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

Acta Biologica Sibirica 12: 1711–1723 (2026)
doi: 10.5281/zenodo.24461465
http://journal.asu.ru

RESEARCH ARTICLE

Transformation of the ichthyofauna and redistribution of species in the upper and middle reaches of the Syr Darya River (Uzbekistan)

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Academic editor: R. Yakovlev | Received 14 September 2026 | Accepted 8 November 2026 | Published 25 November 2026

http://zoobank.org/9E0685FB-F198-4CF6-9BD4-CC8F2CD6CD65

Citation: Nazarov M, Mirzakhalilov M, Gayratova G, Mukimov M (2026) Transformation of the ichthyofauna and redistribution of species in the upper and middle reaches of the Syr Darya River (Uzbekistan). Acta Biologica Sibirica 12: 1711–1723. https://doi.org/10.5281/zenodo.24461465

Abstract

Data on the current state of the Syr Darya ichthyofauna are scarce because the last comprehensive faunistic survey of the basin was carried out in the 1990s. In this study, conducted in 2020–2026 at 21 stations in the main channel of the upper and middle reaches of Syr Darya, 30 species of fish were recorded in each reach and 32 species in total, of which 16 are introduced and 16 native. The results were compared with data from the 1990s (Salikhov 1990; Vundtsettel 1994). Nine species previously recorded in the upper reach and seven in the middle reach were not found, and four species were newly recorded in each reach. The share of introduced species increased from 40% to 50% in the upper reach and from 48% to 50% in the middle reach, mainly because the number of native species decreased (from 21 to 15 in the upper reach and from 17 to 15 in the middle reach). Most native species that were not found are mountain and piedmont species (*Diptychus sewerzowi*, *Glyptosternon oschanini*, *Triplophysa dorsalis* and *T. stoliczkai*). At the same time, *Alburnus chalcoides* was newly recorded in the upper and middle reaches, and *Alburnus taeniatus* and *Leuciscus squaliusculus* in the middle reaches. These results indicate a two-way redistribution of the species composition. Possible links between these changes, hydrotechnical construction, and biological invasions are discussed as hypotheses that should be tested with quantitative data.

Keywords

Freshwater fish, hydrotechnical structures, ichthyofauna, introduced species, species redistribution, Syr Darya

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Introduction

Freshwater ecosystems are among the biomes with the highest losses of biological diversity and the highest levels of anthropogenic pressure worldwide (Dudgeon et al. 2006). In particular, large river basins in arid and semi-arid regions are experiencing serious ecological crises as a result of intensive use of water resources, flow regulation by dams, and the spread of alien species into modified habitats (Xenopoulos et al. 2005; Grill et al. 2019). The Syr Darya River, one of the two large rivers that feed the Aral Sea and the longest river in Central Asia, is a striking example of these global and regional ecological transformations.

The total drainage area of the Syr Darya is approximately 462,000 km². The river is formed by the confluence of the Naryn and Kara Darya rivers and originates in the Central Tien Shan (Ilyin 1959). The tributaries that form the upper reach (the Naryn, Kara Darya, Isfayramsay, Sokh, and Shakhimardansay rivers) descend from the slopes of the Alai-Turkestan, Fergana, and Chatkal-Kurama ranges. The upper reach lies in the Fergana Valley and is separated from the middle reach by these mountains and their watersheds. The middle reach begins at the Bekabad dam and continues to the Chardara Reservoir. In the middle range, the Syr Darya receives mainly two tributaries: the Chirchik River, which descends from the western Tien Shan ranges, and the Ahangaran River, which descends from the slopes of the Chatkal-Kurama ranges.

Zoogeographically, the Syr Darya is distinguished by flowing through three provinces of the Palaearctic. The upper reach belongs to the Tarim province of the Mountain Asia subregion, which is characterized by a comparatively impoverished fauna, but a high degree of species endemism and generic distinctiveness. Representatives of the genera *Schizothorax* Heckel, 1838, *Triplophysa* Rendahl, 1933 and *Glyptosternon* McClelland, 1842 occur here (Berg 1962; Turdakov 1963). The middle and lower reaches of the basin lie in the Mediterranean subregion: the middle reach forms the Turkestan province, whereas the lower reach belongs to the Ponto-Caspian-Aral province (Berg 1962; Turdakov 1963).

In general, the anthropogenic factor plays an increasingly large role in the formation of the contemporary ichthyofauna of the Aral Sea basin and of the Syr Darya, in particular. Until the first half of the twentieth century, the ichthyofauna of the Aral Sea basin consisted mainly of native species, whereas today more than half of it consists of introduced species (Yuldashov and Kamilov 2018). Some of the introduced species arrived accidentally; these are invasive species that have no commercial fishery value.

Diverse researchers have carried out comprehensive studies of the composition of the ichthyofauna of the Syr Darya basin at different times. The works of L.S. Berg (1948–1949, 1962), G.V. Nikolskiy (1938, 1940), F.A. Turdakov (1963), G.K. Kamilov (1973), M.F. Vundtsettel (1994), T.V. Salikhov (1990) and Salikhov and Kamilov (1995) are of particular importance; they provided important data on the composition, formation, and zoogeography of the ichthyofauna of the Syr Darya basin. In

particular, Salikhov (1990) recorded 33 fish species in the middle reach of the Syr Darya, and Vundtsettel (1994) identified 35 fish species in the upper reach.

In addition, a number of studies have been carried out on the ichthyofauna of the Syr Darya over the last decade. These include the works of Afanasyev et al. (2020), Artaev et al. (2025), and Sheraliev and coauthors (Sheraliev et al. 2020; Sheraliev and Peng 2021; Sheraliev and Kayumova 2022; Sheraliev et al. 2022, 2025). Afanasyev et al. (2020) studied the section of the Syr Darya that flows through Tajikistan and the Kayrakkum Reservoir built there, and listed 37 fish species in total; they noted that some species in this list (for example, *Triplophysa dorsalis* (Kessler, 1872) and *T. stoliczkai* (Steindachner, 1866)) were recorded not by the authors themselves but by earlier researchers at various times during the last century. Artaev et al. (2025), in their study of the Tajikistan ichthyofauna, also provided information on fish species that occur in this part of the Syr Darya. Sheraliev et al. (2020) have studied the molecular diversity, taxonomic status, and conservation of fish from Uzbekistan's water bodies and have described new species from the region. However, none of these studies was aimed at a comprehensive investigation of the ichthyofauna of the Syr Darya basin or an analysis of its anthropogenic transformation; that is, no comprehensive faunistic study has been conducted in this basin for more than 30 years.

The main objective of this study was to determine the contemporary composition of the ichthyofauna of the Syr Darya basin and, by comparing it with data from the 1990s, to determine how the composition of the species has changed over the last 30 years and how the species have been redistributed along the river. We hypothesized that the number of native species in the main channel of the Syr Darya has decreased over the past 30 years and that the relative share of introduced species has increased. This hypothesis was tested using presence/absence data.

Materials and methods

Ichthyological material was collected between 2020 and 2026 in the upper and middle reaches of the Syr Darya during seasonal (spring, summer, and autumn) expeditions. Samples were taken only at 21 permanent monitoring stations in the main channel of the Syr Darya (Table 1; Fig. 1). No samples were taken in the Naryn, Kara Darya, Chirchik, and Ahangaran themselves. Twelve stations (1–12) were located in the upper reach, downstream of the confluence of the Naryn and Kara Darya rivers, and nine stations (13–21) in the middle reach, from the Bekabad dam to the Chardara Reservoir. The segment between the upper and middle reaches (including the Kayrakkum Reservoir) passes through the territory of the Republic of Tajikistan and was therefore not sampled; in the middle reach, no stations were placed between Chinaz and Chardara (Fig. 1). For historical comparison, Vundtsettel (1994) was used for the upper reach, and data from Salikhov (1990) for the middle reach.

The origin of each species (native or introduced) was determined following Mirabdullayev et al. (2020), and the same criterion was applied to both periods.

The capture and data collection followed standard methods and protocols generally accepted in freshwater ichthyological studies. The gear consisted of monofilament gill nets (mesh size 10 to 65 mm, length 25 to 50 m), seine nets for shallow and near-shore habitats (length 2 to 40 m, mesh size 3 to 5 mm) and cast nets (diameter 4 m, mesh size 12 mm). These types of gear are recognized as standard methods for studying freshwater fish (Pravdin 1966; Bonar et al. 2009).

Table 1. Coordinates of sampling stations in the upper and middle reaches of the Syr Darya River

Station No.	Latitude	Longitude	Reach
1	40°54.06'N	71°45.46'E	Upper
2	40°53.23'N	71°41.62'E	Upper
3	40°52.69'N	71°37.73'E	Upper
4	40°53.16'N	71°35.31'E	Upper
5	40°52.30'N	71°32.42'E	Upper
6	40°52.88'N	71°27.22'E	Upper
7	40°52.75'N	71°22.96'E	Upper
8	40°52.47'N	71°17.08'E	Upper
9	40°50.58'N	71°02.10'E	Upper
10	40°45.15'N	70°54.11'E	Upper
11	40°36.36'N	70°37.34'E	Upper
12	40°29.33'N	70°25.47'E	Upper
13	40°11.79'N	69°17.72'E	Middle
14	40°12.98'N	69°15.31'E	Middle
15	40°13.69'N	69°13.23'E	Middle
16	40°54.08'N	68°42.80'E	Middle
17	40°47.77'N	68°49.65'E	Middle
18	40°44.31'N	68°54.40'E	Middle
19	40°38.64'N	68°59.49'E	Middle
20	40°33.90'N	69°05.63'E	Middle
21	40°22.47'N	69°06.47'E	Middle

Note: Coordinates are given in degrees and decimal minutes (DDM), WGS 84 datum.

After capture, the taxonomic identity of the samples was determined and recorded in the field. Rare and conservation priority species were measured and immediately released back into their natural habitat. The samples retained for taxonomic analysis were anesthetized with a clove oil solution (0.05 ml/L), fixed in 4% neutral formaldehyde and, after 5–7 days, rinsed in water and transferred to 70%

ethanol for permanent storage. The voucher specimens are deposited in the zoological collection of the Department of Zoology and General Biology, Fergana State University, Fergana, Uzbekistan.

The fish species were identified and classified morphometrically primarily using a regional source devoted to the ichthyofauna of Uzbekistan, the monograph of Mirabdullayev et al. (2020). Kottelat and Freyhof (2007) were used only as an additional source for checking general morphological characters at the genus level and the family-level classification, because that handbook is devoted primarily to European freshwater fish. The current taxonomic status of the species was verified against the international databases Eschmeyer's Catalog of Fishes (Fricke et al. 2026) and FishBase (Froese and Pauly 2026). The authorities of all species names are given in Table 2. The origin and conservation status of the species were determined according to the Red Data Book of the Republic of Uzbekistan (Azimov 2019) and the IUCN Red List of Threatened Species (IUCN 2026, accessed June 2026).

Field and laboratory research was carried out according to the Law of the Republic of Uzbekistan 'On the Protection and Use of Wildlife' (No. O'RQ-408, 19 September 2016) and other applicable regulatory requirements and fishing rules for natural water bodies.



Figure 1. Study area and fish sampling locations on the Syr Darya River. The numbers indicate the 21 permanent monitoring stations in the upper reach (stations 1–12) and the middle reach (stations 13–21) of the Syr Darya River. The map was created in QGIS 3.44 (QGIS Development Team 2025); basemap: Esri World Basemap; rivers and reservoirs: © OpenStreetMap contributors (2026).

Results

Species composition. In 2020–2026, 30 species of fish were recorded in the upper reach of Syr Darya (Table 2), of which 15 (50%) are introduced and 15 (50%) native. Of the introduced species, five were deliberately acclimatized and the remaining 10 entered the basin accidentally, that is, are invasive species. Thirty species were also recorded in the middle range, of which 15 (50%) are introduced and 15 (50%) native. Twenty-eight species are shared between the two reaches; *Schizothorax eurystomus* Kessler, 1872 and *Triplophysa labiata* (Kessler, 1874) were recorded only in the upper reach, and *Hypophthalmichthys nobilis* (Richardson, 1845) and *T. elegans* (Kessler, 1874) only in the middle reach. In total, 32 species were found, of which 16 are are introduced and 16 native.

Four native species (*Alburnus taeniatus*, *Gobio lepidolaemus*, *Leuciscus squaliusculus* and *Luciobarbus conocephalus*) are endemics of the Turkestan zoogeographic province (the Aral Sea basin and the adjacent closed Chu–Talas and Issyk-Kul basins) (Berg 1962; Mirabdullayev et al. 2020), and two (*L. conocephalus* and *Ballerus sapa*) are listed in the Red Data Book of the Republic of Uzbekistan (Azimov 2019).

Triplophysa labiata (Kessler, 1874) and *T. strauchii* (Kessler, 1874) were also classified as introduced species. These two species accidentally entered the Syr Darya basin in the 1950s–1960s with carp fry brought from the Alma-Ata fish farm to the 'Damachi' fish farm and to Kattakurgan (Borisova 1972; Kamilov et al. 2013; Mirabdullayev and Mullabayev 2020; Mirabdullayev et al. 2020).

Table 2. Syr Darya ichthyofauna by reach and survey period

No.	Species	Authority	1 (upper, 2026)	2 (upper, 1994)	3 (middle, 1990)	4 (middle, 2026)	Origin
1	*Abbottina rivularis*	(Basilewsky, 1855)	+	+	+	+	I
2	*Abramis brama*	(Linnaeus, 1758)	+	+	+	+	N
3	*Alburnus taeniatus*	Kessler, 1874	+	+	–	+	N
4	*Alburnus chalcoides*	(Güldenstädt, 1772)	+	–	–	+	N
5	*Aspiolucius esocinus*	(Kessler, 1874)	–	+	–	–	N
6	*Ballerus sapa*	(Pallas, 1814)	+	+	+	+	N
7	Carassius gibelio	(Bloch, 1782)	+	+	+	+	I
8	*Capoetobrama kuschakewitschi*	(Kessler, 1872)	–	–	+	–	N
9	*Channa argus*	(Cantor, 1842)	+	+	+	+	I
10	*Cottus spinulosus*	Kessler, 1872	–	+	–	–	N
11	*Ctenopharyngodon idella*	(Valenciennes, 1844)	+	+	+	+	I
12	*Cyprinus carpio*	Linnaeus, 1758	+	+	+	+	N

No.	Species	Authority	1 (upper, 2026)	2 (upper, 1994)	3 (middle, 1990)	4 (middle, 2026)	Origin
13	*Diptychus sewerzovi*	Kessler, 1872	–	+	–	–	N
14	*Esox lucius*	Linnaeus, 1758	+	–	+	+	N
15	*Gambusia holbrooki*	Girard, 1859	+	+	+	+	I
16	*Glyptosternon oschanini*	(Herzenstein, 1889)	–	+	–	–	N
17	*Gobio lepidolaemus*	Kessler, 1872	+	+	+	+	N
18	*Hemiculter leucisculus*	(Basilewsky, 1855)	+	+	+	+	I
19	*Hypophthalmichthys molitrix*	(Valenciennes, 1844)	+	+	+	+	I
20	*Hypophthalmichthys nobilis*	(Richardson, 1845)	–	+	+	+	I
21	*Iskandaria kuschakewitschi*	(Herzenstein, 1890)	+	+	+	+	N
22	*Leuciscus aspius*	(Linnaeus, 1758)	+	+	+	+	N
23	*Leuciscus squaliusculus*	(Kessler, 1872)	+	+	–	+	N
24	*Luciobarbus conocephalus*	(Kessler, 1872)	+	+	+	+	N
25	*Micropercops cinctus*	(Dabry de Thiersant, 1872)	+	+	+	+	I
26	*Mylopharyngodon piceus*	(Richardson, 1846)	–	–	+	–	I
27	*Opsariichthys bidens*	Günther, 1873	+	+	+	+	I
28	*Pelecus cultratus*	(Linnaeus, 1758)	+	+	+	+	N
29	*Pseudorasbora parva*	(Temminck & Schlegel, 1846)	+	+	+	+	I
30	*Rhinogobius* cf. *lindbergi*	Berg, 1933	+	+	+	+	I
31	*Rhodeus ocellatus*	(Kner, 1866)	+	+	+	+	I
32	*Rutilus lacustris*	(Pallas, 1814)	+	+	+	+	N
33	*Sabanejewia aralensis*	(Kessler, 1877)	–	+	+	–	N
34	*Sander lucioperca*	(Linnaeus, 1758)	+	+	+	+	I
35	*Scardinius erythrophthalmus*	(Linnaeus, 1758)	–	+	+	–	N
36	*Schizothorax eurystomus*	Kessler, 1872	+	+	+	–	N
37	*Silurus glanis*	Linnaeus, 1758	+	+	+	+	N
38	*Triplophysa dorsalis*	(Kessler, 1872)	–	+	+	–	N
39	*Triplophysa labiata*	(Kessler, 1874)	+	–	–	–	I

No.	Species	Authority	1 (upper, 2026)	2 (upper, 1994)	3 (middle, 1990)	4 (middle, 2026)	Origin
40	*Triplophysa strauchii*	(Kessler, 1874)	+	–	+	+	I
41	*Triplophysa elegans*	(Kessler, 1874)	–	–	–	+	N
42	*Triplophysa stoliczkai*	(Steindachner, 1866)	–	+	+	–	N
	Total number of species		30	35	33	30	–
	Of which introduced		15	14	16	15	–

Note: 1 – present study (2020–2026, upper reach); 2 – Vundtsettel (1994, upper reach); 3 – Salikhov (1990, middle reach); 4 – present study (2020–2026, middle reach). Origin: N – native, I – introduced. "+" – recorded, "–" – not recorded.

Comparison with the 1990s. In the upper reach, nine of the 35 species recorded by Vundtsettel (1994) were not found in our study: *Aspiolucius esocinus*, *Cottus spinulosus*, *Diptychus sewerzowi*, *Glyptosternon oschanini*, *Sabanejewia aralensis*, *Scardinius erythrophthalmus*, *Triplophysa dorsalis* and *T. stoliczkai* (native species) and *Hypophthalmichthys nobilis* (introduced). In contrast, four species were newly recorded in the upper reach: *Alburnus chalcoides* and *Esox lucius* (native) and *Triplophysa labiata* and *T. strauchii* (introduced). As a result, the number of native species decreased from 21 to 15, while the number of introduced species changed little (14 and 15), and their share increased from 40% to 50%.

In the middle reach, seven of the 33 species recorded by Salikhov (1990) were not found: *Capoetobrama kuschakewitschi*, *Sabanejewia aralensis*, *Scardinius erythrophthalmus*, *Schizothorax eurystomus*, *Triplophysa dorsalis*, and *T. stoliczkai* (native) and *Mylopharyngodon piceus* (introduced). Four native species were newly recorded in the middle reach: *Alburnus chalcoides*, *A. taeniatus*, *Leuciscus squaliusculus*, and *Triplophysa elegans*. The number of native species decreased from 17 to 15 and the number of introduced species from 16 to 15; the share of introduced species increased from 48% to 50% (Table 2).

Modern taxonomic structure. The 32 species recorded in 2020–2026 belong to 13 families. According to the modern phylogenetic classification of Cypriniformes (Tan and Armbruster 2018), the 21 species that were previously placed in the single family Cyprinidae are now distributed among five separate families: Leuciscidae with eight species (25%: *Abramis brama*, *Alburnus taeniatus*, *A. chalcoides*, *Ballerus sapa*, *Leuciscus aspius*, *L. squaliusculus*, *Pelecus cultratus*, *Rutilus lacustris*); Xenocyprididae with five species (16%: *Ctenopharyngodon idella*, *Hemiculter leucisculus*, *Hypophthalmichthys molitrix*, *H. nobilis*, *Opsariichthys bidens*); Cyprinidae in the narrow sense with four species (13%: *Carassius gibelio*, *Cyprinus carpio*, *Luciobarbus conocephalus*, *Schizothorax eurystomus*); Gobionidae with three species (9%: *Abbottina rivularis*, *Gobio lepidolaemus*, *Pseudorasbora parva*); and Acheilognathidae with one species (*Rhodeus ocellatus*). The family Nemacheilidae is represented by four species (13%: *Iskandaria kuschakewitschi*, *Triplophysa labiata*, *T. strauchii*,

T. elegans). The remaining seven families (Channidae, Esocidae, Odontobutidae, Oxudercidae, Percidae, Poeciliidae and Siluridae) are each represented by a single species. The most species-rich family is Leuciscidae (eight species) and the most species-rich genus is *Triplophysa* Rendahl, 1933 (three species); the genera *Alburnus* Rafinesque, 1820, *Hypophthalmichthys* Bleeker, 1860 and *Leuciscus* Cuvier, 1816 are each represented by two species.

Discussion

Our data show that introduced species make up half of the contemporary ichthyofauna of the upper and middle reaches of the Syr Darya. Compared to the 1990s, this share has increased from 40% to 50% in the upper reach and from 48% to 50% in the middle reach. Importantly, the number of introduced species has changed little (14 and 15 in the upper reach; 16 and 15 in the middle reach), and the increase in their share is mainly the result of a decrease in the number of native species. Thus, the main change over the past 30 years is related less to a mass influx of new alien species than to the less frequent recording of native species in the main channel. The ecological consequences of introduced species in the upper reach were discussed separately by Nazarov et al. (2026).

Most native species that were not found (*Diptychus sewerzowi*, *Glyptosternon oschanini*, *Cottus spinulosus*, *Aspiolucius esocinus*, *Triplophysa dorsalis*, *T. stoliczkai*, and *Sabanejewia aralensis*) are rheophilic mountain and piedmont species that prefer clean, cool, fast flowing water (Berg 1948–1949; Turdakov 1963; Mirabdullayev et al. 2020). The absence of *Schizothorax eurystomus* in the middle reach also fits this group: this species was found only in the upper reach. The disappearance of such species from the main channel may be related to changes in the flow regime caused by dams and water abstraction (Xenopoulos et al. 2005; Grill et al. 2019). However, some of these species are naturally rare and live mainly in tributaries; because we did not sample the tributaries, we cannot distinguish whether they have disappeared entirely from the basin or have only ceased to occur in the main channel. Salikhov (1990) and Vundtsettel (1994) suggested that native species were retreating into the tributaries; testing this suggestion requires a dedicated study of the tributaries.

However, several native species have expanded their ranges. Earlier researchers recorded *Alburnus chalcoides* only in the lower reach of the Syr Darya; today it also occurs in the upper and middle reaches and in the lower parts of the Naryn, Kara Darya, and Chirchik tributaries (Sheraliev et al. 2025). *Alburnus taeniatus*, *Leuciscus squaliusculus*, and *Triplophysa elegans*, which were absent from the list of Salikhov (1990), were recorded in the middle reach in our study. Thus, a two-way redistribution is taking place in the basin: While rheophilic mountain species are recorded less often in the main channel, some ecologically plastic native species are occupying new parts of the river.

Hydrological changes may also influence these processes. The flow of the main rivers of the basin is already regulated by dams in the piedmont areas, an extensive network of irrigation and collector canals has been built, and numerous reservoirs have been constructed (Kamilov 1973; Salikhov 1990). Sharp changes in water level can lead to desiccation of fish eggs and dams can obstruct the migration of migratory fish (Sheraliev et al. 2025). Because the hydrological parameters were not measured in this study, this relationship is presented as a hypothesis based on the literature.

Fish farms may play an important role in the spread of invasive species: invasive species are carried with the fry of farmed fish into ponds and from there spread into natural water bodies. Examples are the introduction of *Triplophysa labiata* and *T. strauchii* with carp fry and the accidental introduction of *Pseudorasbora parva*, *Abbottina rivularis*, *Rhodeus ocellatus*, and other East Asian species with herbivorous fish (Borisova 1972; Kamilov et al. 2013; Yuldashov and Kamilov 2018; Mirabdullayev and Mullabayev 2020).

Study limitations

Several limitations of this study should be noted. First, samples were taken only in the main channel of Syr Darya; the Naryn, Kara Darya, Chirchik, Ahangaran and other tributaries, the segment in Tajikistan and the Chinaz–Chardara section of the middle reach were not studied (Figure 1). Second, historical data (Salikhov 1990; Vundtsettel 1994) were collected by other researchers using other methods and sampling effort; therefore, the nondetection of some species may also be related to differences in sampling efficiency. Third, the study is based on presence/absence data; abundance data and statistical tests were not used. For this reason, causal explanations are given as hypotheses. In the future, standardized monitoring that also covers the tributaries and is based on quantitative indicators.

Conclusion

In 2020–2026, 32 species of fish were recorded in the main channel of the upper and middle reaches of the Syr Darya (30 in each reach); half of them (16 species) are introduced.

Compared to the 1990s, nine species were not recorded in the upper reach and seven in the middle reach, and four species were newly recorded in each. The share of introduced species increased from 40% to 50% in the upper reach and from 48% to 50% in the middle reach, mainly due to a decrease in the number of native species (from 21 to 15 and from 17 to 15, respectively).

Most native species that were not recorded are mountain and piedmont species (*Diptychus sewerzowi*, *Glyptosternon oschanini*, *Triplophysa dorsalis*, *T. stoliczkai*,

and *Sabanejewia aralensis*); *Schizothorax eurystomus* now occurs only in the upper reach.

Some native species have expanded their ranges: *Alburnus chalcoides* was recorded in the upper and middle reaches and *A. taeniatus*, *Leuciscus squaliusculus*, and *Triplophysa elegans* were newly recorded in the middle reach. This indicates a two-way redistribution of species composition across the basin.

The link between the observed changes and the hydrotechnical construction and biological invasions is a hypothesis; testing it requires quantitative monitoring that also covers the tributaries.

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