Marine and Life Sciences

Journal Homepage: https://dergipark.org.tr/en/pub/marlife

A comparative analysis of morphometric and meristic traits of endangered (*Salmo opimus* Turan, Kottelat and Engin, 2012 and *Salmo plathycephalus* Behnke, 1968) and at risk (*Salmo okumusi* Turan, Kottelat and Engin, 2014) trout species

Cemil Kara[1] ✉ • Mehmet Fatih Can[2]

[1] Department of Biology, Faculty of Science, Karadeniz Technical University, Trabzon, TÜRKİYE
[2] Department of Water Resources Management and Organization, Faculty of Marine Science and Technology, Iskenderun Technical University, 31200, Iskenderun, Hatay, TÜRKİYE

✉ Corresponding Author: cemilkara67@gmail.com

Please cite this paper as follows:
Kara, C., & Can, M. F. (2025). A comparative analysis of morphometric and meristic traits of endangered (*Salmo opimus* Turan, Kottelat and Engin, 2012 and *Salmo plathycephalus* Behnke, 1968) and at risk (*Salmo okumusi* Turan, Kottelat and Engin, 2014) trout species. *Marine and Life Sciences*, *7*(2), 56-64. https://doi.org/10.51756/marlife.1747299

Research Article

Article History
Received: 21.07.2025
Accepted: 26.09.2025
Published Online: 10.12.2025

Keywords:

Conservation biology
Endangered trout species
Interspecies differentiation
Meristic traits
Morphometric traits

A B S T R A C T

This study examines interspecies differentiation by comparing the morphometric and meristic characteristics of two endangered trout species (*Salmo opimus* Turan, Kottelat and Engin, 2012 and *Salmo plathycephalus* Behnke, 1968) and a species with the potential to be endangered (*Salmo okumusi* Turan, Kottelat and Engin, 2014). The research was conducted between 2014 and 2016 in the upper tributaries of the Ceyhan, Seyhan, and Euphrates basins in Türkiye. A total of 25 morphometric and 24 meristic characters were examined, and the measurements influencing interspecies differentiation were analyzed using the Random Forest model. The results indicate that *S. plathycephalus* exhibits significant differentiation in metric characteristics. In particular, variables such as predorsal length, head length, and body height are key distinguishing factors for this species. Among the meristic traits, the number of red spots and black markings on the operculum are critical for species identification. This study enhances understanding of species' environmental adaptations and informs conservation strategies, laying a foundation for sustainable management. Future research should focus on habitat conservation efforts.

INTRODUCTION

Türkiye is located at the intersection of three major biogeographic regions Caucasus, Mediterranean, and Iran, Anatolia which results in a high level of species richness and endemism (Şekercioğlu, 2011; Noroozi et al., 2019; Kara and Bozali, 2024). The diversity of naturally occurring trout species in Anatolia has been identified based on morphological and genetic characteristics (Behnke, 1968; Turan et al., 2010, 2011, 2012, 2017, 2020, 2021, 2022; Kaya, 2020). Extensive research has revealed the presence of 17 Salmo species with natural distribution in Türkiye (Turan et al., 2024). Among these, *Salmo opimus*, *Salmo okumusi*, and *Salmo plathycephalus* have been reported to originate from the Adriatic lineage (Turan et al., 2024).

Previously identified as *Salmo trutta macrostigma* (Alp et al., 2003; Alp and Kara, 2004; Geldiay and Balık, 2009), *Salmo okumusi* was reclassified by Turan et al. (2014). This species has been reported in the upper tributaries of the Euphrates River and Göksu (Kara et al., 2011). *S. okumusi* can be distinguished from other trout species by the presence of red spots on its adipose fin and distinctive body coloration. Commonly referred to as "Mercan Alası" by locals, this species has been subjected to excessive fishing due to the belief that it has medicinal benefits and its highly valued taste. Consequently, its populations have significantly declined, leading to a complete ban on fishing throughout the year. However, the conservation status of *S. okumusi* on the Red List remains undetermined.

Trout populations found in the upper tributaries of rivers flowing into the eastern Mediterranean, which were previously reported as *S. trutta macrostigma* (Alp et al., 2003; Alp and Kara, 2004; Geldiay and Balık, 2009), were reclassified by Turan et al. (2012) as *Salmo opimus* based on morphometric and molecular characteristics. Locally known as "Ceyhan Alası" or "Red-Spotted Trout," *S. opimus* is primarily found in the inland waters of Kahramanmaraş and inhabits only the first 15-20 km of streams from their source (Alp and Kara, 2004). This species exhibits a few black spots and numerous red parr marks along its lateral body surface. Its primary food source, *Gammarus* sp., is believed to be responsible for the red pigmentation observed in its body and flesh (Kara and Alp, 2005). Due to excessive fishing, *S. opimus* populations have drastically declined, and the species has been classified as endangered (Endangered, EN) (Freyhof, 2019a).

S. plathycephalus, endemic to the Seyhan River, was first described as a new species in 1968 (Behnke, 1968). It is predominantly found in the Zamantı River, an upper tributary of the Seyhan Basin. This species differs from other trout species in terms of scale count, gill raker count, pyloric caeca count, and other morphological characteristics. Unlike other trout species, *S. plathycephalus* lacks distinct red spotting, and its body coloration is irregularly distributed (Kara et al., 2011a). This species reproduces between October and January, with individuals laying approximately 5,000 eggs per kilogram of body weight (Kara et al., 2011b). Excessive and illegal fishing, along with habitat degradation, pose major threats to this species. Consequently, *S. plathycephalus* is also classified as endangered (Endangered, EN) (Freyhof, 2019b).

This study aims to assess the degree to which certain morphometric and meristic traits contribute to interspecies differentiation among two endangered trout species (*S. opimus* and *S. plathycephalus*) and one species with a potential risk of endangerment (*S. okumusi*). The findings of this research are expected to contribute scientifically to the development of conservation strategies and sustainable management plans for these species. Additionally, understanding interspecies adaptation strategies and providing a foundation for future biodiversity studies are among the key objectives of this study.

MATERIALS AND METHODS

This study focused on the *Salmo opimus*, *Salmo okumusi*, and *Salmo plathycephalus* trout species found in the streams of the Ceyhan, Euphrates, and Seyhan basins, respectively (Figure 1 and Figure 2). The research was conducted between April 2014 and June 2016. Fish samples were collected using electro-shocker, cast nets, and gill nets. In this context; n: 19 *S. okumusi*, n: 15 *S. opimus* and n: 19 *S. plathycephalus* samples were caught. The captured specimens were preserved in a 4% formaldehyde solution and transported to the laboratory for further analysis. The length measurements of the fish were performed using a digital caliper with a precision of 0.01 mm.

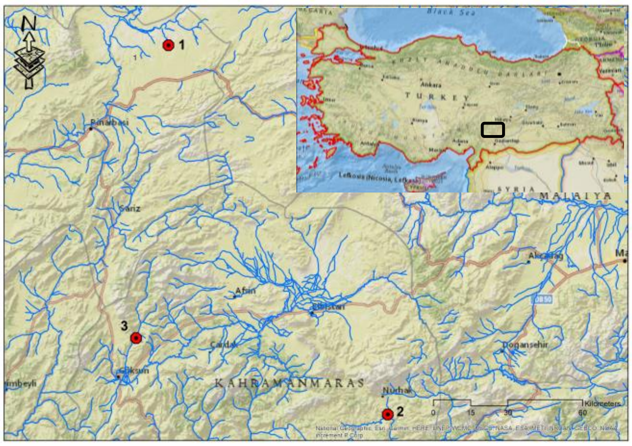

Figure 1. Localities of trout specimens: (1) Upper Seyhan River (Zamantı Stream, Şerefiye), (2) Upper Euphrates (Nurhak, Eskiköy), and (3) Upper Ceyhan River (Kömür Stream)

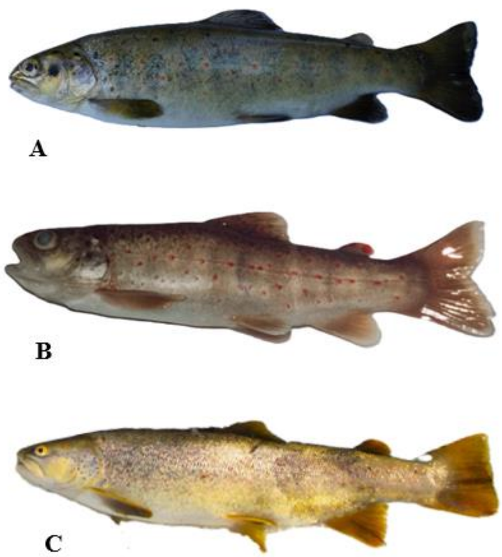

Figure 2. (A) *Salmo opimus* specimen from Kömür Stream, Ceyhan River; (B) *Salmo okumusi* specimen from Upper Euphrates River, Nurhak (Eskiköy, Kahramanmaraş); (C) *Salmo plathycephalus* specimen from Zamantı Stream, Seyhan River (Şerefiye)

Morphometric and Meristic Traits

In the laboratory, a total of 25 morphometric measurements and 24 meristic counts were recorded for each fish (Figure 3, Table 1).

Morphometric measurements were taken from the left lateral aspect and measured to the nearest 0.01 mm using a digital caliper. All meristic characters were counted twice on the same day by the same observer to ensure accuracy. Descriptive statistics of the morphometric and meristic characteristics of the sampled fish are presented in Table 2 and Table 3, respectively.

Table 1. Morphometric and meristic traits analyzed in this study

Morphometric traits (mm)		Meristic traits	
Trait	Acronym	Trait	Acronym
Upper jaw depth	X1	Operculum, black spot; big	Y1
Snout length	X2	Operculum, black spot; small	Y2
Orbital diameter(horizontal)	X3	Red color on the adipose	Y3
Head depth	X4	Red spots on line lateral	Y4
Orbital diameter(vertical)	X5	Red spots on the line lateral dorsal	Y5
Length of maxilla	X6	Red spots on the line lateral ventral	Y6
Upper jaw length	X7	Pyloric ceaca	Y7
Lower jaw length	X8	Gill rakers	Y8
Pectoral fin length	X9	Lingual teeth	Y9
Body depth (dorsal fin)	X10	Lower jaw teeth	Y10
Dorsal fin length	X11	Upper jaw teeth	Y11
Pelvic fin length	X12	Maxilla teeth	Y12
Body depth (anal fin)	X13	Number of red spots on the dorsal fin.	Y13
Adipose fin length	X14	Line lateral scales	Y14
Anal fin length	X15	Line lateral dorsal scales	Y15
Caudal peduncel length	X16	Line lateral abdomen scales	Y16
Caudal pedeuncle depth	X17	Dorsal fin (spine)	Y17
Length of upper caudal fin lope	X18	Dorsal fin (soft)	Y18
Length of middle caudal fin ray	X19	Anal fin (spine)	Y19
Length of lower caudal fin lobe	X20	Anal fin (soft)	Y20
Predorsal length	X21	Caudal fin	Y21
Head length	X22	Pelvic fin(spine)	Y22
Premaxilla length	X23	Pelvic fin(soft)	Y23
Prepelcic length	X24	Pectoral fin (soft)	Y24
Preanal length	X25		

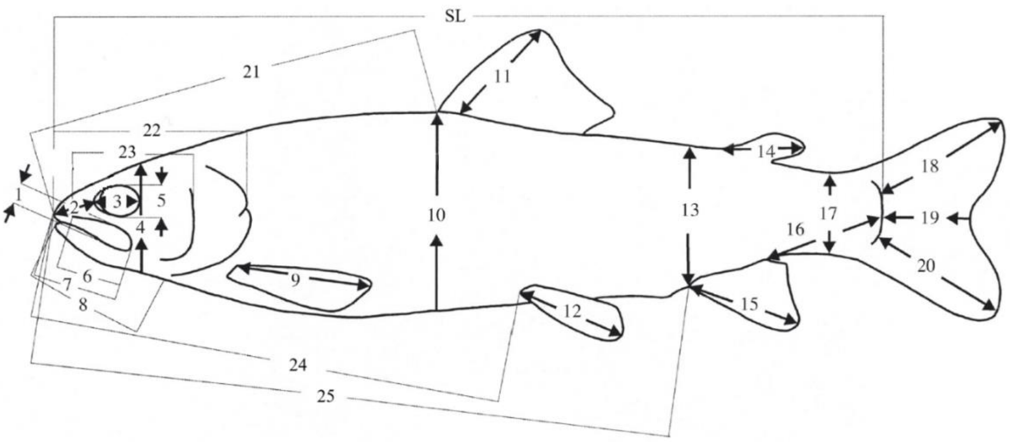

Figure 3. Measurements taken on Salmo specimens

1: upper jaw depth, as largest depth of the maxilla and supramaxilla; **2:** snout length, from symphysis of premaxilla to osseous orbit margin; **3:** orbital horizontal diameter, between osseous orbital margin; **4:** head depth, just posterior to orbit; **5:** orbital vertical diameter, between osseous orbital margin; 6: length of maxilla, from premaxillad end to posterior end of maxilla; **7:** upper jaw length, from symphysis of premaxilla to posterior end of maxilla; **8:** lower jaw length, from symphysis of dentary to retroarticulare; **9:** pectoral fin length, from base of first ray to tip of longest ray; **10:** body depth, at level of origin of dorsal fin; **11:** dorsal fin length, from base to tip of longest ray; **12:** pelvic fin length, from base of first ray to tip of longest ray; **13:** body depth, at level of origin of anal fin; **14:** adipose fin length, from origin to tip; **15:** anal fin length, from base of first ray to tip of longest ray; **16:** caudal peduncle length, from end of anal fin to middle base of caudal fin; **17:** least depth of caudal peduncle; **18:** length of upper caudal fin lobe, from base to tip of longest ray; **19:** length of middle caudal fin ray, from base to tip of shortest ray; **20:** length of lower caudal fin lobe, from base to tip of longest ray; **21:** predorsal length from upper jaw symphysis to origin of dorsal fin; **22:** head length, from upper jaw symphysis to posterior tip of operculum; **23:** premaxilla to preoperculum length, from premaxilla end of maxilla to posterior margin of preoperculum; **24:** prepelvic length, from upper jaw symphysis to origin of pelvic fin; **25:** preanal length, from upper jaw symphysis to origin of anal fin; **SL:** standard length (SL), from upper jaw symphysis to middle base of caudal fin (Modified from Delling, 2002)

Table 2. Descriptive statistics of the morphometric characteristics of the sampled fish

		X1		X6		X11		X16		X21	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	4.72	0.63	10.68	1.34	22.96	2.72	24.43	3.42	53.42	7.41
S. opimus	15	3.77	0.77	9.63	1.19	20.11	3.34	20.27	3.41	50.28	14.01
S. plathycephalus	19	12.22	1.58	22.24	2.11	42.44	5.52	51.39	7.93	121.25	12.40
		X2		X7		X12		X17		X22	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	8.24	1.55	14.61	1.79	17.84	2.28	13.28	1.80	31.50	3.69
S. opimus	15	6.45	0.95	12.45	1.90	22.20	23.59	11.32	1.66	27.67	3.84
S. plathycephalus	19	19.13	2.03	32.05	3.08	36.78	3.13	28.51	2.63	65.73	5.44
		X3		X8		X13		X18		X23	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	7.19	0.61	16.56	2.10	21.95	3.39	20.15	2.62	23.37	2.88
S. opimus	15	6.56	0.37	14.86	2.76	18.92	3.58	16.12	2.27	20.09	2.86
S. plathycephalus	19	11.50	0.82	37.58	4.04	51.38	5.63	38.08	3.22	50.28	4.17
		X4		X9		X14		X19		X24	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	16.68	2.30	24.57	2.64	11.36	1.58	12.09	1.38	63.50	8.05
S. opimus	15	15.72	2.51	21.47	2.54	8.93	1.84	10.24	1.30	51.63	13.54
S. plathycephalus	19	34.15	3.60	47.71	3.92	22.66	3.84	26.31	2.63	140.62	12.09
		X5		X10		X15		X20		X25	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	6.86	0.70	28.71	4.21	20.11	2.49	20.31	2.57	86.36	10.88
S. opimus	15	6.06	0.46	25.75	4.70	16.71	2.30	15.84	2.00	76.08	11.92
S. plathycephalus	19	10.23	0.93	69.94	8.71	41.78	4.29	37.09	2.90	196.95	19.47

Table 3. Descriptive statistics of the meristic characteristics of the sampled fish

		Y1		Y7		Y13		Y19	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	1.00	0.00	23.42	1.61	14.95	1.54	2.00	0.00
S. opimus	15	1.00	0.00	26.67	4.81	0.00	0.00	3.00	0.00
S. plathycephalus	19	0.00	0.00	27.95	4.47	0.00	0.00	2.84	0.37
		Y2		Y8		Y14		Y20	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	9.26	1.52	18.89	0.32	118.68	1.42	8.89	0.46
S. opimus	15	10.73	1.49	17.80	1.70	116.93	4.62	8.33	0.49
S. plathycephalus	19	19.05	1.35	23.84	1.07	114.32	3.02	8.68	0.75
		Y3		Y9		Y15		Y21	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	4.00	0.00	8.00	0.00	24.11	1.24	21.89	0.32
S. opimus	15	0.00	0.00	8.00	0.00	28.33	2.72	22.00	0.00
S. plathycephalus	19	0.00	0.00	9.26	0.99	19.68	1.60	20.21	0.63
		Y4		Y10		Y16		Y22	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	12.95	1.51	16.26	0.81	20.21	1.81	1.00	0.00
S. opimus	15	6.60	2.35	16.20	0.41	19.87	2.13	1.47	0.52
S. plathycephalus	19	0.00	0.00	23.37	1.07	18.63	1.26	1.00	0.00
		Y5		Y11		Y17		Y23	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	15.26	5.13	60.42	3.53	3.00	0.00	7.89	0.32
S. opimus	15	16.27	7.30	59.67	2.02	3.00	0.00	7.80	0.56
S. plathycephalus	19	0.00	0.00	66.05	5.22	3.00	0.00	7.89	0.32
		Y6		Y12		Y18		Y24	
	n	Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD
S. okumusi	19	15.53	3.94	11.00	1.29	10.11	0.57	11.79	0.42
S. opimus	15	14.33	3.62	11.00	1.51	10.13	0.64	11.20	1.01
S. plathycephalus	19	0.00	0.00	10.11	0.99	11.47	0.70	11.89	0.32

Morphometric and Meristic Traits

Because fish exhibit allometric growth, a common issue with morphometric data is the high correlation of all measurements with length. To analyze fish shape independently of size, it is necessary to remove the size factor from the data. In this study, the Random Forest model was used as the statistical method. Unlike linear models, which can suffer from multicollinearity, Random Forest effectively handles correlated features (Thakur 2020). Additionally, to minimize errors arising from differences in fish size, all morphometric measurements taken from each specimen were standardized by their standard length (SL). All statistical analyses were conducted using R (R Core Team, 2025).

RESULTS

Figure 4 and Figure 5 illustrate the interspecies morphological differences in terms of morphometric and meristic characteristics, respectively, using t-Distributed Stochastic Neighbor Embedding (t-SNE) with Random Forest embeddings. These figures provide a two-dimensional visualization of the differentiation among species based on their metric and meristic traits.

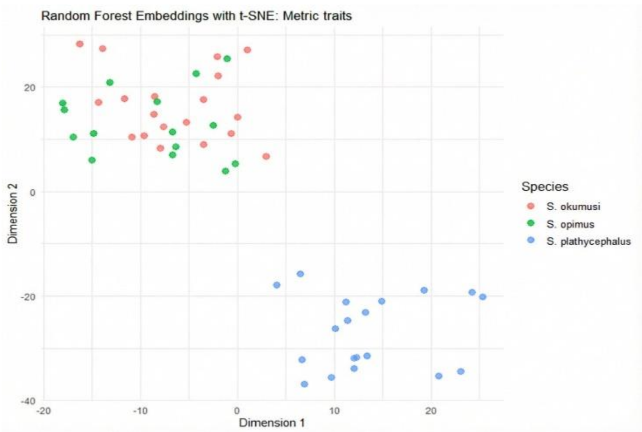

Figure 4. Differentiation of species based on morphometric (metric) characteristics

In terms of morphometric characteristics, *S. plathycephalus* individuals are distinctly clustered separately from the other two species in the Dimension 1 and Dimension 2 space (Figure 4). This indicates that *S. plathycephalus* possesses a significantly different morphometric profile compared to *S. okumusi* and *S. opimus*. However, no clear distinction is observed between *S. okumusi* and *S. opimus*, suggesting that these species may share common phenotypic traits or that the analyzed characteristics may not be sufficient to differentiate them.

Conversely, *S. okumusi*, *S. opimus*, and *S. plathycephalus* exhibit distinct structural differences in meristic characteristics (Figure 4). The pronounced differentiation among species in terms of meristic traits suggests that these features may play a crucial role in biological classification.

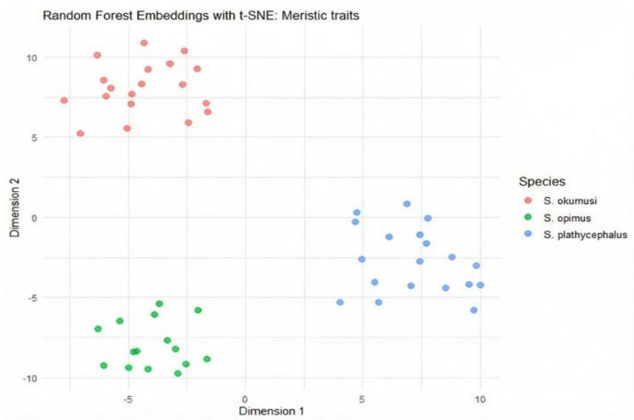

Figure 5. Differentiation of species based on meristic traits

Figures 6 and Figure 7 present the relative importance of variables influencing interspecies differentiation for morphometric and meristic characteristics, respectively, using the Mean Decrease Gini metric from the Random Forest model. A higher Gini value indicates that the corresponding variable contributes more significantly to the decision tree splits, thereby improving the model's predictive performance.

For morphometric characteristics, the variable X3 (Orbital diameter horizontal) has the highest Gini value, making it the most critical feature for species differentiation. X9 (Pectoral fin length) and X5 (Orbital diameter vertical) rank second and third, respectively, highlighting their significant roles in interspecies differentiation. On the other hand, X19 (Length of middle caudal fin lobe) has the lowest Mean Decrease Gini value, suggesting that this trait has a limited impact on distinguishing the species (Figure 6).

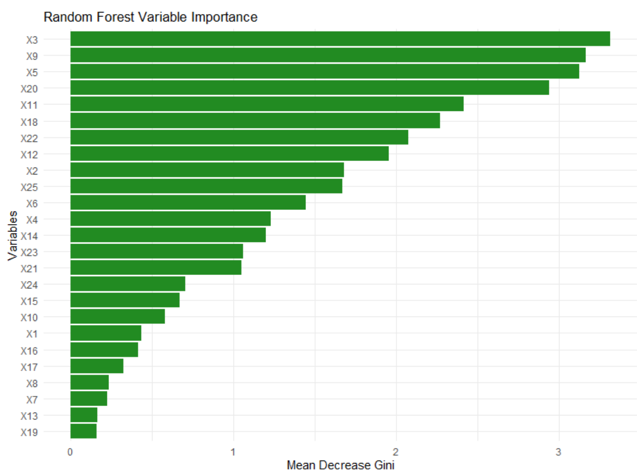

Figure 6. Importance rankings of features influencing species differentiation based on morphometric characteristics

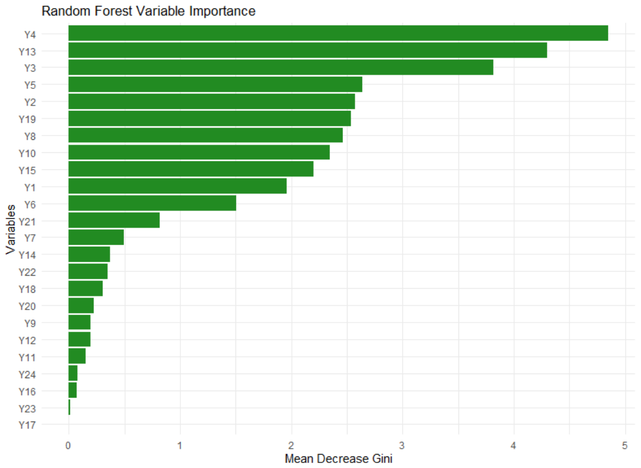

Figure 7. Importance rankings of features influencing species differentiation based on meristic traits

DISCUSSION

In this study, the morphometric and meristic differences among the endangered species *S. opimus* and *S. plathycephalus*, as well as *S. okumusi*, were examined in detail. The obtained data indicate that *S. plathycephalus* is distinctly separated from the other two species in terms of morphometric characteristics. For instance, significantly higher measurements of predorsal length (X21), head length (X22), prepelvic length (X25), body height (X10), and adipose fin length (X14) suggest that this species possesses a larger and structurally different morphology. These findings support the morphological variations observed in the Ceyhan and Seyhan basins, as reported by Alp et al. (2003) and Kara and Alp (2004).

On the other hand, while *S. okumusi* and *S. opimus* generally exhibit similar morphometric traits, certain parameters, such as X5 (orbital diameter vertical), X9 (pectoral fin length), X15 (anal fin length), and X20 (caudal fin lower lobe length), indicate partial phenotypic differentiation between these two species. This finding is consistent with the morphological similarities reported by Turan et al. (2012) and also suggests that the selected metrics might have limited power in distinguishing these two species. Additionally, the identification of X3 (orbital diameter horizontal) as the most critical parameter in species differentiation, based on its highest Mean Decrease Gini value in the Random Forest analysis, underscores the importance of morphometric characteristics in taxonomic classification (Turan et al., 2024).

Regarding meristic traits, the effects of habitat differences on morphological adaptation become evident. While red spots on the body, prominent black parr marks on the operculum, and vibrant color patterns on the dorsal fins were observed in specimens from the Ceyhan and Euphrates basins, *S. plathycephalus* individuals from the Seyhan basin exhibited less distinct spotting and more irregular color distribution. Notably, the presence of one or two red spots (parr) on the adipose fin of *S. okumusi* specimens from the Euphrates basin suggests a connection between environmental factors and the species' adaptive responses (Kara et al., 2011a; Kara et al., 2011b).

These morphological differences highlight the influence of physical and chemical properties of trout ecosystems such as water temperature, flow rate, and habitat structure in shaping species' morphology. As noted by Balık (1988) and Dorofeeva et al. (1986), these environmental factors can result in variations in growth rates, pigmentation patterns, and fin morphology. Additionally, Sušnik et al. (2004) reported that environmental pressures in specific habitats shape the adaptive morphological traits of species, influencing their ecological niche differentiation.

Furthermore, trout farming activities in the study areas and the introduction of non-native species like Oncorhynchus mykiss into natural populations may negatively impact local genetic structure and morphological diversity. As highlighted by Kara and Alp (2005) and Geldiay and Balık (2009), such genetic admixture is one of the critical factors disrupting adaptation processes in native species and complicating conservation efforts. Additionally, the recent proliferation of hydroelectric power plants (HPPs) without sufficient consideration of environmental impacts has led to habitat degradation, posing a serious threat to the sustainability of natural trout populations (Alp et al., 2020).

CONCLUSION

The present study's findings clearly demonstrate significant morphometric and meristic differentiation among the three endemic trout species *S. opimus*, *S. platycephalus*, and *S. okumusi*. Notably, *S. plathycephalus* exhibits a distinctly larger and different morphometric profile setting it apart from the other two trout. These pronounced phenotypic distinctions have important taxonomic and evolutionary implications. They affirm that each population represents a distinct species, highlighting the utility of detailed morphometric and meristic data in trout classification. The variation in traits across different river basins also underscores the role of environmental adaptation in driving divergence; for example, *S. plathycephalus* in the Seyhan basin shows reduced red spotting and more irregular coloration compared to the more vividly spotted *S. opimus* and *S. okumusi* from the Ceyhan and Euphrates basins. Such patterns are consistent with the notion that local habitat conditions (e.g. water temperature, flow rate, and habitat structure) can shape phenotypic traits over time, as observed in other trout populations. Therefore, the study indicates that species differences arise from an interplay of genetic lineage and adaptive responses to unique environmental pressures in each habitat. Recognizing this environmental influence is crucial for taxonomy and conservation, since it suggests that preserving the distinct habitats of each trout is integral to maintaining their phenotypic and genetic identity.

From a conservation perspective, delineating these species' unique characteristics is essential for guiding management efforts. Both *S. opimus* and *S. platycephalus* are currently listed as Endangered (EN) and have suffered severe population declines largely due to overfishing and habitat degradation. *S. okumusi*, while not yet officially Red-Listed, has similarly experienced drastic declines, prompting a complete fishing ban to prevent its extinction. The insights from this study provide a valuable scientific basis for developing targeted conservation strategies and sustainable management plans for each species. In practice, this means that management can be tailored to each trout's specific needs and vulnerabilities for instance, protecting the cold, upper stream habitats that *S. opimus* requires, or enforcing stricter fishing and habitat restoration measures in the Seyhan River for *S. platycephalus*. Mitigating anthropogenic threats is also a high priority: measures such as enforcing fishing regulations, preventing genetic introgression from non-native trout (e.g. hatchery-reared *O. mykiss*), and curbing environmentally destructive activities (like unregulated hydropower development) are vital for the long term survival of these trout populations. By addressing these threats and incorporating the species specific knowledge of morphological and ecological requirements, conservation efforts can more effectively halt declines and promote recovery. Finally, the study highlights the need for continued research to support and refine these conservation initiatives. High priority should be given to genetic studies detailed molecular analyses can clarify the genetic differentiation and diversity among *S. opimus*, *S. platycephalus*, and *S. okumusi* which would complement the morphological evidence and inform management of their genetic resources. Such analyses could detect hidden structure among populations or identify any hybridization and introgression from introduced trout, an issue already flagged as a risk to the genetic integrity of native stocks. Equally important is research focused on habitat conservation and monitoring: long-term ecological studies should examine how habitat restoration, improved water quality, and protection of critical headwater spawning grounds affect population trends and adaptive traits over time. This will help evaluate the effectiveness of conservation actions and allow adaptive management as environmental conditions change. In summary, a multidisciplinary approach that integrates morphology, genetics, and ecology is essential for understanding the adaptive processes shaping these endangered trout and for guiding effective conservation strategies to ensure their persistence in native Anatolian waters.

ACKNOWLEDGEMENTS

This research was supported by the Kahramanmaraş Sütçü İmam University Scientific Research Projects (BAP) Coordination Unit, Project No. 2014/1-16 M, and was carried out with the legal consent of the Ministry of Food, Agriculture, and Livestock, General Directorate of Fisheries and Aquaculture (permission date 03.04.2014; permission number: 01334). We thank the pertinent institutions on behalf of the authors. We would also like to thank Biologist Ali Kuzhan for his help in field studies.

COMPLIANCE WITH ETHICAL STANDARDS

Authors' Contributions

The study was conceived and designed by Cemil Kara and Mehmet Fatih Can. Cemil Kara and Mehmet Fatih Can were in charge of collecting data and conducting research. The manuscript was drafted by Cemil Kara and Mehmet Fatih Can. The manuscript was reviewed and revised by Cemil Kara and Mehmet Fatih Can. The final manuscript was read and approved by all authors.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

Ethical Approval

In this study; it was found "appropriate" by Kahramanmaraş Sütçü İmam University, Faculty of Agriculture Animal Experiments Local Ethics Committee (KSÜZİRHADYEK) with the decision dated 28.02.2014 and numbered 2014/1.

Funding

This work was supported by Kahramanmaraş Sütçü İmam University Scientific Research Projects (BAP) Coordination Unit, Project Number: 2014/1-16 M.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon request.

AI Disclosure

Generative AI was not used in this research paper.

REFERENCES

Alp, A., Kara, C. E. M. İ. L., & Büyükçapar, H. M. (2003). Reproductive biology of brown trout, *Salmo trutta macrostigma* Dumeril 1858, in a tributary of the Ceyhan River which flows into the eastern Mediterranean Sea. *Journal of Applied Ichthyology*, 19(6), 346-351. https://doi.org/10.1111/j.1439-0426.2003.00455.x

Alp, A., & Kara, C. (2004). Length, weight and condition factors of the native brown trouts (*Salmo trutta macrostigma* Dumeril, 1858 and *Salmo platycephalus* Behnke, 1968) in the Ceyhan, Seyhan and Euphrates basins. *Ege Journal of Fisheries and Aquatic Sciences*, 21(1-2), 9-15. (In Turkish)

Alp, A., Akyüz, A., Özcan, M., & Yerli, S. (2020). Efficiency and suitability of the fish passages of River Ceyhan, Turkey. *Journal of Limnology and Freshwater Fisheries Research*, 6(1), 1-13. https://doi.org/10.17216/LimnoFish.618924

Behnke, R. J. (1968). A new subgenus and species of trout, *Salmo (Platysalmo) platycephalus*, from southcentral Turkey, with comments on the classification of the subfamily Salmoninae. *Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut*, 66, 1-15.

Balık, S. (1988). Systematic and zoogeographic investigations on inland water fishes of the Mediterranean Region of Turkey. *Turkish Journal of Zoology*, 2, 156-179.

Delling, B. (2002). Morphological distinction of the marble trout, *Salmo marmoratus*, in comparison to marbled Salmo trutta from River Otra, Norway. *Cybium*, 26(4), 283-300.

Dorofeeva, E. A., Vukovich, T., & Kosorich, D. (1986). Morphological features of mediterranean Trouts as Related to their Position in the polimorphic species *Salmo trutta* L. (Salmonidae). *Morphological Ecology of Fishes*, 154, 66-75.

Freyhof, J. (2019a). *Salmo opimus*. The IUCN Red List of Threatened Species 2019: e.T19516862A19849331. https://.doi.org/10.2305/IUCN.UK.2019-

Freyhof, J. (2019b). *Salmo platycephalus*. The IUCN Red List of Threatened Species 2019: e.T19854A19849937. https://dx.doi.org/10.2305/IUCN.UK.2019-

Geldiay, R., & Balık, S. (1999). *Türkiye Tatlısu Balıkları (Freshwater fishes of Turkey)*. Ege Üniversitesi Su Ürünleri Fakültesi Yayınları, No: 46, Ders Kitabı Dizini, No:16, Izmir, 519 pp. (in Turkish). https://doi.org/10.13140/2.1.3034.0160

Kara, C., Alp, A., & Gürlek, M. E. (2011a) Morphological variations of the trouts (*Salmo trutta* and *Salmo platycephalus*) in the rivers of Ceyhan, Seyhan and Euphrates, Turkey, *Turkish Journal of Fisheries and Aquatic Sciences*, 11(1), 77-85. https://doi.org/10.4194/trjfas.2011.0111

Kara, C., Alp, A., & Can, M. F. (2011b). Growth and Reproductive Properties of Flathead Trout (*Salmo platycephalus* Bhenke, 1968) Population from Zamantı Stream, Seyhan River, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, 11, 367-375; https://doi.org/10.4194/1303-2712-v11_3_05

Kara, C., & Alp, A. (2005). Feeding habits and diet composition of brown trout (*Salmo trutta*) in the upper streams of River Ceyhan and River Euphrates in Turkey. *Turkish Journal of Veterinary & Animal Sciences*, 29(2), 417-428.

Kara, C., & Bozali, N. (2024). Some morphometric characteristics of *Alburnus caeruleus* (Heckel, 1843) in Adıyaman region, Türkiye. *Marine and Life Sciences*, 6(2), 96-100. https://doi.org/10.51756/marlife.1519973

Kaya, C. (2020) The first record and origin of *Salmo trutta* populations established in the upper Tigris river and Lake Van basin (Teleostei: Salmonidae). *Journal of Anatolian Environmental and Animal Sciences*, 5(3), 366-372. https://doi.org/10.35229/jaes.777575v

Noroozi, J., Zare, G., Sherafati, M., Mahmoodi, M., Moser, D., Asgarpour, Z., & Schneeweiss, G. M. (2019). Patterns of endemism in Turkey, the meeting point of three global biodiversity hotspots, based on three diverse families of vascular plants. *Frontiers in Ecology and Evolution*, 7, 159. https://doi.org/10.3389/fevo.2019.00159

R Core Team. (2025) R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.r-project.org/

Sušnik, S., Schöffmann, J., & Snoj, A. (2004). Phylogenetic position of *Salmo (Platysalmo) platycephalus* Behnke 1968 from south-central Turkey, evidenced by genetic data. *Journal of Fish Biology*, 64(4), 947-960. https://doi.org/10.1111/j.1095-8649.2004.0363.x

Şekercioğlu, Ç. H., Anderson, S., Akçay, E., Bilgin, R., Can, Ö. E., Semiz, G., Tavşanoğlu, Ç., Yokes, M. B., Soyumert, A., İpekdal, K., Sağ, İ. K., Yücel, M., & Dalfes, H. N. (2011). Turkey's globally important biodiversity in crisis. *Biological Conservation*, 144(12), 2752-2769. https://doi.org/10.1016/j.biocon.2011.06.025

Thakur, A. (2020). *Approaching (almost) any machine learning problem*. Abhishek Thakur.

Turan, D., Kottelat, M., & Engin, S. (2010). Two new species of trouts, resident and migratory, sympatric in streams of northern Anatolia (Salmoniformes: Salmonidae). *Ichthyological Exploration of Freshwaters*, 20(4), 333-364.

Turan, D., Kottelat, M., & Bektas, Y. (2011). *Salmo tigridis*, a new species of trout from the Tigris River, Turkey(Teleostei: Salmonidae). *Zootaxa*, 2993(1), 23-33. https://doi.org/10.11646/zootaxa.2993.1.2

Turan, D., Kottelat, M., & Engin, S. (2012). The trouts of the Mediterranean drainages of southern Anatolia, Turkey, with description of three new species (Teleostei: Salmonidae). *Ichthyological Exploration of Freshwaters*, 23(3), 219-236.

Turan, D., Kottelat, M., & Kaya, C. (2017). *Salmo munzuricus*, a new species of trout from the Euphrates River drainage, Turkey (Teleostei: Salmonidae). *Ichthyological Exploration of Freshwaters*, 28(1), 55-63.

Turan, D., Kalaycı, G., Bektaş, Y., Kaya, C., & Bayçelebi, E. (2020). A new species of trout from the northern drainages of Euphrates River, Turkey (Salmoniformes: Salmonidae). *Journal of Fish Biology*, 96(6), 1454-1462. https://doi.org/10.1111/jfb.14321

Turan, D., Aksu, İ., Oral, M., Kaya, C., & Bayçelebi, E. (2021) Contribution to the trout of Euphrates River, with description of a new species, and range extension of *Salmo munzuricus* (Salmoniformes, Salmonidae). *Zoosystematics and Evolution*, 97(2), 471-482. https://doi.org/10.3897/zse.97.72181

Turan, D., Kottelat, M., & Kaya, C. (2022). The trouts of the upper Kura and Aras rivers in Turkey, with description of three new species (Teleostei: Salmonidae). *Zootaxa*, 5150(1), 43-64. https://doi.org/10.11646/zootaxa.5150.1.2

Turan, D., Bayçelebi, E., Aksu, S., & Oral, M. (2024). The trouts of the Marmara and Aegean Sea drainages in Türkiye, with the description of a new species (Teleostei, Salmonidae). *Zoosystematics and Evolution*, 100(1), 87-99. https://doi.org/10.3897/zse.100.112557

Turan, D., Kottelat, M., & Engin, S. (2014). Two new species of trouts from the Euphrates drainage, Turkey (Teleostei: Salmonidae). *Ichthyological Exploration of Freshwaters*, 24(3), 275-287.