index; J – Shannon's evenness index.

To identify groups of rivers with similar fish species diversity, the Sorensen similarity coefficient, based solely on the presence - absence of taxa, was applied. The coefficient values were calculated for each of the 120 pairwise combinations of rivers (Table 6).

The similarity of ichthyofaunal composition among the studied rivers, according to the Sorensen index, ranged from 0 to 1, with a mean value of 0.265. Zero values of the coefficient were predominantly observed in comparisons involving the taxonomic lists of the Kyzylsai, Shygys Zhinishke, and Maibulak rivers, as well as, to a lesser extent, the Kalguty, Karasu, and Turan rivers, indicating the absence of shared species between the respective watercourses.

Overall, the values of the Sorensen similarity coefficient indicate a low degree of similarity in both the taxonomic composition and the structure of relative abundance of ichthyofauna among the studied rivers. Within the analyzed dataset, a pronounced spatial heterogeneity of ichthyofauna is evident, reflecting substantial differences in species composition and occurrence among rivers. Cluster analysis, performed at a Sorensen similarity threshold of approximately 0.10, allowed the identification of seven distinct clusters, each comprising between one and four rivers (Fig. 2).

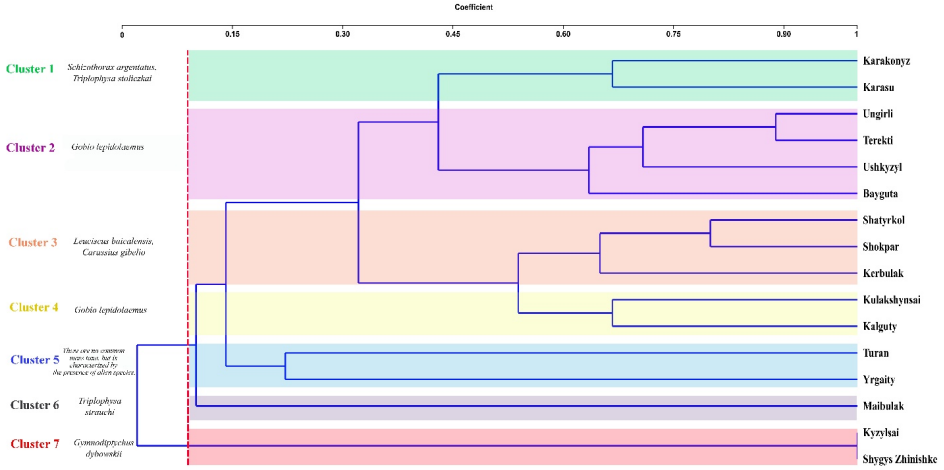


Figure 2. Cluster analysis of ichthyofaunal composition similarity (based on the Sorensen index) in small rivers of the Shu-Ile Mountains (with indication of dominant taxa).

Cluster 1 comprised two rivers (Karakonyz and Karasu). In both rivers, the species composition included six fish species, four of which were shared. The ichthyofaunal composition similarity was 0.667. In these two rivers, the dominant and subdominant species were the Balkhash marinka (*Schizothorax argentatus*) and the spotted thicklip loach *Triplophysa strauchi*.

Table 6. Similarity of ichthyofaunal composition in small rivers of the southern slope of the Shu-Ile Mountains (based on the Sorensen index)

River	Kalguty	Maibulak	Kyzylsai	Shygys Zhinishke	Karakonyz	Karasu	Ungirli	Shatyrkol	Bayguta	Turan	Terekti	Shokpar	Kerbulak	Kulakshynsai	Ushkyzyl	Yrgaity
Kalguty	1															
Maibulak	0	1														
Kyzylsai	0	0	1													
Shygys Zhinishke	0	0	1	1												
Karakonyz	0.500	0.286	0.286	0.286	1											
Karasu	0.250	0.286	0	0	0.667	1										
Ungirli	0.333	0.400	0	0	0.600	0.400	1									
Shatyrkol	0.500	0	0	0	0.250	0	0.222	1								
Bayguta	0.500	0	0	0	0.500	0.250	0.667	0.500	1							
Turan	0	0	0	0	0.167	0.167	0.400	0	0.250	1						
Terekti	0.286	0.333	0	0	0.545	0.545	0.889	0.286	0.571	0.364	1					
Shokpar	0.400	0	0	0	0.222	0	0.286	0.800	0.400	0	0.250	1				
Kerbulak	0.500	0	0	0	0.250	0	0.333	0.500	0.500	0	0.286	0.800	1			
Kulakshynsai	0.667	0	0	0	0.286	0	0.400	0.667	0.667	0	0.333	0.500	0.667	1		
Ushkyzyl	0.333	0	0	0	0.400	0.200	0.750	0.333	0.667	0.200	0.667	0.571	0.667	0.400	1	
Yrgaity	0	0	0	0	0	0	0.286	0.400	0	0.222	0.250	0.333	0	0	0.286	1

Cluster 2 was formed by four rivers – Ungirli, Terekti, Ushkyzyl, and Bayguta – with Sorensen similarity coefficients among these rivers ranging from 0.571 (Bayguta and Terekti) to 0.889 (Ungirli and Terekti). The number of species and forms recorded in these rivers was two and five, respectively. The Turkestan gudgeon *Gobio lepidolaemus* and Siberian roach *Rutilus lacustris* were present in all these rivers and were also the numerically dominant species.

Cluster 3 includes three rivers: Shatyrkol, Shokpar, and Kerbulak. The number of species and intraspecific taxa in these rivers is low, ranging from 2 to 3 taxa. The Turkestan gudgeon *Gobio lepidolaemus* and the Siberian dace *Leuciscus baicalensis* were present in almost all rivers, with the latter occupying a subdominant position in all except the Ushkyzyl river.

Cluster 4 was formed by two rivers – Kulakshynsai (1 species) and Kalguty (2 species). The Sorensen similarity coefficient between their taxonomic compositions was 0.667. In both rivers, the Turkestan gudgeon *Gobio lepidolaemus* was a shared and dominant species.

Cluster 5 comprises the Turan (6 species) and Yrgaity (3 species) rivers. The ichthyofauna of these watercourses is characterized by a high proportion of non-native taxa (five species), among which Chinese false gudgeon, Chinese sleeper, and Japanese rice fish occur exclusively within this cluster. The similarity of species composition between these rivers is extremely low (0.222), as the only shared species is the stone moroko *Pseudorasbora parva*.

Cluster 6 is represented solely by the Maibulak river, due to the extremely low species diversity of its ichthyofauna. Only a single species – the spotted thicklip loach *Triplophysa strauchi* – was recorded in this watercourse, entirely determining the community structure. The absence of other taxa resulted in the isolated position of the Maibulak river in the cluster analysis.

Cluster 7 unites two rivers – Kyzylsai and Shygys Zhinishke – where ichthyofauna exhibit a highly simplified structure. Only one fish species – the naked osman *Gymnodiptychus dybowskii* – was recorded in both rivers. The complete identity of their taxonomic composition led to the maximum value of the Sorensen similarity coefficient.

The cluster analysis of ichthyofauna in the studied rivers revealed pronounced spatial differentiation of fish communities, driven both by species diversity and the degree of similarity in taxonomic composition. The identified clusters reflect differences in community structure, ranging from relatively rich and numerically balanced assemblages to highly simplified communities dominated by a single species.

The distribution of samples from the different rivers in the principal component space is presented in Figure 3.

Along the first principal component (PC1), the highest positive factor loadings were observed for the Turan and Shokpar rivers, indicating relatively high species diversity of ichthyofauna and a more even distribution of abundance among taxa. In contrast, the Ushkyzyl, Ungirli, and Karasu rivers exhibited the largest negative loadings, reflecting a combination of a comparatively high number of taxa with

reduced overall fish abundance and pronounced dominance of certain species. It should also be noted that these watercourses contained non-native fish species not recorded in the other studied rivers.

Along with the second principal component (PC2), the highest positive factor loading was recorded for the Terekti River. The ichthyofauna of this river was characterized by the presence of its own dominant species, notably the spotted thicklip loach *Triplophysa strauchi* and goby *Rhinogobius* sp., its abundances strongly predominated in the community structure. Negative loadings were observed for the Turan and Karakonyz rivers. These watercourses were distinguished by higher species richness and overall fish abundance, with the Karakonyz river featuring an exclusively native ichthyofaunal composition.

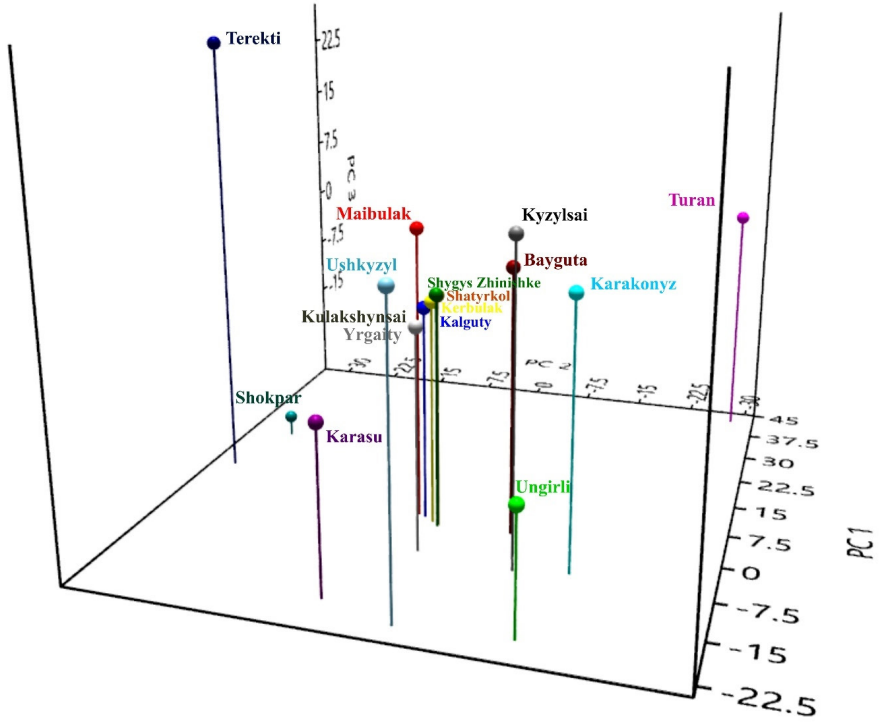


Figure 3. Distribution of samples from various small rivers on the southern slope of the Shu-Ile Mountains.

Along the third principal component (PC3), the highest positive factor loadings were observed for the Turan and Kulakshynsai rivers. The Turan river, as noted earlier, is characterized by high species diversity and substantial fish community abundance, whereas only a single species – the Turkestan gudgeon *Gobio lepidolaemus*, represented by a single individual – was recorded in the Kulakshynsai river. Negative factor loadings for this component were identified in the Shokpar and Ungirli

rivers, indicating structural characteristics of their ichthyofauna that are opposite to those of the watercourses forming the positive pole of the component. The principal component loadings for the rivers are presented in Table 7.

Table 7. Principal component loadings characterizing the structure of fish communities in small rivers of the Shu-Ile Mountain region. (The largest loads are indicated in bold)

Name of Rivers	Principal Components		
	PC 1	PC 2	PC 3
Kalguty	2.1255	2.8468	-2.5418
Maibulak	2.5129	3.7257	6.3689
Kyzylsai	0.26534	0.78287	-0.29527
Shygys Zhinishke	0.26534	0.78287	-0.29527
Karakonyz	-6.0488	**-16**	3.1302
Karasu	**-18.462**	7.0368	-8.6143
Ungirli	**-20.061**	-13.745	**-13.679**
Shatyrkol	0.51698	0.72914	-0.46826
Bayguta	0.94658	-7.6836	3.2699
Turan	**42.048**	**-28.304**	1.0848
Terekti	9.0907	**30.875**	**25.194**
Shokpar	**19.922**	**27.96**	**-25.376**
Kerbulak	1.1693	1.6317	-1.4755
Kulakshynsai	-7.1532	-10.051	**9.0077**
Ushkyzyl	**-21.133**	-1.5576	6.7827
Yrgaity	-6.0048	0.97107	-2.0925

The principal component analysis revealed pronounced heterogeneity in the structure of ichthyofauna across the studied rivers. Overall, the PCA results underscore the key role of species diversity, dominance structure, and species origin in shaping the differences among fish communities in the region.

Discussion

The water flow of small rivers on the southern slope of the Shu-Ile Mountains within the Shu River basin is limited and largely dependent on local and climatic conditions. The regional climate is characterized by low moisture availability, while the feeding of these small rivers is of a mixed nature, including snowmelt, rainfall, and groundwater sources. During our study, three rivers were completely dry. Several other rivers were in a stage of seasonal drying: their flow weakened to the level of a stream and was locally interrupted, resuming only through groundwater input. The

physical basis of the drying process in small rivers lies in the cessation of surface flow due to the depletion of groundwater that sustains the watercourses during low-flow periods (Pearce 2018; Chakraborty 2021).

The seasonal drying of small rivers in Kazakhstan is driven by the interaction of climatic and anthropogenic factors, which reduce runoff, alter seasonal flow patterns, and increase water losses (Akiyanova et al. 2019). The expansion of irrigation and outdated water-use practices (extensive water exploitation) in southern Kazakhstan led to localized desertification, decreased soil and pasture productivity, and a reduction in base flow in downstream rivers. According to projected climate scenarios, by 2050, the mean annual runoff in the Shu River basin (Northern Tien Shan) is expected to decrease by 25–30% (Kaliyeva et al. 2021).

Although the hydrochemical parameters of the studied rivers generally fell within ranges favorable for the survival and normal functioning of aquatic organisms, data from Tazhiyev et al. (2025) indicate that maximum allowable concentrations were exceeded for several indicators in groundwater at certain water intakes within the Shu river basin, particularly in areas experiencing significant anthropogenic pressure. Small rivers are typically located away from major sources of surface-water pollution, which allows them to be considered natural refuges for ichthyofauna, including native species.

The study revealed pronounced spatial heterogeneity in the ichthyofauna of small rivers on the southern slope of the Shu-Ile Mountains. Despite a total of 16 recorded species, fish communities in individual watercourses differed markedly in structure, ranging from monotypic assemblages to relatively species-rich complexes comprising six taxa. Such heterogeneity is typical of small mountainous rivers in arid regions and is driven by a combination of hydrological instability, channel isolation, and local ecological conditions (Linnik et al. 2002; Mamilov et al. 2021; Sharakhmetov 2022; Kegenova 2023; Sapargaliyeva et al. 2024; Mamilov et al. 2025).

The dominance of cyprinids is consistent with general patterns in the formation of ichthyofauna in continental water bodies of Central Asia, where species of this group exhibit high ecological plasticity and the ability to inhabit a wide range of biotopes (Mitrofanov et al. 1987; Abell et al. 2008). Based on the ecological and geographical characteristics of the river system, Kaynaeva and Shabdanova (2020) identify three potential fish habitats within the Shu River: the foothill, steppe, and lower zones. The ichthyofauna of these sections is represented, respectively, by the Highland Asian, Turkestan, and Aral faunal complexes, with a predominance of species from the family Cyprinidae. However, the proposed zonation applies exclusively to the Shu River channel and does not encompass other watercourses within the basin. In the present study, the widespread occurrence of the Turkestan gudgeon *Gobio lepidolaemus* and Siberian roach *Rutilus lacustris* indicates their high ecological plasticity and resilience to fluctuations in hydrological regime, temperature contrasts, and limited food resources. The widespread presence of non-native species in small rivers has led to the disappearance of local species and a significant restructuring of biodiversity patterns across different regions (Cavalcante et al. 2025; Danet

et al. 2024). In half of the rivers we studied, the ichthyofauna consisted exclusively of native species, whereas in the other half, non-native species were recorded, their abundance and occurrence did not exceed the total abundance of native fishes in individual rivers, with the exception of the Turan river. However, according to previous studies (Mamilov 2011; Bekkozhaeva, Mamilov 2014), some non-native fish species have become widely established, and in certain sections of the Shu River basin, they have emerged as dominant components of the ichthyofauna (Sansyzbayev et al. 2024).

Numerous empirical studies (Casatti et al. 2009; Franssen et al. 2011; Erős et al. 2020) indicate that low species diversity and complete dominance of a single species in certain rivers reflect environmental instability. Rivers with higher species richness and more abundance distribution (Karakonys, Karasu, Terekti) exhibited elevated diversity index values, suggesting greater stabIlety of their ichthyocenoses. At the same time, low Sorensen similarity coefficients and the results of cluster analysis reflect weak connectivity among fish communities and a high degree of isolation, which is typical of small mountainous rivers (Rosenfield 2002; Sheldon et al. 2010). The results of the principal component analysis confirmed the key role of species richness, dominance structure, and the proportion of non-native species in shaping differences among ichthyocenoses.

Overall, the ichthyofauna of small rivers in the Shu-Ile Mountains is shaped by a combination of natural and anthropogenic factors, among which hydrological instability, orographic isolation, and introduction processes play a determining role.

Conclusion

The hydrochemical parameters of small rivers on the southern slope of the Shu-Ile Mountains generally fell within ranges favorable for the survival and normal functioning of aquatic organisms.

The study demonstrated that the ichthyofauna of these rivers is characterized by low species richness (1–6 species) and pronounced spatial heterogeneity of communities. Among the 23 surveyed watercourses, fish were recorded in 16 rivers, with a total of 16 species belonging to four orders, dominated by cyprinids. Despite the presence of non-native species, the numerical proportion of native fishes exceeded that of the introduced taxa. Low species diversity and the dominance of a single species in several rivers (Maibulak, Kyzylsai, and Shygys Zhinishke) indicate environmental instability, driven by seasonal drying, habitat fragmentation, and hydrological fluctuations. In contrast, rivers such as Karakonys, Terekti, and Karasu, which exhibit higher species richness (5–6 species) and more evenly structured communities, demonstrate greater ecological stability. The most widespread native species – the Turkestan gudgeon *Gobio lepidolaemus* and Siberian roach *Rutilus lacustris* – exhibited high ecological plasticity and play a key role in structuring ichthyocenoses. The results of cluster analysis and principal component analysis

confirm the pronounced heterogeneity of ichthyofauna in the studied region and highlight the important roles of species diversity, dominance structure, and species origin in shaping differences among the region's fish communities.

Overall, the observed differentiation in ichthyofauna reflects the isolation of watercourses, the orographic characteristics of the region, and variations in hydrological regimes. Since the study was conducted during the summer period, it provides a limited assessment of the seasonal and interannual dynamics of ichthyofauna. Therefore, long-term monitoring of fish communities in the region is necessary to evaluate the resilience of native species and to conserve the biodiversity of small rivers.

Institutional Review Board Statement

Ethical review and approval were waived for this study, as all fish collection and research were conducted in accordance with the laws of the Republic of Kazakhstan, including the Law "On the protection, reproduction, and use of fauna" (9 July 2004 No. 593-II, with subsequent amendments: 3 July 2013 No. 124-V; 16 May 2014 No. 203-V; 29 September 2014 No. 239-V; 29 December 2014 No. 269-V ZRK; 29 October 2015 No. 376-V ZRK; 29 March 2016 No. 479-V; 15 June 2017 No. 73; 2 April 2019 No. 241; 28 October 2019 No. 268; 23 February 2021 No. 11; 30 April 2021 No. 34; 24 November 2021 No. 75; 14 July 2022 No. 141), the Law "On the responsible treatment of animals" (30 December 2021 No. 97-VII ZRK), and the Order of the Minister of Agriculture of the Republic of Kazakhstan "On approval of the Rules for the use of animals, except rare and endangered species, for scientific, cultural, educational, and aesthetic purposes, including the creation of zoological collections" (10 November 2004 No. 652).

Acknowledgements

The authors express their sincere gratitude to S. Karlybay and Zh.M. Bakkhozha, staff members of the Laboratory of Ichthyology of LLP "Fisheries Research and Production Center" (Almaty, Kazakhstan), for their assistance in the collection of field materials.

This study was funded by the Scientific Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the program (Grant No. AP26100721, "Investigation of the taxonomic and functional diversity of the ichthyofauna of Alatau").

References

A trip to the Chu-Ili Mountains. Available from: https://silkadv.com/en/content/chu-iliyskie-gory (Accessed 12.07.2026).

Abell R, Thieme ML, Revenga C, Bryer M, Kottelat M, Bogutskaya N, Coad B, Mandrak N, Contreras Balderas S, Bussing W, Stiassny MLJ, Skelton P, Allen GR, Unmack P, Naseka A, Ng R, Sindorf N, Robertson J, Armijo E, Higgins JV, Heibel TJ, Wikramanayake E, Olson D, López HL, Reis RE, Lundberg JG, Sabaj Pérez MH, Petry P (2008) Freshwater ecoregions of the world: A new map of biogeographic units for freshwater biodiversity conservation. BioScience 58(5): 403–414. https://doi.org/10.1641/B580507

Akiyanova FZ, Frolova NL, Avezova AA, Shaimerdenova AM, Oleshko AB (2019) Water resources and system of the River Yesil (ISHIM) under conditions of active anthropogenous transformation and climate change. EurAsian Journal of BioSciences 13(2): 1275–1289.

Alekhin OA (1970) Fundamentals of Hydrochemistry. Gidrometeoizdat, Leningrad, 443 pp. [In Russian]

Baimbetov AA, Timirkhanov SR (1999) Kazakh-Russian Guide to the Simple fish and Fish of Kazakhstan. Kazakh University, Almaty, 347 pp. [In Kazakh and Russian]

Bekkozhayeva DK, Mamilov NSh (2014) Current diversity of the fish fauna of the middle reaches of the Shu River. Bulletin of KazNU, Ecology Series 1(40): 195–200. [In Russian]

Biggs J, Von Fumetti S, Kelly-Quinn M (2017) The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. Hydrobiologia 793(1): 3–39. https://doi.org/10.1007/s10750-016-3007-0

Casatti L, de Paula Ferreira C, Carvalho FR (2009) Grass-dominated stream sites exhibit low fish species diversity and dominance by guppies: an assessment of two tropical pasture river basins. Hydrobiologia 632(1): 273–283. https://doi.org/10.1007/s10750-009-9849-y

Cavalcante LL, Occhi TV, Olden JD, Padial AA (2025) Non-native species drive the global loss of freshwater fish beta-diversity. NeoBiota 97: 257–277. https://doi.org/10.3897/neobiota.97.126607

Chakraborty SK (2021) Geo-hydrological perspectives of riverine flows. In: Riverine Ecology 1: Eco-functionality of the Physical Environment of Rivers Cham. Springer International Publishing, Cham, 375–476. https://doi.org/10.1007/978-3-030-53897-2_6

Chu-Ili Mountains. Available from: https://adrenalinicsilence.kz/avtoputeshestviya/chu-ilijskie-gory/ (Accessed 11.07.2026)

Clottes J (Ed.) (2011) Rock art in Central Asia: A thematic study. ICOMOS, Paris 381 pp.

Danet A, Giam X, Olden JD, Comte L (2024) Past and recent anthropogenic pressures drive rapid changes in riverine fish communities. Nature Ecology & Evolution 8(3): 442–453. https://doi.org/10.1038/s41559-023-02271-x

Dryagin PA (1936) Fishes of the Chu River and the use of this river for fishery purposes. Fisheries of the Kyrgyz SSR. Proceedings of the Kyrgyz Complex Expedition 1932–1933 3(1): 49–87. [In Russian]

Dujsebayeva TN (2020) Short description of nature conditions of Shu-Ile Mountains. Khantau Transit Corridor in the Paleometal Era. Series "History and Archaeology of Semirechye" 7: 7–20. [In Russian]

Dukravets GN, Mamilov NSh (1994) The status of populations of rare and endangered fish species in the Ili and Chu river basin]. Kazakh State University, Almaty, 25 pp. [In Russian]

Dukravets GM, Karpov VE, Mamilov NSh, Merkulov EA, Mitrofanov IV (2001) On the composition and distribution of the ichthyofauna in the Kazakhstani part of the Chu River basin. Bulletin of Kazakh State University, Biological Series 2(14): 94–104. [In Russian]

Erős T, Comte L, Filipe AF, Ruhi A, Tedesco PA, Brose U, Fortin M-J, Giam X, Irying K, Jacquet C, Larsen S, Sharma S, Olden JD (2020) Effects of nonnative species on the stability of riverine fish communities. Ecography 43(8): 1156–1166. https://doi.org/10.1111/ecog.04985

Ferreira V, Albariño R, Larrañaga A, LeRoy CJ, Masese FO, Moretti MS (2023) Ecosystem services provided by small streams: an overview. Hydrobiologia 850(12): 2501–2535. https://doi.org/10.1007/s10750-022-05095-1

Franssen NR, Tobler M, Gido KB (2011) Annual variation of community biomass is lower in more diverse stream fish communities. Oikos 120(4): 582–590. https://doi.org/10.1111/j.1600-0706.2010.18810.x

Fricke R, Eschmeyer WN, Van der Laan R (Eds) Eschmeyer's catalog of fishes. California Academy of Sciences. https://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp [Accessed: 27.02.2025].

Hammer Ø, Harper DAT, Ryan PD (2001) PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4(1): 1–9.

Hill D, Fasham M, Tucker G, Shewry M, Shaw P (Eds) (2005) Handbook of biodiversity methods: Survey, evaluation and monitoring. Cambridge University Press, xii + 573 pp.

Kainaeva Zh, Shabdanoa N (2020) Fish of the Chu and Talas river basins. In: Tugolukov AV (Ed.) Innovative and Technological Development of Science and Education in the 21st Century: Proceedings of the International Scientific and Practical Conference (Moscow, July 31, 2020). Moscow, 220–224. [In Russian]

Kaliyeva K, Punys P, Zhaparkulova Y (2021) The impact of climate change on hydrological regime of the transboundary River Shu Basin (Kazakhstan–Kyrgyzstan): forecast for 2050. Water 13(20): 2800. https://doi.org/10.3390/w13202800

Kegenova GB (2023) Fish communities in small water bodies of the Ila River basin. Experimental Biology 94(1): 121–133. https://doi.org/10.26577/eb.2023.v94.i1.011

Klimov FV (2005) The state of the fish fauna of the Akzhaikyn lake system in the lower reaches of the Shu River. In: Fisheries Research in the Republic of Kazakhstan: History and Current Status. Bastau, Almaty, 186–193. [In Russian]

Koblitskaya AF (1981) A Guide to the Juveniles of Freshwater Fish. Light and Food Industry, Moscow, 208 pp. [In Russian]

Lakin GF (1990) Biometrics. Vysshaya Shkola, Moscow, 352 pp. [In Russian]

Lehner B, Grill G (Eds) HydroSHEDS database. Available from: https://www.hydrosheds.org/ (Accessed 27.06.2026).

Linnik AS, Gapparova DM, Kostyuk TP (2002) The status of the fish fauna of some small rivers in the Balkhash Basin. Tethys Aqua Zoological Research 1: 117–123. [In Russian]

Magurran E (1992) Ecological Diversity and Its Measurement. Mir, Moscow, 181 pp. [In Russian]

Mamilov NSh (2011) Modern diversity of alien fish species in the Chu and Talas River basins. Russian Journal of Biological Invasions 2(2–3): 112–119. https://doi.org/10.1134/S207511171102007X

Mamilov N, Sharakhmetov S, Amirbekova F, Bekkozhayeva D, Sapargaliyeva N, Kegenova G, Tanybayeva A, Abilkasimov K (2021) Past, current and future of fish diversity in the Alakol Lakes (Central Asia: Kazakhstan). Diversity 14(1): 11. https://doi.org/10.3390/d14010011

Mamilov NS, Ibrayeva GS, Amirbekova FT, Bartunek DK, Sapargaliyeva NS, Kozhabaeva EB, Bilyalova GZ, Ziyayeva GK, Levin BA (2025) Recent changes in fish diversity in the ancient oases of the Syr Darya River (Central Asia). Ecologica Montenegrina 86: 119–134. https://dx.doi.org/10.37828/em.2025.86.5

Mitrofanov VP, Dukravets GM, Sidorova AF, Soloninova LN, Bashunova NN (1987) Fishes of Kazakhstan. Vol. 2. Cyprinids. Nauka, Alma-Ata, 344 pp. [In Russian]

Nikolsky GV (1931) Fishes of the middle and lower reaches of the Chu River. Annual Report of the Zoological Museum of the USSR Academy of Sciences 32(2): 227–268. [In Russian]

Pearce F (2018) When the rivers run dry, fully revised and updated edition: water, the defining crisis of the twenty-first century. Beacon Press, Boston, 328 pp.

Pivnev IA (1985) Fish of the Talas and Chu River Basins. Ilim, Frunze, 188 pp. [In Russian]

Pravdin IF (1966) A Guide to the Study of Fish. Food Industry, Moscow, 376 pp. [In Russian]

QGIS Development Team (2025) QGIS (Version 3.34) [Geographic information system software]. Open Source Geospatial Foundation. Available from: http://qgis.osgeo.org (Accessed 10.10.2026).

Rosenfield JA (2002) Pattern and process in the geographical ranges of freshwater fishes. Global Ecology and Biogeography 11(4): 323–332. https://doi.org/10.1046/j.1466-822X.2002.00287.x

Sansyzbayev ET, Sharakhmetov SE, Amirbekova FT (2025) Current state of the ichthyofauna of the Kazakh part of the Aksu River (Shu River basin, Kazakhstan). Experimental Biology 102(1): 106–114. https://doi.org/10.26577/bb202510219 [In Kazakh]

Sapargaliyeva N, Sharakhmetov S, Kobegenova S, Kegenov E, Kozhabaeva E (2024) Diversity of the ichthyofauna in small rivers of the northern macro-slope of Saur-Tarbagatai (Central Asia). BIO Web of Conferences 100: 04036. https://doi.org/10.1051/bioconf/202410004036

Severtsov NA (1873) A journey through the Turkestan region and an exploration of the Tien Shan mountains. K.V. Trubnikov's Printing House, Saint Petersburg, 461 pp. [In Russian]

Sharakhmetov SE (2022) Diversity of the fish fauna of the rivers on the southern macro-slope of the Tarbagatai Range (Alakol Basin, Kazakhstan). Eurasian Journal of Ecology 70(1): 108–120. https://doi.org/10.26577/EJE.2022.v70.i1.10

Sheldon F, Bunn SE, Hughes JM, Arthington AH, Balcombe SR, Fellows CS (2010) Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes. Marine

and Freshwater Research 61(8): 885-895. https://doi.org/10.1071/MF09239

Tazhiyev S, Murtazin Y, Rakhimova V, Rakhmetov I, Adenova D, Koshpanova K, Sotnikov Y, Abdizhalel M, Akylbayeva A, Yerezhep D (2025) Applied hydrogeological assessment and GIS-based modeling of transboundary aquifers in the Shu River Basin. Water 17(16): 2476. https://doi.org/10.3390/w17162476

Tkachev BP, Bulatov VI (2002) Small rivers: current status and environmental issues (Series Ecology, Issue 64). SPSTL SB RAS, 114 pp. [In Russian]

Turdakov FA (1963) The Fishes of Kyrgyzstan. Publishing House of the Academy of Sciences of the Kyrgyz SSR, Frunze, 283 pp. [In Russian]

Veselov EA (1977) A Guide to the Freshwater Fish of the USSR. Prosveshchenie, Moscow, 238 pp. [In Russian]

Zhakyp BO (Ed.) (2011) Atameken: Geographical Encyclopedia. Kazakh Encyclopedia, Almaty, 648 pp. [In Kazakh]

Zyryanov VN (2015) Relevant water problems and the role of science in their solutions. Central Asian Journal of Water Research (CAJWR) 1: 93–97.