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Scoliosis deformity in *Alburnus escherichii*, an endemic freshwater leuciscid (Teleostei) from the Sakarya River Basin, Türkiye: morphological description and a case study

by

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Abstract

In this study, a total of eight *Alburnus escherichii* individuals were captured from the Sakarya River Basin, Türkiye. In only one of these specimens, a skeletal deformity (scoliosis) was observed and examined. The scoliosis affected the caudal region of the vertebral column, presenting two curves originating posterior to the dorsal fin. These curves formed two angles, measuring 135° and 152°. Externally, at the point of scoliosis onset, the body contour and lateral line scales were deformed. The deformity affected the posterior part of the dorsal fin and the anterior part of the anal fin. Additionally, the neural and hemal spines of the ultimate abdominal vertebra were slightly deformed. This study discusses the possible causes of scoliosis and the significance of reporting such deformities for anatomical and broader ichthyological research.

Key words: Central Anatolia, digital radiography, environment, skeletal anomalies, vertebral column

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1. Introduction

Alburnus Rafinesque, 1820, is one of the most widespread genera within the family Leuciscidae. This genus, which comprises over 30 described species, is distributed from the Atlantic Ocean to the western Mediterranean, Adriatic, Aegean, Black, and Caspian Seas (Froese & Pauly, 2025; Kottelat & Freyhof, 2007). *Alburnus* is considered a representative example of endemism and advanced diversification, occurring in the northern regions of Europe and southwestern Asia (Bektaş et al., 2020). A total of 20 *Alburnus* species have been recorded from inland waters of Türkiye (Freyhof et al., 2025; Kaya et al., 2026), among which *Alburnus akili* has become extinct (Küçük, 2012).

The Anatolian endemic *A. escherichii* naturally occurs in the upper reaches of the Sakarya, Kızılırmak, and Yeşilırmak rivers, as well as in the Akarçay Basin (including Lakes Eber, Akşehir, and Çavuşçu, and the Sarayönü–Konya region). Through fish stocking, it has been introduced into the Manavgat River and Lake Beyşehir Basin, where it has established self-sustaining populations (Bayçelebi et al., 2020; Çiçek et al., 2023; Freyhof et al., 2025; Geldiay & Balık, 2007; İlhan & Balık, 2008).

As a fundamental developmental issue, skeletal deformities can adversely affect the morphology, growth, and survival of fish. Their apparent rarity in wild populations is attributed either to a genuinely low prevalence or to the diminished viability of deformed individuals in natural environments (Bogutskaya et al., 2011; Gavaia et al., 2009; Jawad et al., 2015, 2018).

Scoliosis, a lateral curvature of the vertebral column, is a severe vertebral anomaly in fish. Although considered less common than lordosis (Boglione et al., 2013a), it may manifest in both pre-hemal and hemal regions (Boglione et al., 1995). This particular deformity is the most readily identifiable vertebral anomaly in live specimens and is confirmed by dorsal–ventral observation (Boglione et al., 2011). The most reliable method for identifying scoliosis in live fish is observation from the dorsal or ventral side (Arbuatti et al., 2013; Basaran et al., 2007; Fernández et al., 2018; Gorman & Breden, 2007; Torres-Dowdall et al., 2018).

Reports of scoliosis abnormality cases in cyprinid fishes are not common. Sajeevan and Anna-Mercy (2016) described such a case in the hatchery-bred redline torpedo fish, *Sahyadria denisonii*. To the best of our knowledge, documented occurrences of scoliosis in *Alburnus* species are very limited and poorly reported. Probably, the best-documented example of this type of skeletal deformity in *Alburnus* species is the work of Mineev (2025), who described several skeletal deformities, including scoliosis, in a number of cyprinid species, including *A. alburnus*.

The documentation of a skeletal deformity in *A. escherichii* from the Sakarya River Basin gains particular significance when considered within the context of mounting evidence of environmental stress affecting this water system. The Sakarya River, one of Türkiye's longest rivers, faces multiple anthropogenic pressures throughout its course. Extensive and largely unregulated sand mining operations in the lower reaches near Adapazarı have caused severe habitat destruction, with approximately 80% of the floodplain either exploited or severely altered, resulting in loss of agricultural land and destruction of natural habitats (Okur & Korhan Erturaç, 2018). These operations have intensified dramatically in recent decades, with an estimated 50 million m^3 of material extracted since 1980, causing irreversible floodplain alteration, water table changes, and continuous pollution from heavy vehicle traffic (Okur et al., 2024). Water quality degradation further compounds these physical habitat alterations. A 2025 study documented significant arsenic contamination in the Lower Sakarya Basin, finding that 33%–41% of deep groundwater samples exceeded the WHO drinking water standard of 10 μg L^{-1}, with maximum values reaching 373 μg L^{-1}, alongside manganese concentrations exceeding limits in up to 44% of samples (Talay & Yolcubal, 2025). Historical research has consistently demonstrated heavy metal contamination in the basin, with elevated levels of lead, cadmium, copper, and manganese detected in water, sediment, and fish tissues (Barlas, 1999a). The biological impacts of such contamination are well-documented in the region: histopathological examinations of carp from the upper Sakarya River Basin revealed gill lesions including lamellar fusion and hyperplasia, liver abnormalities, and kidney tubular degeneration (Barlas, 1999b), while studies on fishes from nearby contaminated rivers have documented scale deformities including damaged circuli, eroded foci, and asymmetric structures linked to heavy metal exposure (Iram et al., 2013). Organic pollution from untreated domestic and food industry discharges has further impacted the basin, as evidenced by benthic macroinvertebrate communities dominated by pollution-tolerant taxa such as Tubificidae (Kılıç & Şişman, 2024). Even protected areas within the basin, such as the Balıkdamı Wetland, experience considerable pressure from agricultural water extraction, habitat degradation, and contamination (Iram et al., 2013). This convergence of physical habitat destruction, chemical contamination, and documented biological responses in fishes provides a compelling regional context for investigating morphological abnormalities in resident species, as deformities may serve as visible indicators of broader environmental stress affecting the Sakarya River ecosystem.

Studies on anomalies in freshwater fish species in Türkiye are very limited. To our knowledge, the only available studies on fish skeletal abnormalities in Türkiye include the work by Jawad and Öktener (2007) on *Planiliza abu* collected from the Atatürk Dam Lake; the experimental work by Çelik et al. (2012) on the common carp, *Cyprinus carpio*; the work by İnnal et al. (2019) on *Barbus pergamonensis* from the Dalaman Stream; the work of Jawad and Güçlü (2022) on *B. xanthos* (Teleostei: Cyprinidae) from the Dalaman River in southwestern Anatolia; and the studies by Şavran et al. (2026) on *Pseudorasbora parva, Pseudophoxinus battalgilae*, and *Oxynoemacheilus eregliensis* sampled from the Göksu River basin in Eastern Mediterranean.

Therefore, the present study adds to the known prevalence of abnormalities observed so far in the freshwaters of Türkiye by describing a case of severe scoliosis in one specimen of *A. escherichii*, an endemic freshwater leuciscid (Teleostei) from the Sakarya River Basin. The availability of such information is very important for aquaculturists, fisheries biologists, and environmentalists.

2. Materials and Methods

2.1. Sampling locality

The Sakarya River, extending 824 km, is the third-longest river in Türkiye, draining a basin of 58,160 km^2. The site, located approximately 300 m from the Sakaryabaşı Irrigation Association and 2.4 km from Eminekin Village, was near the Sakaryabaşı Regulator (39°22´54.70˝N, 31°06´28.91˝E) in an area approximately 1 m deep (Fig. 1). Its principal tributaries are the Porsuk, Ankara, Mudurnu, Koca, and Kirmir streams, along with the Çark Stream and Darıçay Creek. The river has two main sources: one originates from the Bayat Plateau in northeastern Afyonkarahisar and the other from Sakaryabaşı in the Çifteler district of Eskişehir. The Sakaryabaşı Wetland, located in Çifteler, is widely regarded as the river's primary source. Specimens of *A. escherichii* were collected near the Sakaryabaşı regulator (39°22´54.70˝N, 31°06´28.91˝E), situated approximately 300 m from the Sakaryabaşı Irrigation Union and 2.4 km from Eminekin Village.

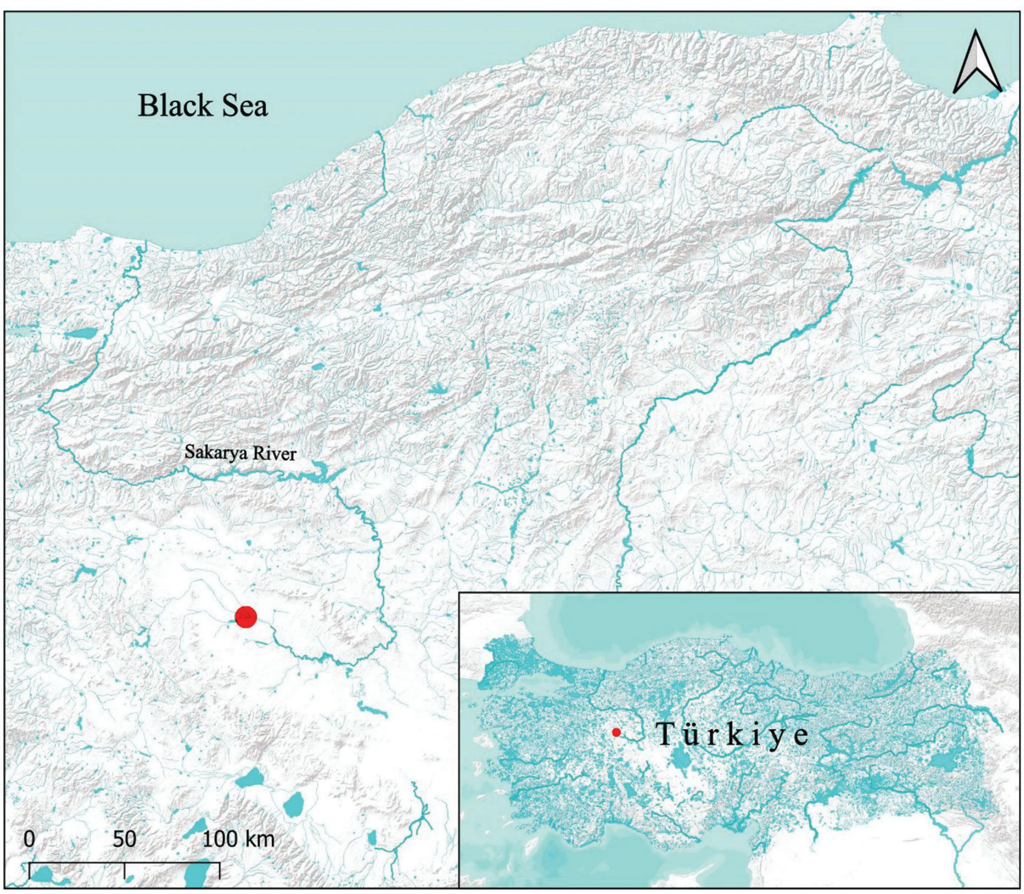

Figure 1

Map showing the location of fish sampling (Sakaryabaşı regulator, Sakarya River Basin).

2.2. Fish sampling and Methodology

Specimens of *A. escherichii* were collected in June 2025 using electrofishing along a 50-m transect section downstream of the Eminekin regulator in the Sakaryabaşı spring waters (Çifteler, Eskişehir, Türkiye). In this section, the channel width is approximately 8 m, and the average depth varies between 50 cm and 110 cm. The bottom structure of the sampling area consists mainly of sand, gravel, and underwater macrophytes. During the June 2025 sampling, flow conditions were stable due to regulation in the upstream basin, the water was stagnant, and the estimated flow velocity was 0.05–0.25 ms^{-1}. No abnormal discharge events were observed.

The basic in situ water quality parameters measured during the June 2025 sampling are temperature: 19.4°, pH: 7.8, dissolved oxygen: 7.6 mg L^{-1}, electrical conductivity: 580 µS cm^{-1}, and salinity (PSU): 0.46.

A total of eight *A. escherichii* individuals were captured. All sampling was conducted under authorization from the Ministry of Agriculture and Forestry of the Republic of Türkiye, General Directorate of Nature Conservation and National Parks (Permit No: E-21264211-288.04-6036040). To examine osteological features, digital radiography was performed using a mammography device (Siemens Mammomat Inspiration, 2013). The procedure was conducted at the Mammography Department of Meddem Hospital's Radiology Department in Isparta, Türkiye, using settings of 60–80 kV, 30–45 mA, and an exposure time of 2.1 s to visualize skeletal structures. Morphologically normal specimen provided baseline anatomical references for comparison. Morphometric characteristics were measured using a digital ruler and recorded to the nearest millimeter. Eye diameter (ED) represents the distance between the anterior and the posterior edges of the orbit. Body depth (BD) is the greatest distance between the dorsal and the ventral profile of the fish body. Caudal peduncle depth (CPD) is the greatest distance of the caudal peduncle taken vertically. Caudal peduncle length (CPL) is the distance from the posterior end of the anal fin to the base of the caudal fin. Head length (HL) is the distance between the tip of the snout and the posterior edge of the operculum. Postanal fin length (PostAFL) is the distance between the tip of the snout and the posterior edge of the anal fin. Postdorsal fin length (PostDFL) is the distance between the tip of the snout and the posterior edge of the dorsal fin base. Preanal fin length (PreAFL) is the distance between the tip of the snout and the anterior edge of the anal fin base. Prepectoral fin length (PrePFL) is the distance between the tip of the snout and the anterior edge of the pectoral fin base. Predorsal fin length (PreDFL) is the distance between the tip of the snout and the anterior edge of the dorsal fin base. Prepelvic fin length (PrePelFL) is the distance between the tip of the snout and the anterior edge of the pelvic fin base. Standard length (SL) was measured from the tip of the snout to the posterior edge of the hypural bone, which was located by bending the caudal fin forward and identifying the crease at the base of the hypural plates. Total length (TL) was measured from the tip of the snout to the farthest point of the caudal fin, with both lobes compressed. The angles formed at the intersection of these lines were then measured using a protractor.

3. Results

This study documents a case of scoliosis in one specimen of *A. escherichii*. While only a single individual was affected, the description of such vertebral deformities in wild fish is uncommon. This report therefore adds to the baseline knowledge of skeletal variation and anomalies in freshwater species.

A single abnormal specimen of *A. escherichii* (95.60 mm SL, 117.77 mm TL) was obtained. For comparison, a normal specimen (88.10 mm SL, 109.43 mm TL) was used to evaluate the skeletal deformity (Figs. 2A–C). Radiographs of the abnormal and normal specimens are shown in Figs. 3A and 3B.

Scoliosis was visible externally on the fish, with the spine curved laterally at two points compared to the normal specimen (Figs. 2B and 2C). The body contour and lateral line scales were disrupted at the site of the scoliosis onset, posterior to the dorsal fin, which appeared depressed well below the posterior dorsal profile. No other external deformities were observed.

The digital radiography revealed that both curves occurred in the caudal region of the vertebral column, involving the 1st to 12th caudal vertebrae. These two scoliotic curves formed two angles: angle *A* of 135° and angle *B* of 152° within the caudal vertebral column (Fig. 4).

Compared to the radiograph of the normal specimen (Fig. 3A), the depression at the posterior edge of the dorsal fin—caused by the onset of scoliosis—was shown to displace the posterior dorsal fin rays and their supporting pterygiophores downward and to the right. This effect did not, however, appear to reduce the number of dorsal rays or pterygiophores.

Ventrally, the first scoliotic curve affected the anterior part of the anal fin, displacing the pterygiophores supporting the anal fin rays. Although the abdominal

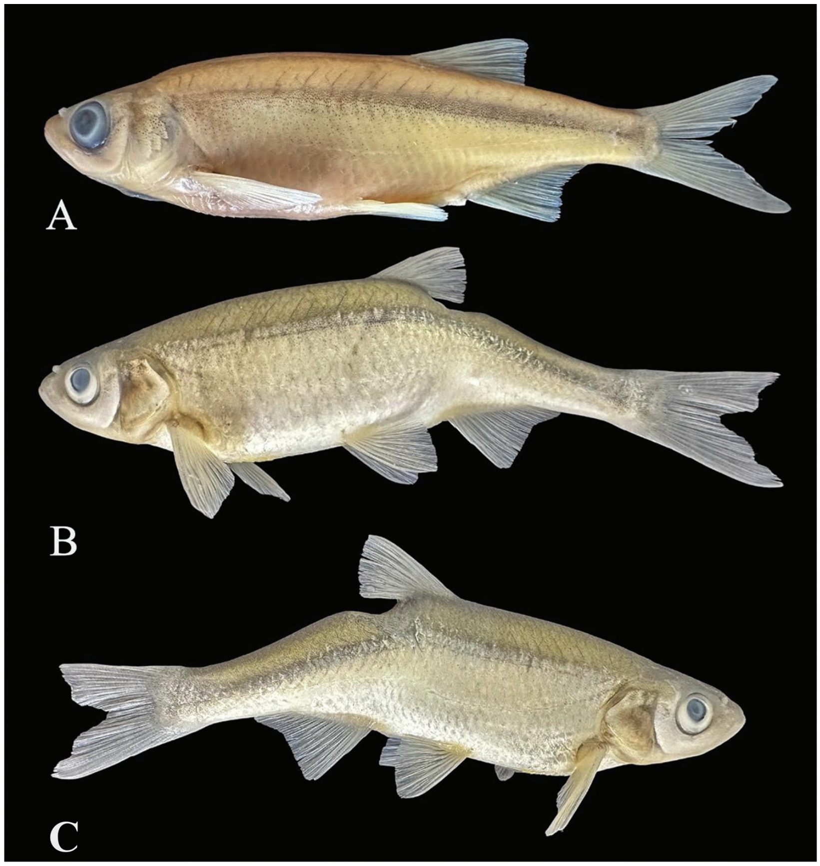

Figure 2

(A) *A. escherichii*, normal specimen (88.10 mm SL, 109.43 mm TL); **(B)** abnormal specimen (left side) (95.60 mm SL, 117.77 mm TL); **(C)** abnormal specimen (right side) (95.60 mm SL, 117.77 mm TL). SL, standard length; TL, total length.

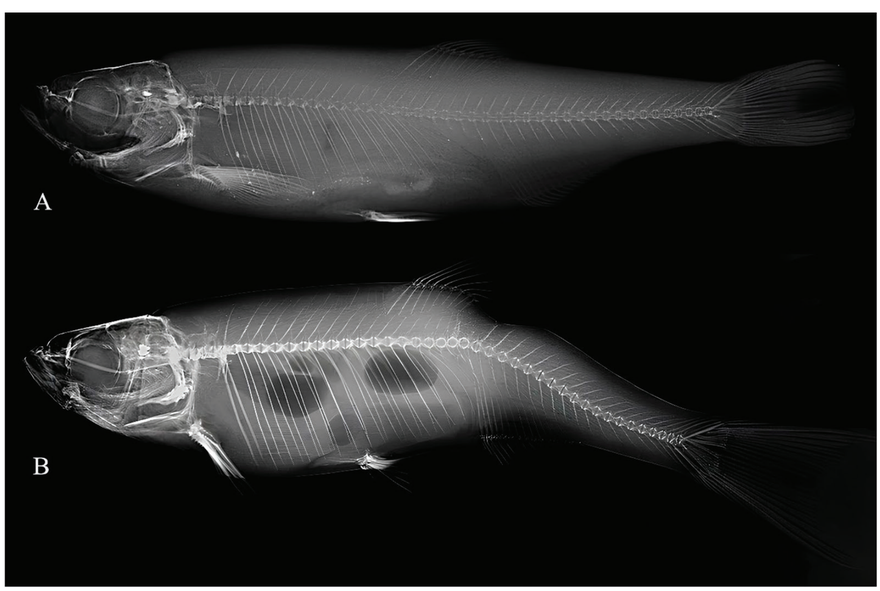

Figure 3

Digital radiography of *A. escherichii*. **(A)** normal specimen (88.10 mm SL, 109.43 mm TL); **(B)** abnormal specimen (dorsal view) (95.60 mm SL, 117.77 mm TL). SL, standard length; TL, total length.

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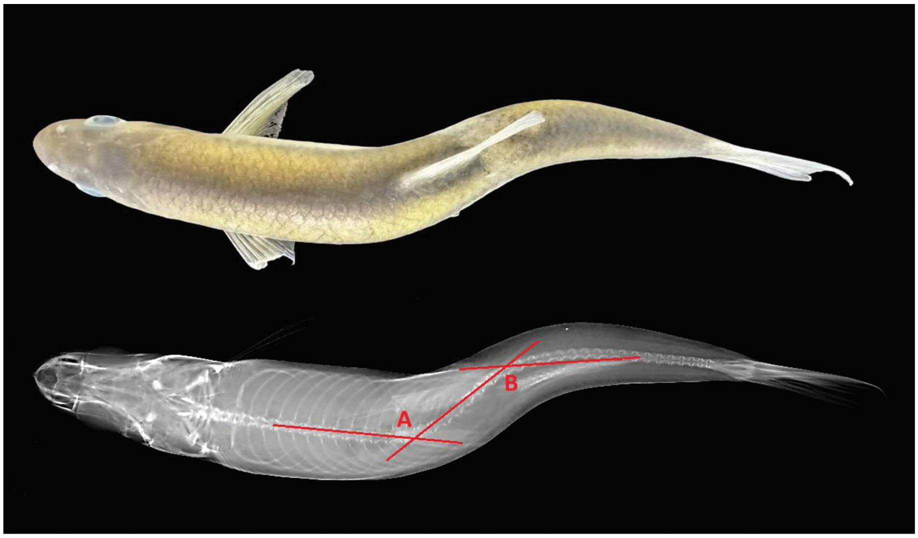

Figure 4

Abnormal specimen of *A. escherichii* (95.60 mm SL, 117.77 mm TL). **(A)** whole fish (dorsal view); **(B)** Digital radiography (dorsal view). SL, standard length; TL, total length.

vertebrae were not involved in the primary deformity, the neural and hemal spines of the ultimate abdominal vertebra were slightly deformed (Fig. 4B).

The morphometric comparison between the abnormal and normal specimens of *A. escherichii* from the Sakarya River Basin revealed distinct differences in body proportions (Table 1). The abnormal specimen exhibited a larger overall size, with a TL of 117.7 mm compared to 109.43 mm in the normal specimen. When expressed as percentages of SL, the abnormal fish displayed notably longer prepectoral (46.6% SL vs 22.7% SL), prepelvic (63.9% SL vs 48.9% SL), and PreAFLs (75.1% SL vs 69.0% SL), suggesting an anterior shift in body mass or elongation of the thoracic region. Conversely, the PostDFL was considerably shorter in the abnormal specimen (70.7% SL) compared to the normal one (94.7% SL). While head length was relatively similar, the abnormal individual had a slightly larger ED relative to head length (25% HL vs 30.5% HL in the normal). Despite these variations, CPD was nearly identical between the two specimens, indicating that the abnormality primarily affected the anterior–posterior body patterning rather than the terminal structures.

4. Discussion

The scoliosis observed in this single specimen of *A. escherichii* may represent the outcome of multiple interacting factors. Radiographic analysis revealed a skeletal deformity with vertebral distortion and displacement of fin supports, which could suggest a developmental origin rather than traumatic injury. The species belongs to Leuciscidae, a family known for both potential genetic susceptibility to vertebral anomalies and an absolute dietary requirement for Vitamin C, which is essential for collagen synthesis (Dabrowski & Hinterleitner, 1989; Gorman et al., 2012). While the precise cause cannot be determined from a single individual, the deformity might reflect an interaction between inherent genetic vulnerability and an epigenetic or environmental stressor—such as transient hypoxia, nutritional deficiency, or pollutant exposure—during early development (Boglione et al., 2013b). This case may therefore illustrate the multifactorial etiology often proposed for fish scoliosis, where latent genetic risk factors could potentially be realized through environmental pathways.

The morphological changes observed—anterior–posterior curvature with vertebral compression—resemble those described in other teleosts. The distorted vertebral shape, with reduced height on the convex side and greater height on the concave side, could result from either abnormal developmental patterning or active bone remodeling in response to extrinsic mechanical forces (Kranenbarg et al., 2005).

The pronounced morphological differences in the abnormal *A. escherichii* specimen—particularly elongated prepectoral, prepelvic, and preanal fins alongside reduced PostDFL—may suggest disrupted developmental patterning. Such deviations have been associated with developmental instability from genetic or environmental stressors during ontogeny

Table 1

Morphometric characteristics of the abnormal and normal specimens of *A. escherichii* collected from the Sakarya River Basin, Türkiye

Morphometric characteristics (millimeter)	Abnormal specimen	Normal specimen
TL	117.7	109.43
SL	95.6	88.1
SL (% TL)	81.2	80.5
HL (% SL)	20.7	20.1
ED (% HL)	25.0	30.5
PreDFL (% SL)	50.9	54.1
PostDFL (% SL)	70.7	94.7
PrePFL (% SL)	46.6	22.7
PrePELFL (% SL)	63.9	48.9
PreAFL (% SL)	75.1	69.0
PostAFL (% SL)	75.9	83.4
BD (% SL)	27.6	27.1
CPD (% SL)	9.6	10.4
CPL (% SL)	13.8	13.1

BD, body depth; CPD, caudal peduncle depth; CPL, caudal peduncle length; ED, eye diameter; HL, head length; PostAFL, postanal fin length; PostDFL, postdorsal fin length; PreAFL, preanal fin length; PreDFL, predorsal fin length; PrePFL, prepectoral fin length; PrePELFL, prepelvic fin length; SL, standard length; TL, total length.

(Almeida et al., 2008). In cyprinids, morphological abnormalities have been linked to overcrowding, poor water quality, and nutritional stress, with captive goldfish and carp exhibiting fin length disparities showing similarities to those observed in the present specimen (Almeida et al., 2008). Skeletal deformities and altered body proportions in fishes have also been attributed to parasitic infections, bacterial diseases, and toxicological exposure (Brazova et al., 2020; Pasnik et al., 2007). Pasnik et al. (2007) documented vertebral abnormalities in *Streptococcus agalactiae*-challenged Nile tilapia, while studies on fish parasites from polluted environments report increased morphological malformations, suggesting contaminants may have teratogenic effects (Barčák et al., 2023). The nearly identical CPD between specimens might indicate that developmental disruption selectively targeted anterior–posterior patterning while sparing posterior elements, though confirmation requires examination of additional abnormal specimens.

The species-specific context of *A. escherichii* warrants caution when drawing conclusions from a single individual. As an endemic species to Türkiye's Sakarya River Basin, this population could be particularly vulnerable to environmental perturbations (Freyhof, 2014). The Sakarya River Basin faces multiple anthropogenic stressors that may contribute to morphological abnormalities in resident fish populations. Extensive and largely unregulated sand mining operations in the lower reaches have caused complete and irreversible alteration of floodplain habitat amounting to approximately 970 hectares, with an estimated 50 million m^3 of material extracted since 1980, resulting in substantial land loss, soil erosion, water table alterations, and continuous pollution from heavy vehicle traffic (Okur et al., 2024; Okur & Korhan Erturaç, 2018). These operations have rendered agricultural land unsuitable for cultivation and destroyed natural habitats, with approximately 80% of the floodplain currently exploited or severely altered (Okur & Korhan Erturaç, 2018). Water quality degradation compounds these physical habitat alterations comprehensive analysis using the river pollution index (RPI) has classified the Sakarya River as ranging from "severely polluted" to "moderately polluted," driven by high levels of suspended solids and biochemical oxygen demand from agricultural runoff and industrial discharge (Yavuz et al., 2024). Heavy metal contamination is well-documented in the basin, with studies detecting elevated concentrations of lead, cadmium, copper, cobalt, nickel, and manganese in water, sediment, and fish tissues in the upper Sakarya River Basin (Barlas, 1999a). More recent assessments identified cadmium as the most hazardous heavy metal in terms of potential ecological risk, with nickel and arsenic also posing significant concerns (Köse et al., 2023). Additionally, the Karasu Stream within the Sakarya system contains aluminum concentrations (823 μg L^{-1}) exceeding WHO-drinking-water limits (200 μg L^{-1}), alongside elevated levels of antimony, arsenic, barium, chromium, selenium, lead, iron, and zinc derived from natural geological weathering (Yavuz et al., 2024). Parasite loads represent another potential stressor—studies have documented 11 parasite species across multiple fish hosts in the Sakarya River (Yavuz et al., 2024), and notably, *A. escherichii* has been identified as a new host record for *Posthodiplostomum cuticola*, the causative agent of black spot disease, which induces melanin pigmentation and muscle atrophy in affected fish (Köse et al., 2023). Otolith phenotypic analyses have demonstrated intraspecific morphological variability in *A. escherichii*, with discriminant function analysis correctly classifying 79.9% of specimens by length classes (Özpicak et al., 2021). This documented phenotypic plasticity might explain the extreme variation observed, though natural variation within the normal range requires larger sample sizes for confirmation. The abnormal specimen's deviation—anterior elongation and posterior truncation—might represent a pathological response to these cumulative environmental stressors rather than natural variation, but this hypothesis requires histological, genetic, or controlled experimental testing. Given the convergence of physical habitat destruction, chemical contamination, and documented parasite pressures on the Sakarya River Basin, future investigations should examine water quality parameters, heavy metal bioaccumulation, parasite loads, and potential genetic bottlenecks in this population to identify possible stressors underlying such anomalies. Examination of additional specimens from the same locality and controlled experiments would help determine whether these abnormalities represent a consistent response to specific environmental factors or an isolated developmental anomaly.

Although only a single abnormal specimen was documented, descriptions of skeletal deformities in wild fish populations remain relatively uncommon. Each such case may contribute to understanding morphological variation within species and could provide baseline data for future comparative studies. Isolated reports might also offer insights into developmental plasticity or serve as potential indicators of environmental conditions affecting fish populations (Boglione et al., 2013b).

The etiology of scoliosis in fishes is likely multifactorial, potentially involving genetic, environmental, and nutritional components. Spinal deformities have been associated with heavy metal exposure, temperature shocks, hypoxia, and nutritional deficiencies—particularly of Vitamin C, which cypriniforms cannot synthesize endogenously (Boglione et al., 2013b; Dabrowski & Hinterleitner, 1989). Genetic susceptibility within Cypriniformes may further increase vulnerability to such stressors (Gorman et al., 2012; Kause et al., 2007).

Regarding the subtle deformations observed in the neural and hemal spines of the ultimate abdominal vertebra, these might represent secondary effects of the primary caudal curvature. It is possible that biomechanical loads resulting from spinal misalignment influenced the development or remodeling of these adjacent structures. This hypothesis could be tested through comparative micro-computed tomography (μCT) analysis of normal and affected specimens, which might reveal consistent asymmetries or morphological deviations at the abdominal-caudal transition in scoliotic individuals.

5. Conclusion

The examination of a wild-caught *A. escherichii* with severe caudal scoliosis, characterized by two distinct vertebral curves and compensatory displacements of the dorsal and anal fin supports, provides a concrete case supporting the multifactorial etiology of such deformities in fish. The findings, combined with the species' genetic predisposition as a leuciscid cyprinid and its absolute dietary requirement for Vitamin C, could indicate that this condition arose from an interplay of inherent genetic vulnerability and an epigenetic or environmental stressor during development, consistent with established models. This single specimen underscores the broader significance of documenting skeletal anomalies, as such records are vital for anatomical studies of vertebrate development, environmental biomonitoring, and informing aquaculture and fisheries management practices aimed at mitigating deformity risks.

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Conflict of interest statement

The authors declare that they have no known conflict of interest that could have appeared to influence the work reported in this article.

Ethical approval

All *A. escherichii* specimens used in this study were collected under the authorization of the Ministry of Agriculture and Forestry of the Republic of Türkiye, General Directorate of Nature Conservation and National Parks (Permit No: E-21264211-288.04-6036040). This approval also fulfills the function of a local ethics committee authorization in accordance with Article 8/L of the *Regulation on the Working Procedures and Principles of Animal Experiments Ethics Committees,* established by the Ministry of Forestry and Water Affairs and published in the Official Gazette on February 15, 2014.

Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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