Journal of Anatolian Environmental and Animal Sciences
(*Anadolu Çevre ve Hayvancılık Bilimleri Dergisi*)
DOI: https://doi.org/10.35229/jaes.1766787

JAES
Year: 10, No: 6, 2025 (838-843)
AÇEH
Yıl: 10, Sayı: 6, 2025 (838-843)

ARAŞTIRMA MAKALESİ RESEARCH PAPER

Effects of Toxic and Essential Heavy Metals in *Chelon auratus* (Risso, 1810) Muscles on Human Health

Elif ARICI[1]* **Levent BAT[2]**
[1]*Vocational School of Health Services, University of Sinop, Türkiye*
[2]*Department of Hydrobiology, Fisheries Faculty, University of Sinop, Türkiye*

Received: *16.08.2025* ***Accepted:*** *27.10.2025* ***Published:*** *30.11.2025*

How to cite: **Arıcı, E., & Bat, L. (2025).** Effects of Toxic and Essential Heavy Metals in *Chelon auratus* (Risso, 1810) Muscles on Human Health. *J. Anatol. Env. Anim. Sci.*, ***10***(6), 838-843. https://doi.org/10.35229/jaes.1766787

Atıf yapmak için: **Arıcı, E., & Bat, L. (2025).** *Chelon auratus* (Risso, 1810) Kaslarındaki Toksik ve Esansiyel Ağır Metallerin İnsan Sağlığı Üzerindeki Etkileri. *Anadolu Çev. ve Hay. Dergisi*, ***10***(6), 838-843. https://doi.org/10.35229/jaes.1766787

*: https://orcid.org/0000-0001-6359-9194
: https://orcid.org/0000-0002-2289-6691

***Corresponding author's:**
Elif ARICI
Vocational School of Health Services,
University of Sinop, Türkiye
: earici@sinop.edu.tr

Abstract: The purpose of the present study was to investigate the levels of toxic (Pb, Hg, Cd) and essential (Cu, Zn) heavy metals in the edible tissues of *Chelon auratus* (Risso, 1810) purchased from fish markets in Sinop in October, November, and December 2023. In the muscle tissue of the fish, essential metals were found at much higher concentrations than toxic ones. Among the three toxic metals, Pb had the highest concentration, while Cd had the lowest. The concentrations of toxic metals in *C. auratus* tissues were below the maximum acceptable limits; the target hazard quotient values for Hg, Cd, Cu, and Zn were below 1, and the risk index for Pb was 0.21. In conclusion, the golden grey mullet is considered safe for human consumption.

Keywords: Black Sea, golden grey mullet, health risk index, sinop fish market.

Chelon auratus (Risso, 1810) Kaslarındaki Toksik ve Esansiyel Ağır Metallerin İnsan Sağlığı Üzerindeki Etkileri

***Sorumlu yazar:**
Elif ARICI
Sinop Üniversitesi Sağlık Hizmetleri Meslek Yüksekokulu, Türkiye
: earici@sinop.edu.tr

Öz: Bu çalışmanın amacı, 2023 yılı Ekim, Kasım ve Aralık aylarında Sinop'taki balık pazarlarından temin edilen *Chelon auratus* (Risso, 1810) türünün yenilebilir dokularındaki toksik (Pb, Hg, Cd) ve esansiyel (Cu, Zn) ağır metal düzeylerini araştırmaktır. Balık kas dokusunda, esansiyel metallerin derişimleri toksik metallere kıyasla çok daha yüksek bulunmuştur. Üç toksik metal arasında Pb en yüksek, Cd ise en düşük derişime sahip olmuştur. *C. auratus* dokularındaki toksik metal derişimleri, kabul edilebilir maksimum sınırların altında kalmış; Hg, Cd, Cu ve Zn için hedef tehlike katsayısı değerleri 1'in altında, Pb için ise risk indeksi 0,21 olarak belirlenmiştir. Sonuç olarak, altın kefal türü insan tüketimi için güvenli kabul edilmektedir.

Anahtar Kelimeler: Altın kefal, karadeniz, sağlık risk indeksi, sinop balık pazarı.

INTRODUCTION

The existence of environmental contaminants, particularly heavy metals, in marine ecosystems is one of the major issues today. Aquatic organisms, including fish, can accumulate metals from water, sediments, and especially through the food chain (Bat & Arıcı, 2018; Pashtiri et al. 2025). Metals such as copper and zinc are essential components of living organisms and play important roles in various biochemical processes. However, when their concentrations are elevated, these metals can become toxic. The feeding habits of fish species have a significant impact on the accumulation of heavy metals. Toxic heavy metals, such as mercury, lead, and cadmium, can accumulate in fish tissues and may be passed on to humans through consumption. This process, known as biomagnification, occurs when smaller aquatic organisms consume algae or other plants that have absorbed heavy metals from the water; these metals are then passed on to larger predatory species as the smaller organisms are eaten.

Human exposure to heavy metals through the consumption of contaminated fish and other seafood can lead to a range of health effects, depending on the specific metal and the level of exposure. For example, mercury and lead can affect the nervous system, causing behavioural and cognitive changes. Cadmium can impair reproduction and development in humans, and it is also a known carcinogen that may increase the risk of cancer. Lead has been linked to

[*] *This study was produced from the master thesis.*

adverse effects on the cardiovascular system (FAO/WHO, 2011).

Risk analysis is a tool used to assess the potential risks of human exposure to heavy metals through seafood consumption. This process involves evaluating the concentrations of heavy metals in seafood, estimating consumption rates, and assessing the potential health effects associated with exposure. Risk analysis can help identify populations at higher risk of heavy metal exposure and inform the development of risk management strategies, such as setting guidelines for safe levels of heavy metal intake.

Many health organizations, such as the U.S. Environmental Protection Agency (EPA) and the Risk Assessment Information System (RAIS), have developed fish consumption guidelines that recommend safe species and quantities for consumption. These guidelines consider the levels of toxic metals in different fish species and the potential health effects associated with exposure to these substances (RAIS, 2024; USEPA, 2024).

The Black Sea is a large, semi-enclosed marine ecosystem that has been affected by various human activities, including pollution. Due to its semi-enclosed nature, limited water exchange with the Mediterranean, and the inflow of pollutant-loaded rivers such as the Danube, Dniester, and Sakarya, the Black Sea is particularly vulnerable to the accumulation of contaminants, including heavy metals. Such pollution can negatively impact aquatic organisms in the Black Sea, including fish (Bat et al., 2018).

The golden grey mullet (*Chelon auratus*) is a commercially important species in the Black Sea, where it is widely consumed in coastal regions. It is recognized as one of the major resources for Turkish fisheries (Kesiktaş et al., 2020). However, official catch statistics for *C. auratus* in Türkiye are not available; the species is often grouped under "grey mullet" in national statistics. The catches of grey mullets (including *C. auratus*) were estimated to have decreased from approximately 1 721 tons in 2014 to 1 445 tons in 2024 in Türkiye (Kartal et al., 2025, TÜİK 2025). The species contributes to both artisanal and commercial fisheries, particularly along the Turkish Black Sea coast, which accounts for approximately 70–80% of Turkey's total marine capture production. The present study aims to determine the levels of essential and toxic heavy metals in the muscle tissue of golden grey mullet caught in the Black Sea and sold in Sinop markets, compare them with the values permitted by national and international organizations, and assess whether they pose a risk to human health.

MATERIAL AND METHOD

In October, November, and December 2023, a total of fifteen golden grey mullets were purchased from the Sinop fish market. The mean length and weight of *C. auratus* were 31 ± 3 cm and 290 ± 14 g, respectively (Figure 1).

Spawning period of *Chelon* sp. generally extends from July to November. Therefore, the October–December sampling period overlaps with the late spawning and early post-spawning phase, when metabolic activity, feeding intensity, and lipid content in fish tissues may vary. These biological factors can influence the bioaccumulation dynamics of metals in muscle tissue.

The samples were dissected to obtain dorsal muscle, which was then homogenized, immediately frozen, and stored at −21 °C until metal analysis.

Figure 1. Photograph of *Chelon auratus* (golden grey mullet).

All reagents used in the analysis were of reagent grade. Double-deionized water obtained using a Milli-Q system was used for all dilutions. Chemicals for microwave digestion (Milestone SK10), nitric acid (HNO_3, 65%), and hydrogen peroxide (H_2O_2, 30%) in a 7:1 ratio were of high-purity grade (Merck). Element standard solutions (Merck) used for calibrations were prepared by diluting stock solutions of 1000 mg L^{-1}. Metals were measured using an inductively coupled plasma mass spectrometer (ICP-MS, Agilent 7700X). Multi-element standard solutions provided by Agilent (27-element mixture: 8500-6940 2A and 8500-6940 Hg) were used to generate calibration curves. A 1 ppm internal standard (Agilent 5188-6525) was continuously analysed with the samples. All digested samples were analysed in triplicate for each metal. Results are expressed as mg kg^{-1} wet weight, calculated as the mean of these measurements. The limits of detection (LOD) were 0.001 µg L^{-1} for Cd and Pb, 0.01 µg L^{-1} for Hg and Zn, and 0.0001 µg L^{-1} for Cu. The limit of quantification (LOQ) was defined as three times the LOD (Figure 2).

Figure 2. Schematic representation of the analytical procedure for heavy metal determination in *C. auratus* muscle by ICP-MS.

Health risk assessment

Estimated daily intake (EDI): The Estimated Daily Intake (EDI) was calculated using the formula:

$$EDI = \frac{C \times FIR}{BW}$$

where C is the concentration of heavy metal in golden grey mullets' samples (mg kg^{-1}, wet weight), FIR is the daily fish ingestion rate (g day^{-1}). In this study, the average fish consumption rate (FIR) was assumed to be 19.72 g day^{-1} (0.01972 kg day^{-1}) for adults, based on national dietary data for Türkiye (Çöteli 2024), while the average body weight (BW) was considered to be 70 kg.

Non-carcinogenic health risk: The noncarcinogenic risk related to the consumption of golden grey mullets and its associated metals was evaluated using the target hazard quotient (THQ). The THQ formulation was given below:

$$THQ = \frac{EF \times ED \times FIR \times C}{RfD \times BW \times AT} \times 10^{-3}$$

where FIR is the food ingestion rate (g day^{-1}), ED is the exposure duration (70 years), C is the concentration of heavy metal in the golden grey mullets' samples (mg kg^{-1}, wet weight), EF is the exposure frequency (350 days per year), AT is the average exposure duration for non-carcinogens days for an adult, BW is the average body weight (kg) and RfD is the oral reference dose (mg kg^{-1} day^{-1}) for the metal, which was calculated in this study using the most recent data from the United States Environmental Protection Agency and the Risk Assessment Information System, respectively (USEPA, 2024; RAIS, 2024).

The Hazard Index (HI) is the sum of the THQs. If the HI is less than 1.0, there are no health concerns; however, an HI greater than 1.0 indicates the possibility of adverse effects.

The risk index (RI) is calculated using the following formula:

RI = EDI x SF

RI $<10^{-6}$ is considered insignificant, $10^{-6}<RI<10^{-4}$ is considered acceptable, and RI $> 10^{-4}$ is considered significant.

Statistical analysis: All fish samples were analysed in triplicate, and the results are expressed as the mean ± standard deviation. Statistical analyses were performed using Student's t-test for significance and analysis of variance (ANOVA) followed by Tukey's multiple comparison test to determine significant differences between means. A significance level of 0.05 was used for all tests.

RESULTS AND DISCUSSION

Chelon auratus is an important fish species in the Black Sea and is mostly caught from September to April, which is the commercial fishing season in Türkiye (Kartal et al. 2025). The species usually spawns between August and November (Kesiktaş et al. 2020). Therefore, the October–December sampling period overlaps with the end of the spawning season and the beginning of the post-spawning period. During this time, changes in feeding activity, energy use, and fat content in the fish may occur, and these factors can influence how heavy metals accumulate in their muscles.

Table 1 displays the accumulation of heavy metals in the edible tissues of golden grey mullet. The increasing order of heavy metals in *C. auratus* was: Cd < Pb < Hg < Cu < Zn. The concentration of Zn was significantly the highest ($p < 0.05$), followed by Cu. The current metal accumulation is thought to originate from the diet of the fish. *C. auratus* feed on small benthic organisms, detritus, and occasionally on insects and plankton (Froese & Pauly, 2025). Malvandi (2024) reported a correlation between mercury concentrations in the muscle and morphological parameters in *Chelon saliens*, but this relationship was not observed in *C. auratus*. In southern Caspian Sea, the average Hg concentration in the muscle was 39.51 µg g^{-1} dw, which is higher than the levels observed in the present study.

Cd is known to disrupt reproductive and developmental processes in humans and has been classified as a carcinogenic element associated with increased cancer risk. Pb, on the other hand, has been linked to various cardiovascular disorders (FAO/WHO, 2011). Similar observations were reported in the lagoons of Bizerte and Ghar El Melh in Tunisia, where *C. auratus* specimens exhibited elevated Cd accumulation (Ameur et al. 2025). Such contamination not only poses potential risks to human health through biomagnification but also indicates persistent environmental pollution that may adversely affect the ecological balance of the aquatic ecosystem.

Table 1. Concentrations of toxic and essential heavy metals in *C. auratus* muscle (wet weight basis).

	Heavy metal concentrations				
Months	**Pb (mg kg⁻¹)**	**Hg (mg kg⁻¹)**	**Cd (mg kg⁻¹)**	**Cu (mg kg⁻¹)**	**Zn (mg kg⁻¹)**
October	0.04±0.01	0.03±0.01	0.01±0.0	0.34±0.05	8.51±1.3
November	0.04±0.01	0.03±0.01	0.01±0.0	0.29±0.04	7.15±1.2
December	0.03±0.01	0.04±0.02	0.01±0.0	0.31±0.05	6.38±1.1

The latest regulations do not specify maximum acceptable values for essential metals. According to the Turkish Food Codex, the permitted limits for Cu and Zn are 30 and 50 mg kg^{-1} wet weight, respectively (Official Gazette of the Republic of Türkiye, 2002) and the concentrations measured in this study were well below these values. In the Caspian Sea, *C. auratus* samples collected from Guilan province had average concentrations of Cd (0.127 µg g^{-1}) and Pb (0.182 µg g^{-1}) in their muscle tissues. These values are similar to those found in the Black Sea samples. These results agree with this study, where essential metals like Cu and Zn were also found at higher levels than toxic ones (Pashtiri et al. 2025).

For toxic metals, the permissible limits for Pb, Hg, and Cd set by both international and national authorities are 0.3, 0.5, and 0.05 mg kg^{-1} wet weight, respectively (Official Journal of the European Union, 2006; Official Gazette of the Republic of Türkiye, 2002). In the present study, all measured concentrations of these toxic metals were substantially lower than the established safety thresholds, indicating minimal risk to consumers from *C. auratus* caught in the study area. In contrast, Bakhshalizadeh et al. (2022) reported Pb, Hg, and Cd concentrations in fish that exceeded the maximum levels permitted by the European Union in the southern Caspian Sea, suggesting significant regional variability in contamination.

The results of the studies conducted with mullet species in Sinop coasts (Bat et al., 2015; 2018b, 2022) are like the present study. Bat et al. (2015) found Cd, Hg, Pb, Cu and Zn in muscle tissues of golden grey mullet caught from Sinop coast at <0.02, <0.05, <0.05, <0.05, <0.05, <0.5 and 2.9 mg kg^{-1} wet weight, respectively.

In another study conducted along the coast of Sinop, the mean Pb, Hg, and Cd concentrations in the edible tissues of *C. auratus* were 0.061 ± 0.012, 0.034 ± 0.009, and 0.015 ± 0.008 mg kg^{-1} wet weight, respectively (Bat et al., 2018b).

Bat et al (2022) found that the toxic metals (Cd, Hg and Pb) detected in the muscle tissues of *M. cephalus* species in Sinop coasts in 11 years of data were quite low and did not pose any risk to consumers. Similar results obtained in the present study support these findings.

The relatively low concentrations of heavy metals in Sinop may be attributed not only to the absence of major industrial activities but also to the hydrodynamic and geographic characteristics of the Sinop coastline. The effective circulation and limited riverine input may help dilute trace metals, consistent with findings from other low-industrialized sectors of the Black Sea (Gurov and Kotelyanets 2022). The Sinop peninsula, located along the open waters of the Black Sea, is influenced by cyclonic circulation and strong vertical stratification, which together enhance dilution, limit fluvial inputs, and reduce contaminant accumulation in the coastal zone (Oğuz and Beşiktepe 1999). Metal pollution in this region primarily originates from domestic waste, port activities, and tourism. In addition, pollutants carried by small streams into the Sinop coast also contribute to this pollution (Bat et al. 2018a). Similar observations have been reported in other semi-enclosed or less industrialized coastal systems, such as the South Adriatic (Antović et al., 2019) and the southern Caspian Sea (Bakhshalizadeh et al., 2022; Malvandi, 2024), where hydrological and trophic factors play a key role in modulating metal accumulation in fish.

According to the data given in Table 2, the estimated daily intake (EDI) values of heavy metals through the consumption of *C. auratus* were below the recommended tolerable daily intake values set by the Joint FAO/WHO Expert Committee on Food Additives (2011) and the USEPA (2021). Therefore, consumption of *C. auratus* containing these heavy metals is unlikely to pose any health risk to consumers.

EDI values were calculated based on a fish consumption rate of 19.72 g day^{-1}. Since fish consumption rates vary widely among populations, regional dietary habits can significantly influence risk levels. Therefore, a higher consumption rate would proportionally increase the EDI and THQ values.

Table 2. Estimated daily intake (EDI) values of metals through consumption of *C. auratus* (mg kg^{-1} body weight per day)

	EDI				
Months	**Pb**	**Hg**	**Cd**	**Cu**	**Zn**
October	1.4×10^{-5}	8.4×10^{-6}	2.8×10^{-6}	9.5×10^{-5}	2.39×10^{-3}
November	8.5×10^{-6}	8.4×10^{-6}	2.8×10^{-6}	8.1×10^{-5}	2.01×10^{-3}
December	7.04×10^{-6}	1.1×10^{-5}	2.8×10^{-6}	8.7×10^{-5}	1.79×10^{-3}

The daily intake was calculated by taking the weighted average concentrations of Hg, Cd, Cu, and Zn in *C. auratus* and multiplying them by the respective consumption rate. Since the RfD value for Pb is not provided, this calculation was not performed for Pb. Each metal's EDI, showing that Zn and Cu have the highest intake levels, while Cd remains consistently low across months. The mean daily intake of Cd for consumers was estimated at 2.8×10^{-6} mg, which is well below the RfD value of 1×10^{-4} mg kg^{-1} body weight per day (USEPA, 2024).

The provisional tolerable daily intakes of Hg for all months were estimated to range between 8.4×10^{-6} and 1.1×10^{-5} mg kg^{-1} body weight per day for consumers, which are well below the RfD value of 3×10^{-4} mg kg^{-1} body weight per day established by WHO (2000).

The Cu intake of consumers was estimated to range between 8.1×10^{-5} and 9.5×10^{-5} mg day^{-1}, which is consistent with the recommended dietary allowance of 4×10^{-2} mg day^{-1} established by the USEPA (2021).

The daily intake of Zn for consumers during all months was estimated to range between 1.79×10^{-3} and 2.39×10^{-3} mg day^{-1}, which is 125–167 times lower than the RfD value of 0.3 mg day^{-1}.

Table 3 presents the target hazard quotient (THQ) values. For all metals, the THQ values in *C. auratus* were found to be below 1, indicating no significant non-carcinogenic health risk from the consumption of this species. Examination of the hazard index (HI) values for the five heavy metals measured shows that they did not exceed 1 in any month. The average HI value for adults was calculated as 0.21. These results indicate that the estimated exposure is below the USEPA reference dose for the relevant metals for October, November and December in 2023. Comparable results were reported for the South Adriatic, where the THQ values for Pb and Cd associated with fish consumption were also low (<0.055), further supporting the conclusion that consumption of fish from relatively less industrialized marine areas poses minimal health risk (Antovic et al., 2019).

Table 3. Target hazard quotients (THQ) values and hazard index (HI) for non-carcinogenic risk assessment of heavy metal intake except Pb through *C. auratus* consumption.

	THQ and HI			
Months	**Hg**	**Cd**	**Cu**	**Zn**
October	2.8×10^{-2}	2.8×10^{-2}	2.4×10^{-3}	7.9×10^{-3}
November	2.8×10^{-2}	2.8×10^{-2}	2.1×10^{-3}	6.7×10^{-3}
December	3.7×10^{-2}	2.8×10^{-2}	2.2×10^{-3}	5.9×10^{-3}

HI = 0.21

Although THQ values were calculated for Hg, Cd, Cu, and Zn, Pb was excluded because no official oral RfD is currently defined by the U.S. EPA; thus, a reliable THQ could not be derived.

RI values for Pb were calculated monthly and are presented in Table 4.

Table 4. Risk index (RI) values for potential carcinogenic risk associated with Pb intake through *Chelon auratus* consumption

	RI
Months	**Pb**
October	1.19×10^{-7}
November	7.18×10^{-8}
December	5.98×10^{-8}

Since there is no RfD value for Pb (USEPA, 2021), it was compared using the SF value (0.0085) set by RAIS (2021). In our study, the RI values for consumers ranged from 5.98×10^{-8} to 1.19×10^{-7}, which are far below the SF value for all months. The average RI value was calculated for Pb only, and the results did not indicate carcinogenicity. Comparing the RI values for Pb with the guideline values shows that fish from the Sinop coast of the Black Sea are safe for human consumption. According to the International Environmental Protection Agency (EPA), RI values for Pb below 1×10^{-6} are considered insignificant.

CONCLUSION

In the present study, *C. auratus* had heavy metal levels below the allowable values established by international guidelines. Estimated daily intake (EDI) values for all measured metals were substantially lower than the reference doses established by WHO, FAO/WHO, and USEPA. The estimation of non-carcinogenic risk (THQs) in this study indicated that adverse health effects are unlikely to occur at the observed levels of fish consumption. However, the target cancer risk (RI) associated with Pb exposure through *C. auratus* consumption suggests no potential carcinogenic risk to consumers.

REFERENCES

Ameur, W. B., Annabi, A., Lahmar, S., & Marini, M. (2025). First assessment of heavy metals contamination and human health risk in Chelon auratus (Risso, 1810) from Tunisian aquatic ecosystems: Case of Bizerte Lagoon and Ghar El Melh Lagoon (Ramsar site). *Regional Studies in Marine Science*, 104472. DOI: 10.1016/j.rsma.2025.104472

Antović, I., Šuković, D., Andjelić, S., & Svrkota, N. (2019). Heavy metals and radionuclides in muscles of fish species in the South Adriatic-Montenegro. *In RAP Conference Proceedings*, Vol. 4, pp. 96-102.

Bakhshalizadeh, S., Mora-Medina, R., Fazio, F., Parrino, V., & Ayala-Soldado, N. (2022). Determination of the heavy metal bioaccumulation patterns in muscles of two species of mullets from the Southern Caspian Sea. *Animals*, ***12***(20), 2819. DOI: 10.3390/ani12202819

Bat, L., & Arıcı, E. (2018). Chapter 5. *Heavy metal levels in fish, molluscs, and crustacea from Turkish seas and potential risk of human health.* In: Holban AM, Grumezescu AM. (Eds.) Handbook of Food Bioengineering, Volume 13, Food Quality: Balancing Health and Disease. Elsevier, Academic Press, ISBN: 978-0-12-811442-1, pp. 159-196. DOI: 10.1016/B978-0-12-811442-1.00005-5

Bat, L., Öztekin, H.C., & Üstün, F. (2015). Heavy metal levels in four commercial fishes caught in Sinop coasts of the Black Sea, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, ***15***, 393-399. DOI: 10.4194/1303-2712-v15_2_25

Bat, L., Öztekin, A., Şahin, F., Arıcı., E., & Özsandıkçı, U. (2018a). An overview of the Black Sea Pollution in Turkey. *MedFAR*, ***1***(2), 67-86.

Bat, L., Şahin, F., & Öztekin, A. (2018b). Toxic metal amounts in *Chelon auratus* (Risso, 1810): a potential risk for consumer's health. *Journal of Aquaculture & Marine Biology*, ***7***(6), 303-306. DOI: 10.15406/jamb.2018.07.00225

Bat, L., Şahin, F., Öztekin, A., & Arici, E. (2022). Toxic metals in seven commercial fish from the Southern Black Sea: Toxic risk assessment of eleven-year data between 2009 and 2019. *Biological Trace Element Research*, ***200***, 832-843. DOI: 10.1007/s12011-021-02684-4

Çöteli, F.T. (2024). Su Ürünleri Ürün Raporu 2024 (Yayın No: 403). Tarım ve Orman Bakanlığı, Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü (TEPGE). Accessed 26.09.2025

FAO/WHO. (2011). Food Standards Programme: Codex Committee on Contaminants in Foods, Fifth Session. Codex Alimentarius Commission, The Hague, The Netherlands.

Froese, R., & Pauly, D. (2025). FishBase. World Wide Web electronic publication. Retrieved April 11, 2025, from www.fishbase.org

Gurov, K.I., & Kotelyanets, E.A. (2022). Distribution of Trace Metals (Cr, Cu, Ni, Pb, Zn, Sr, Ti, Mn and Fe) in the Vertical Section of Bottom Sediments in the Sevastopol Bay (Black Sea). *Physical Oceanography*, ***29***(5), 491-507.

Kartal, D.U., Yeşilçiçek, T., & Kalaycı, F. (2025). Biological traits and population dynamics of *Chelon auratus* in the Southeastern Black Sea with a perspective on sustainable fisheries management. *Scientific Reports*, *15*(1), 30333. DOI: 10.1038/s41598-025-15857-1

Kesiktaş, M., Yemişken, E., Yildiz, T., & Eryilmaz, L. (2020). Age, growth and reproduction of the golden grey mullet, *Chelon auratus* (Risso, 1810) in the Golden Horn Estuary, Istanbul. *Journal of the Marine Biological Association of the United Kingdom*, ***100***(6), 989-995. DOI: 10.1017/S0025315420000764

Malvandi, H. (2024). Metals concentration and human health risk assessment in some fish species from the southern Caspian Sea. *Mar. Pollut. Bull.*, ***202***, 116336. DOI: 10.1016/j.marpolbul.2024.116336

Official Gazette of the Republic of Türkiye. (2002). *Turkish Food Codex:* Communiqué on Maximum Levels of Certain Contaminants in Foodstuffs (No. 2002/63). No. 24885, September 23, 2002.

Official Gazette of the Republic of Türkiye. (2011). *Turkish Food Codex:* Contaminants Regulation. No. 28157 (3rd repeat), December 29, 2011.

Official Journal of the European Union. (2006). Commission Regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Union*, ***L364***, 5-24.

Oguz, T., & Besiktepe, S. (1999). Observations on the Rim Current structure, CIW formation and transport in the western Black Sea. Deep Sea Research Part I: *Oceanographic Research Papers*, ***46***(10), 1733-1753.

Pashtiri, Z.H., Karsidani, S.H., & Roohi, J.D. (2025). Investigating the amounts of some heavy metals in muscle and liver tissues of golden grey mullet (*Chelon auratus*) in the coasts of Guilan province. *Journal of Animal Environment*, *17*(1), 81-86.

RAIS. (2024). The Risk Assessment Information System. University of Tennessee. Retrieved from https://rais.ornl.gov/index.html

TÜİK. (2025). https://biruni.tuik.gov.tr/medas/?kn=97&locale=tr, Accessed 26.09.2025

USEPA. (2000). Risk-based concentration table. Philadelphia PA: United States Environmental Protection Agency, Washington D.C.

USEPA. (2001). Risk Assessment Guidance for Superfund: Volume III - Part A, Process for Conducting Probabilistic Risk Assessment EPA 540-R-02-002. US Environmental Protection Agency, Washington D.C.

USEPA. (2021). Regional Screening Levels (RSLs) - User's Guide November 2021 https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

USEPA. (2024). Regional Screening Levels (RSLs) - Generic Tables: November 2024. Retrieved from https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

WHO. (1996). Trace elements in human nutrition and health. 1. Trace elements - metabolism 2. Trace elements–standards 3. Nutrition 4. Nutritional requirements. NLM Classification: QU 130.

WHO. (2000). Evaluation of certain food additives and contaminants. Report of the Fifty-Third of the Joint FAO/WHO Expert Committee on Food Additives. Technical Report Series No. 896 Geneva.