JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(8), 108–119
https://doi.org/10.12911/22998993/203812
ISSN 2299–8993, License CC-BY 4.0

Received: 2025.03.26
Accepted: 2025.05.26
Published: 2025.06.10

Microplastic contamination in commercial fish from the Central Black Sea

Bilge Bilgin Fıçıcılar[1*], Mehmet Aydın[1], Koray Korkmaz[1]

[1] Department of Fisheries Technologies Engineering, Fatsa Faculty of Marine Sciences, Ordu University, Fatsa, Ordu, Turkey
* Corresponding author's e-mail: bilgebilginficicilar@odu.edu.tr

ABSTRACT

Plastics have become integral to modern life due to their versatility, affordability, durability, and lightweight nature. Microplastic (MP) pollution is a significant danger to marine ecosystems. This study examines MP ingestion in nine commercially important fish species (European anchovy *Engraulis encrasicolus*, whiting *Merlangius merlangu*s, red mullet *Mullus barbatus*, Mediterranean horse mackerel *Trachurus mediterraneus*, Atlantic bonito *Sarda sarda*, picarel *Spicara flexuosa*, garfish *Belone svetovidovi*, bluefish *Pomatomus saltatrix*, and round goby *Neogobius melanostomus*) from the central Black Sea coast of Turkey. In total, 111 MPs were identified in the gastrointestinal tracts of 270 fish, with no MPs found in the fillets. Fibers were the most found MP type; the predominant polymers were polyethylene and polypropylene. *Pomatomus saltatrix*, *Engraulis encrasicolus*, and *Neogobius melanostomus* exhibited the highest rates of MP ingestion, averaging 0.66 MPs per fish. This research provides fundamental data for evaluating the environmental hazards of microplastics in fish species found in the Black Sea. It emphasizes the urgent need for efficient waste management strategies to reduce plastic pollution.

Keywords: Black Sea, microplastics, ingestion.

INTRODUCTION

In 2022, worldwide production of plastic reached an astonishing 400 million tons, highlighting its essential function in several industries such as clothing, storage, transportation, packaging, and construction. The increase in production has led to a proportional growth in plastic use, consequently increasing the detrimental effects of plastic waste. Annually, around 75 to 80 million tons of plastic waste are released into the seas, resulting in considerable contamination of the marine environment. The marine litter of plastic originates from several sources, such as coastal regions, fishing activities, maritime sectors, and urban pollution that are transported to the oceans via rivers (Andrady, 2011; Veiga and R.C., 2016).

Microplastics are tiny particles of plastic debris smaller than 5 mm in size. These particles can vary in shape and form, including fibers, fragments, and beads (Li, 2018). There are several sources of microplastics, including the breakdown of larger plastic items, the shedding of microfibers from synthetic clothing, and the degradation of plastic waste in the environment. These particles can be found in various ecosystems, including oceans, rivers, and soil. The pervasive nature of microplastics has raised concerns about their potential impact on the environment and wildlife. Understanding the sources and distribution of microplastics is crucial for developing effective strategies to mitigate their harmful effects (Wang et al., 2019).

The Black Sea is located between longitudes 28° and 42° East and latitudes 41° and 46° North. It is surrounded by Ukraine, Russia, Romania, Bulgaria, Turkey, and Georgia. The Bosphorus Strait serves as the connection between the Asian continent and the Mediterranean Sea. The sea is described as semi-closed, indicating a restricted natural circulation and self-cleaning ability. This leads to major environmental strain since there's a limited water exchange with the Mediterranean Sea (Mee, 2005).

The Black Sea region is widely recognized for its remarkable biodiversity and cultural importance as a connecting link between Europe and Asia. It sustains a population of about 200 million people. These populations impose significant pressure on its resources. Since the 1960s, the sea has experienced significant deterioration, predominantly due to pollution. Waste originating from agricultural, urban, and industrial activities, including those discharged by major European rivers such as the Danube, Dnieper, and Don, substantially contributes to contamination. The Dniester, Southern Bug, Chorokh, Rioni, Sakarya, Kizilirmak, and Yesilirmak rivers also contribute to this pollution. Research has revealed concerning levels of plastic contamination, with an estimated daily influx of 4.2 tones and a yearly release of around 2 trillion microplastic particles or 500 tones from the Danube River (Commission, 2013; Topçu et al., 2013). A recent study suggested that rivers contribute to the transport of a significant number of plastic items into the Black Sea, ranging from 4 to 75 every hour (Fernández et al., 2020). Plastics constitute almost 80% of the marine litter discovered on the sea floor.

Plastic pollution has emerged as a critical challenge for the Black Sea's ecological health, as the Black Sea Commission noted in 2007. Consequently, research interest in this area has been growing. Various studies focusing on macroplastics within the region have revealed significant levels of macroplastic contamination along the shores of the Black Sea (Simeonova and Chuturkova, 2020). As a result, there has been an increasing scientific interest in this field. Several studies investigating microplastics in the area have revealed significant amounts of microplastic pollution along the coastlines of the Black Sea (Aytan et al., 2020; Gül, 2023; Pojar et al., 2021; Topçu et al., 2013).

While most of the studies have focused on assessing microplastic pollution on the shores, beaches, at the water's surface, and within marine debris, there is an abundance of studies on microplastic contamination in fish tissues. Specifically, few studies have explored microplastics in the fillets, stomachs, and intestines of commercially significant fish species in the Black Sea. This study investigated the ingestion of microplastics by important commercial fish species in the central Black Sea and along Turkey's mid-coastline, focusing on pelagic and demersal groups including *Mullus barbatus, Trachurus mediterraneus, Sarda sarda, Merlangus merlangus, Spicara flexuosa, Belone svetovidovi, Pomatomus saltatrix, Engraulis encrasicolus,* and *Neogobius melanostomus,* to assess the level of plastic pollution affecting these marine populations.

Figure 1. Location of the Black Sea and the catching area of the fishes used in this study

MATERIALS AND METHODS

Study area

The research examined three sampling locations across two cities (Samsun and Ordu) situated along the central part of the Black Sea coast, as depicted in Figure 1. The study focused on six main fish species: *Engraulis encrasicolus, Merlangius merlangus, Mullus barbatus, Trachurus mediterraneus*, *Sarda sarda*, and *Pomatomus saltatrix*. The selection of these species was based on their high capture frequency and widespread consumption in the Turkish Black Sea region (Tuik, 2022). In addition, three other species, namely *Spicara flexuosa, Belone svetovidovi*, and *Neogobius melanostomus*, were included in the study due to their considerable consumption in the Turkish market (Table 1). From January to December 2022, a total of 270 fish from nine different commercial species were caught during routine fishing operations along the middle Black Sea shoreline. The samples were kept in ice boxes to isolate them from external conditions and then taken to the Ordu University, Fatsa Faculty of Marine Sciences laboratory. Before analysis, all samples were stored in a freezer at -20 °C.

Microplastic extraction

During the analysis of the samples, fish belonging to the same species were collected and defrosted, followed by a total of three times of rinsing with distilled water. Samples were washed using 70% alcohol in a fume hood, and an empty Petri dish was inserted as a control sample. The samples were divided into two parts: the gastrointestinal system (from the esophagus to the anus) and the fillets. The fish were measured for their lengths, and their weights were recorded on aluminum foil within the fume hood using a precise scale. All solutions were filtered through Whatman No. 540 filter paper (with an 8 µm pore size) to prevent contamination. The glassware was initially cleansed using commercial dish detergent, followed by rinsing with HPLC-grade distilled water, and subsequently rinsing with ethanol. Finally, the glassware was dried in an oven. Throughout the analysis process, researchers wore cotton laboratory coats, nitrile gloves, and face masks. The extraction of microplastics from the fish samples was carried out inside a fume hood (Karami et al., 2017). For each fish sample, 10 grams of internal organs and fillet (or the entire weight for smaller fish) were weighed and placed in Duran bottles.

Table 1. Fish collected (sample size, habitat, diet, trophic level, mean weight ± SD, length ± SD)

Species	Habitat	Diet	Trophic level	Number of fish analyzed	Mean weight (g) ± SD (min, max)	Mean length (cm) ± SD (min, max)
Engraulis encrasicolus	Pelagic	Plankton, zooplankton, sea mosses, small crustaceans, and other small sea organisms	3.1(Fishbase, 2024)	30	6.03±1.29	9.73±0.55
Mullus barbatus	Demersal	Small benthic crustaceans, worms, mollusks	3.37 (Karachle & Stergiou, 2017)	30	12.23±0.82	20.04±4.11
Trachurus mediterraneus	Pelagic	Copepods, decapods, fish eggs and larvae, small fish, cephalopods	3.69 (Fishbase, 2024)	30	12.87±1.08	17.92±2.04
Pomatomus saltatrix	Pelagic	Bony fish, crustaceans, anchovies	4.5 (Fishbase, 2024)	30	32.82±8.53	14.65±1.30
Neogobius melanostomus	Demersal	Crustaceans and mollusks, polychaete species, small fish, and benthic eggs	3.54 (Herlevi et al., 2018)	30	24.85±1.40	13.20±0.60
Belone svetovidovi	Pelagic	Usually anchovies, sardines, and other small-sized fish, zooplankton, invertebrates	4.2 (Fishbase, 2024)	30	40.05±13.20	33.00±3.25
Spicara flexuosa	Pelagic	Small fishlike sardines, anchovies, crustaceans, krill	3.0 (Fishbase, 2024)	30	38.00±14.28	14.59±1.75
Sarda sarda	Pelagic	Small pelagic fishlike sardines, anchovies, and mackerel, small cephalopods, crustaceans	4.5 (Fishbase, 2024)	30	440.52±25.10	20.15±5.74
Merlangius merlangus	Benthopelagic	Crustaceans, molluscs, fish, and polychaetes	4.4 (Fishbase, 2024)	30	26.80±1.40	15.50±0.85

Following that, 10% (w/v) KOH (Merck, Germany) was added. The bottles were subsequently placed in a closed oven and incubated at 40 °C for 48 hours. Afterward, the contents were filtered using a vacuum pump through a filter membrane with a pore size of 22 µm (Whatman 541). Next, the filter membrane (22 µm) was submerged in 10–15 mL of NaI solution and left in an ultrasonic bath (ISOLAB, Germany) at 50hz for 5 minutes. It was then shaken on an orbital shaker at 200 rpm for 5 minutes and centrifuged at 500*g for 5 minutes. The supernatant of the mixture was filtered through another filter membrane, Whatman 540 (8 µm), to isolate plastic particles. Finally, the filter membrane was placed in a clean glass Petri dish and dried in an oven at 40 °C for 5 hours. Using a stereomicroscope (Motic SMZ-140, China), a visual examination was conducted on the filter membranes to sample particles that resembled microplastics based on their color and morphologies, as described by Karami et al. (2017). Samples exhibiting similar qualities to plastic polymers were subjected to a hot needle test under microscopic examination. All suspect particles were also collected for Raman spectroscopy analysis. The selected particles were photographed using a camera attached to the microscope (AxioCam, ERc 5S, Germany) (Figure 2).

Raman analysis

The samples were analyzed within a spectral range from 150 to 3000 cm^{-1} utilizing a Raman spectrometer (WITech alpha 300R) that is outfitted with a DPSS laser and a back-illuminated CCD detector. The collected spectra were processed and then cross-referenced with spectral libraries, specifically those for Raman polymers

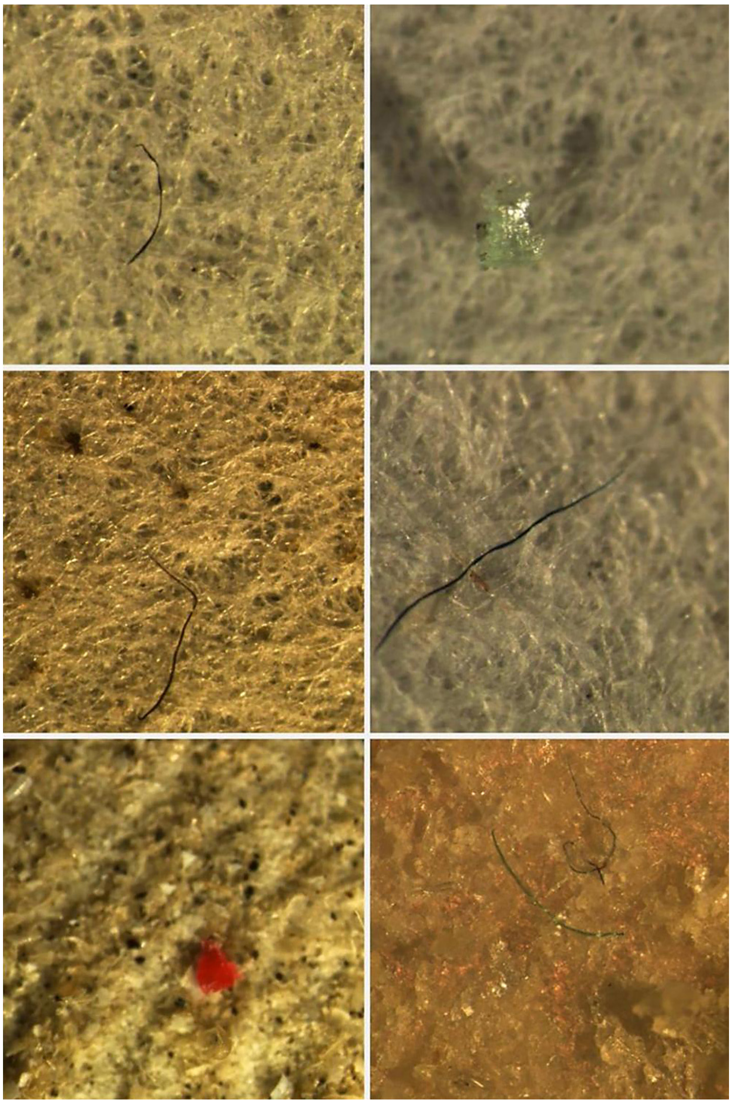


Figure 2. Stereomicroscope images of microplastics in the fish sampled

and monomers by Bio-Rad Sadtler, as well as the Raman Forensic library from Horiba. This comparison was facilitated by the KnowItAll software provided by Bio-Rad. Using the Correlation algorithm within KnowItAll, each spectrum obtained from the samples was methodically compared to the database spectra for analysis. Due to the time-intensive and resource-demanding nature of Raman spectroscopy, a representative subset of 20 particles was selected for polymer identification. The selection was based on diversity in color, morphology, and fish species to ensure a comprehensive representation of the total microplastic particles detected.

Data analysis

The statistical analysis was conducted using SPSS for Windows, version 21.0, developed by SPSS Inc. in Chicago, IL, USA. The variables were represented by minimum, maximum, and mean ± standard deviation. Differences in mean microplastic ingestion among the nine fish species were analyzed using one-way ANOVA. Tukey's HSD post-hoc test was applied to identify which species pairs showed significant differences.

RESULTS

Plastics were detected in each of the gastrointestinal tracts of the nine fish species. 111 plastic particles were obtained from the gastrointestinal tracts of 270 fish. No microplastic was detected in the fish fillets. The quantities of microplastics isolated from the fish samples are shown in Table 2.

Total count of examined fish (T), number of fish that ingested microplastics (NIM), Percentage of Occurance (P, %), the total number of fiber (Fb), film (Fl), fragment (Fr), foam, (Fm), The total number of plastic particles detected in the gastrointestinal tracts (GITs) of fish is Total MP, The average number of plastics (mean ± standard deviation) found in all the analyzed fish (X) and in the fish that ingested plastic (Y). Tukey's HSD post-hoc test was applied to determine pairwise differences among species. Species that do not differ significantly from each other (p > 0.05) were grouped under the same letter in the superscript letter display.

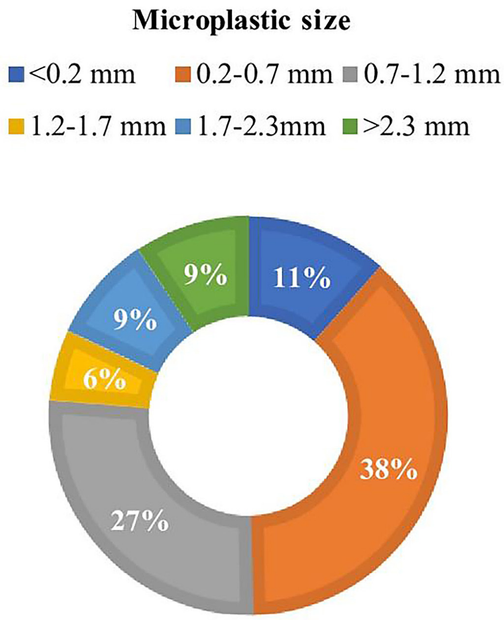
Among all individuals, the concentration of microplastics was 0.41 items per fish. *Pomatomus saltatrix, Engraulis encrasicolus,* and *Neogobius melanostomus* had the highest microplastic ingestion rates, each at 0.66 items per fish, while *Belone svetovidovi* had the lowest at 0.16 items per fish. Four different types of plastics were found: fibers, films, fragments, and foams (Figure 2). The most common types of plastics were fibers (80%), followed by fragments (17.04%), filaments (2.22%), and foam (0.74%) (Figure 3). The foam was only detected in *Neogobius melanostomus* samples.

A total of nine different colors of plastics were found, with the most common being black (66.13%), followed by blue (19.5%), transparent (18.1%), red (9.2%), orange (4.6%), green (3.4%), white (2.9%), yellow (1.1%), grey (0.9%), pink

Table 2. Microplastic occurrence in gastrointestinal tracts of selected marine fish species from Black Sea

Species	T	NIM	P (%)	Fb	Fl	Fr	Fm	Total MP	Max	X	Y
Engraulis encrasicolus	30	12	40	14	0	6	0	20^{ab}	4	0.66	1.67
Trachurus mediterraneus	30	6	20	6	0	2	0	8^{bc}	2	0.2	1.33
Sarda sarda	30	17	57	16	0	1	0	17^{ab}	1	0.57	1
Belone svetovidovi	30	5	16	2	0	3	0	5^{bc}	1	0.16	1
Pomatomus saltatrix	30	20	66.66	24	0	1	0	25^{a}	3	0.66	1.25
Merlangius merlangus	30	6	20	3	0	4	0	7^{bc}	2	0.2	1.16
Mullus barbatus	30	17	56.66	17	0	3	0	20^{ab}	3	0.57	1.17
Spicara flexuosa	30	13	43.33	11	1	1	0	13^{bc}	1	0.43	1
Neogobius melanostomus	30	15	50	15	2	2	1	20^{ab}	2	0.66	1.33
Total	270	111	41.11	108	3	23	1	135		0.41	1.22

Note: Total count of examined fish (T), number of fish that ingested microplastics (NIM), Percentage of occurance (P, %), the total number of fiber (Fb), film (Fl), fragment (Fr), foam (Fm), the total number of plastic particles detected in the gastrointestinal tracts (GITs) of fish is total MP, the average number of plastics (mean ± standard deviation) found in all the analyzed fish (X) and in the fish that ingested plastic (Y). Tukey's HSD post-hoc test was applied to determine pairwise differences among species. Species that do not differ significantly from each other (p > 0.05) were grouped under the same letter in the superscript letter display.



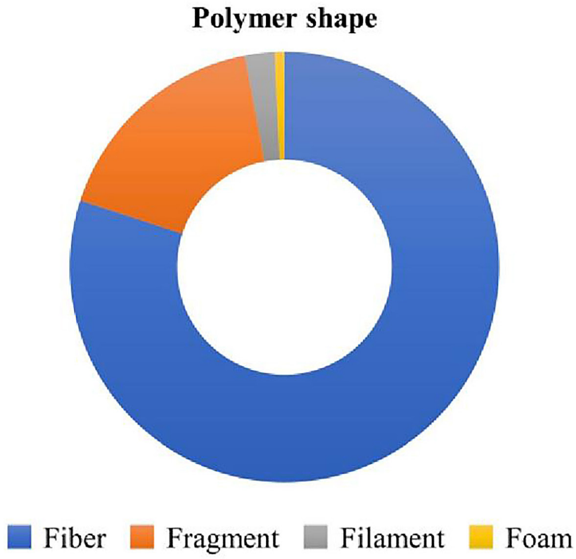


Figure 3. Size and shape of microplastics in all the samples

(0.9%) and purple (0.3%) (Figure 4). The variety of colors was higher in *E. encrasicolus* (N = 11) and *S. sarda* (N = 8) and lower (N = 2) in *B. belone* and *P. saltatrix* (Figure 5).

Microplastics less than 5 mm in size made up 100% of the plastics found in the fish. The sizes of these plastic particles varied from 0.10 to 3.5 mm, with the average size falling within the 0.2–1 mm range, accounting for 38.00% of the particles. This was followed by sizes between 0.7–1.2 mm at 27.00%, less than 0.2 mm at 12%, 1.7–2.3 mm at 9%, more than 2.3 mm also at 9%, and 1.2–1.7 mm at 6% (Figure 3, Figure 4). Smaller microplastic particles (< 0.7 mm) were more frequently ingested across most species, suggesting higher availability or susceptibility to these sizes. Larger particles (> 1.2 mm) were less commonly ingested. However, they were still present in notable quantities in certain species like *Pomatomus saltatrix* and *Sarda sarda*, indicating their ability to ingest larger particles (Figure 3).

DISCUSSION

The present study thoroughly assesses the presence of plastic in nine commercially fished species from the Black Sea. Plastic contamination was detected in close to 41% of the git of fish examined, with each species containing plastic, predominantly in the form of microplastics. No microplastics were found in the fillets of the examined fish, potentially due to the instrument's limitations, which was neither SEM nor TEM. Further analysis is necessary to detect such small particles.

The European anchovy is a highly popular Black Sea fish species and the most caught pelagic species. Thus, anchovy's role in transferring plastics and toxic chemicals to humans and anchovy predators cannot be underestimated. Our findings show that the average MP per European anchovy differs according to previous studies. The value obtained in this study (0.66) was higher than that reported in a previous study conducted in the Black Sea (Eryaşar et al., 2022), lower than the value reported by (Aytan, 2022), (Renzi et al., 2019). There is variation in the frequency of plastic occurrence in European anchovy among previous reports. The value obtained in this study (40%) is higher than the percentages reported in the Western Mediterranean Sea (15.2%) (Compa et al., 2018), the percentage was comparatively lower when compared to other studies conducted in anchovies in various regions such as the Monterey Bay, California (58%) (Michishita et al., 2023), Talisayan harbor, East Kalimantan, Indonesia (50%) (Ningrum et al., 2019) and Western Mediterranean Sea (60%) (Pennino et al., 2020).

In a recent study, the average number of microplastics (MPs) per fish found in *Trachurus mediterraneus* was reported as 0.22 ± 0.14 (Mutlu, 2022) which is similar to our result (0.20 per individual). In a study by (Neves et al., 2015) examining 26 fish species along the coast of Portugal, the average number of microplastics per horse mackerel was reported as 0.07 ± 0.25,

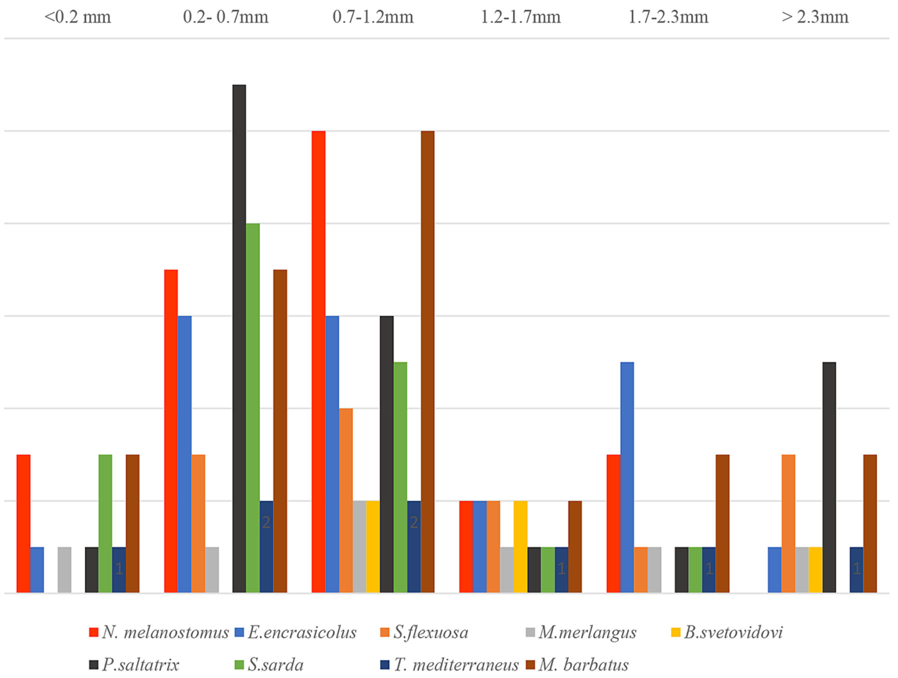


Figure 4. Distribution of microplastic particle sizes ingested by different fish species

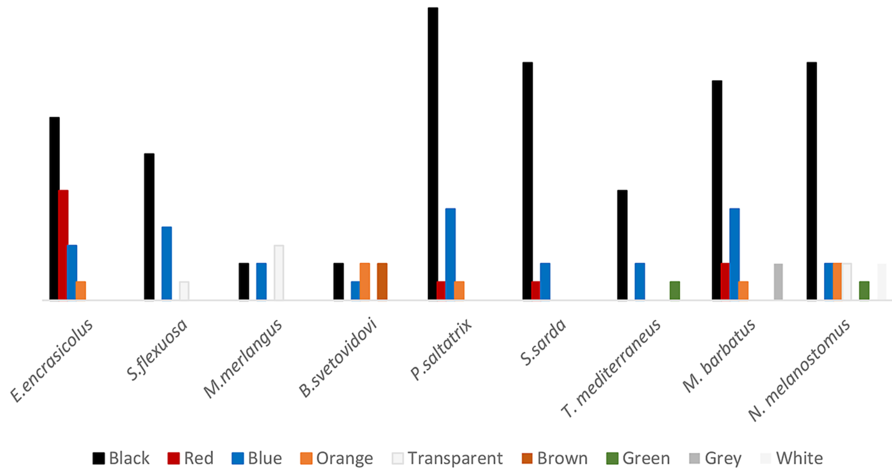


Figure 5. Distribution of microplastic colors ingested by various fish species

significantly lower than the average number of microplastics found in our research. In contrast, another study conducted in Portugal by (Lopes et al., 2020) found a significantly greater average of 1.75 microplastics per individual.

In our research, we found that the Atlantic bonito (*Sarda sarda*), an important predator and migratory fish in the Black Sea environment, had a significantly high rate of ingesting plastics. Microplastics were found in 66% of the samples. This result is consistent with previous observations that highlighted the high frequency of plastic ingestion among pelagic fish, including a report of plastics in 70% of Atlantic bonito individuals (Aytan, 2022). The species migrates annually from the Aegean Sea to the Black Sea via the Turkish Strait each spring, returning to the Sea of Marmara and the Aegean Sea after late autumn, with a small number remaining in the Black Sea year-round (Polat and Ergün, 2008). Atlantic bonito mostly consumes plastics either by directly mistaking them for food or indirectly through contaminated prey.

To date, just one previous study has examined the relationship between microplastics and *Belone svetovidovi* (garfish). This study only examined the presence of microplastic collars on these fish, rather than their ingestion. Our study indicates the presence of microplastic particles in 16% of the examined *Belone svetovidovi* samples, suggesting that these fish consume an average of 0.16 microplastic particles per individual. Garfish are active predators that mostly consume tiny schooling fishes and crustaceans. They are often found in the top levels of the water column. Their migratory patterns are similar to those of mackerels, arriving in their breeding grounds shortly before the latter. The occurrence of microplastics in our study reflects these ecological and behavioral characteristics, highlighting the wider environmental influence on pelagic fish species. *Pomatomus saltatrix*, being a highly migratory species with a wide distribution, is susceptible to various environmental stressors, including microplastic pollution. In a study by (Aytan, 2022) microplastics were detected in 2 out of 17 samples of *Pomatomus saltatrix*. The average number of microplastic particles per individual was found to be 0.12, which is lower than our result (0.66). The changes in the catching zone and time might be linked to this. Various places can exhibit different degrees of contamination and microplastic abundance as a result of their proximity to sources of pollution, water currents, and environmental conditions. Fluctuations in water quality and variations in fish feeding patterns due to seasonal and temporal variables can also influence the quantity of microplastics consumed by the fish.

In a study analyzing 104 samples of *Merlangius merlangus*, 29 were found to contain microplastics. The mean number of microplastic particles per individual was 0.28 ± 0.06 (Eryaşar et al., 2022). In another study, microplastics were detected in *Merlangus merlangus* (whiting), with 3 out of 33 samples containing microplastic particles. In our study on *Merlangius merlangus* (whiting), 6 out of 30 samples contained microplastics, with an average of 0.2 particles per individual. Studies have demonstrated that the diet of whiting includes a range of prey, such as zooplankton and other kinds of fish. Whiting juveniles have been observed to feed on a diverse zooplankton community, while adults may preferentially select specific prey items (Shaw et al., 2008). The feeding behavior of whiting has been studied in both pelagic and demersal zones, with observations indicating differences in the feeding cycle between pelagic and demersal whiting populations (Pedersen, 2000).

Whiting samples had lower levels of microplastic (MP) contamination in comparison to demersal fish species such as *Mullus barbatus* (red mullet) and *Neogobius melanostomus* (round goby). This difference could be attributed to the distinct habitats and feeding patterns of these species. Our findings indicate that the red mullet had the second-highest abundance of MP among the commercially studied species in this research (Table 2). The demersal species exhibited a significantly higher abundance of MP compared to the pelagic species. (Giani et al., 2019) found the occurrence of microplastics (MPs) in red mullet (*Mullus barbatus*) across different regions with the following percentages: 16.6% in the North Tyrrhenian Sea, 29% in the Adriatic Sea, and 15.5% in the Ionian Sea.

Spicara flexuosa, a member of the Sparidae family, is a ray-finned fish species frequently referred to as one of the picarels. This species is found in the eastern Atlantic Ocean, the Mediterranean Sea, and the Black Sea. It falls under the category of pelagic-neritic. In our study, 13 out of 30 samples had ingested microplastics. The average number of plastics in the analyzed fish was 0.43 (mean ± standard deviation). In a study conducted in the Mediterranean Sea, 23 out of 39 samples were found to have ingested microplastics, with an average of 0.51 particles per individual which is higher than our values (Alomar et al., 2020).

Neogobius melanostomus, commonly known as the round goby, is a benthic fish native to the Ponto-Caspian region of Eastern Europe. Round gobies are known for their high dietary plasticity, feeding mainly on benthic organisms such as crustaceans, insect larvae, mollusks, and small fishes. According to our results, microplastics were found in 15 out of 30 gobies, with an average of 0.66 particles per fish. Mcneish et al. found that *Neogobius melanostomus* had the highest concentration of gut microplastics compared to other fish taxa measured, with an average of 19 particles per fish (McNeish et al., 2018). Round gobies from Basel were previously found to ingest microplastics at a rate of 1.25 microplastics per fish (Roch and Brinker, 2017).

According to our results, Benthic fish showed a greater prevalence of microplastic ingestion, with an average of 42%, in comparison to pelagic fish, which had an average of 39.53%. The average number of microplastics per fish is slightly higher in benthic fish (0.47 ± 1.17) compared to pelagic fish (0.45 ± 1.25). Benthic fish tend to ingest more microplastics on average than pelagic fish, likely due to their proximity to the seabed where microplastics accumulate. Nevertheless, the disparities in the overall microplastic count and the average quantity of microplastics per fish are relatively small in the two groups. Studies have found that pelagic fish consume an increased amount of microplastics than fish from other environments (Güven et al., 2017) and also have higher rates of microplastic ingestion compared to demersal fish (Rummel et al., 2016). However, this is not always constant as other research indicated no significant difference in the frequency of microplastic ingestion between pelagic and demersal fish ((Lusher et al., 2017);(Neves et al., 2015); (Phillips and Bonner, 2015)). Moreover, recent findings suggest a higher abundance of microplastics in benthopelagic fish compared to demersal fish (Bessa et al., 2018). (Siddique et al., 2024) observed a strong connection between the ratio of a fish's mouth size to its body size and the ingestion of MPs. The research examined six tropical fish species from Saint Martin's Island in the Bay of Bengal. It concluded that fish with larger mouth-to-body ratios are more likely to accidentally consume microplastics(Siddique et al., 2024) In our study, species with larger mouths, such as *Pomatomus saltatrix*, were more likely to ingest microplastics. The reason is probably because their bodies can ingest bigger prey that could carry microplastics. Species with smaller mouths relative to their body size (e.g., *Mullus barbatus*) also showed significant microplastic ingestion, possibly due to their benthic feeding habits and sediment ingestion.

Black microplastics were the most common across almost all species, notably in *Pomatomus saltatrix*, *Sarda sarda*, and *Neogobius melanostomus* (Figure 4 and 5). This high incidence indicates that black microplastics are easily available or more likely to be consumed due to their size, form, or environmental presence.

Blue microplastics were the second most detected color in the samples, especially in Pomatomus saltatrix, *Mullus barbatus*, and *Sarda sarda*, suggesting a significant occurrence of this color in the marine environment. In substantial quantities, red microplastics have been found in many species, particularly in *Pomatomus saltatrix* and *Sarda sarda*. Colors such as orange, brown, green, gray, and white are less commonly consumed but can still be found in some species. These findings indicate that while these colors are not as prevalent, they still pose a risk of ingestion (Figure 4). The color of microplastics found in ingested fish differs in different studies. A study conducted by (Pattira and Wipavee, 2020) revealed that blue microplastics were the predominant color consumed by fish, with red, black, and yellow being the subsequent most prevalent colors. According to a study by (Koongolla et al., 2022) translucent, black, and blue microplastics were the most common colors observed in marine fish samples. Furthermore, (Phaksopa et al., 2021) proposed that the color of microplastics and their similarity to food may impact the probability of ingestion, especially in planktivorous fish.

A total of 20 particles were analyzed using Raman spectroscopy, and only those spectra that matched reference data by over 70% were classified. The primary polymers identified in GITs were polyethylene (PE) (40%), polyester (given as polyethylene terephthalate: PET) (25%), polypropylene (15%), polystyrene (PS) (5%), and 15% of the polymers were cellulosic (cotton fibers). Polyethylene is the most prevalent type of plastic globally and, consequently, the most common plastic debris found in both the Black Sea and around the world. This plastic typically comes from items such as plastic bags and bottles. Plastics like polyethylene (PE) and polypropylene (PP) have a lower density than water, causing polymers to float on the surface of the water. In contrast, polymers such as polyethylene terephthalate (PET) and polytetrafluoroethylene (PTFE), which have a higher density than water, tend to sink and are thus more prone to being consumed by benthic creatures. PP and PE were also found to be the dominant polymer types in both surface waters and sediments in other studies conducted in Black Sea. (Aytan et al., 2020; Cincinelli et al., 2021; Eryaşar et al., 2022; Eryaşar et al., 2021).

CONCLUSIONS

This research highlights the widespread problem of microplastic pollution in economically important fish species in the Black Sea. The study revealed that 41% of the fish analyzed had plastic particles, mostly in the form of microplastics. These results highlight the considerable ecological danger resulting from plastic pollution. The lack of microplastics in the fillets indicates that contamination is mainly restricted to the gastrointestinal tracts. However, further investigation with more advanced methods is necessary, since the microplastics present in fillets are often smaller in size and hence particularly difficult to detect using the current methodology.

The species *Pomatomus saltatrix, Engraulis encrasicolus*, and *Neogobius melanostomus* had the highest rates of microplastic ingestion, indicating their susceptibility due to their eating habits and habitats. The categorization of microplastics into four distinct types – fibers, fragments, films, and foams – reveals that fibers are the most often found, which is consistent with the worldwide distribution of plastic pollution.

The diverse spectrum of colors and sizes of microplastics consumed by the fish suggests a broad range of possible environmental sources and the possibility of important ecological impacts. The prevalence of black and blue microplastics indicates the significant occurrence of these colors in the marine ecosystem and, maybe as such are easily seen and mistaken for feed.

The results emphasize the urgent need for efficient waste management techniques and more strict regulations to mitigate plastic pollution. Due to the ecological and economic significance of the Black Sea, it is essential to implement comprehensive measures to protect its biodiversity and ensure the safety of its aquatic resources. Further research should prioritize the examination of the persistent ecological effects of consuming microplastics and explore innovative solutions to address this growing environmental situation.

The results of this study emphasize the need for improved waste management practices and stronger regulatory measures to reduce plastic pollution, particularly in environmentally sensitive and economically important regions such as the Black Sea. The presence of microplastics in commercially significant fish species highlights the importance of establishing focused monitoring programs, especially in demersal and benthic habitats. Increasing public awareness through well-designed outreach efforts is also important to support prevention strategies.

REFERENCES

1. Alomar, C., Deudero, S., Compa, M., Guijarro, B. (2020). Exploring the relation between plastic ingestion in species and its presence in seafloor bottoms. *Marine Pollution Bulletin*, *160*, 111641. https://doi.org/https://doi.org/10.1016/j.marpolbul.2020.111641
2. Andrady, A. L. (2011). Microplastics in the marine environment. *Mar Pollut Bull*, *62*(8), 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030
3. Aytan, U., Esensoy, F., Senturk, Y., Agirbas, E., Valente, A. (2020). Presence of microplastics in zooplankton and planktivorous fish in the southeastern Black Sea. In: Aytan, Ü., Pogojeva, M., Simeonova, A. (Eds.) Marine Litter in the Black Sea. Turkish Marine Research Foundation, Publication No: 56, Istanbul, Turkey, p. 314–325.
4. Aytan, U., Esensoy, F.B., Senturk, Y., Arifoğlu, E., Karaoğlu, K., Ceylan, Y., Valente, A. (2022). Plastic occurrence in commercial fish species of the Black Sea *Turkish Journal of Fisheries and Aquatic Sciences 22*(7).
5. Cincinelli, A., Scopetani, C., Chelazzi, D., Martellini, T., Pogojeva, M., Slobodnik, J. (2021). Microplastics in the Black Sea sediments. *Science of The Total Environment*, *760*, 143898. https://doi.org/https://doi.org/10.1016/j.scitotenv.2020.143898
6. Commission, E. (2013). *Guidance on monitoring of marine litter in European seas*. Publications Office. https://doi.org/doi/10.2788/99816
7. Compa, M., Ventero, A., Iglesias, M., Deudero, S. (2018). Ingestion of microplastics and natural fibres in Sardina pilchardus (Walbaum, 1792) and Engraulis encrasicolus (Linnaeus, 1758) along the Spanish Mediterranean coast. *Marine Pollution Bulletin*, *128*, 89-96. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.01.009
8. Eryaşar, A. R., Gedik, K., Mutlu, T. (2022). Ingestion of microplastics by commercial fish species from the southern Black Sea coast. *Mar Pollut Bull*, *177*, 113535. https://doi.org/10.1016/j.marpolbul.2022.113535
9. Eryaşar, A. R., Gedik, K., Şahin, A., Öztürk, R. Ç., & Yılmaz, F. (2021). Characteristics and temporal trends of microplastics in the coastal area in the Southern Black Sea over the past decade. *Marine Pollution Bulletin*, *173*, 112993. https://doi.org/https://doi.org/10.1016/j.marpolbul.2021.112993
10. Fishbase. (2024). Retrieved 12.04.2024 from https://www.fishbase.se/search.php
11. Giani, D., Baini, M., Galli, M., Casini, S., & Fossi, M. C. (2019). Microplastics occurrence in edible fish species (Mullus barbatus and Merluccius merluccius) collected in three different geographical sub-areas of the Mediterranean Sea. *Marine Pollution Bulletin*, *140*, 129–137. https://doi.org/https://doi.org/10.1016/j.marpolbul.2019.01.005
12. González-Fernández, D., Pogojeva, M., Hanke, G., Machitadze, N., Kotelnikova, Y., Tretiak, I., Savenko, O., Gelashvili, N., Bilashvili, K., Kulagin, D., Fedorov, A.V., Şenyiğit, M., Aytan, U. (2020). Anthropogenic litter input through rivers in the Black Sea. In: Aytan, Ü., Pogojeva, M., Simeonova, A. (Eds.) Marine Litter in the Black Sea. Turkish Marine Research Foundation, Publication No: 56, Istanbul, Turkey, p. 183–191.

13. Gül, M. R. (2023). Short-term tourism alters abundance, size, and composition of microplastics on sandy beaches. *Environmental Pollution*, *316*, 120561. https://doi.org/https://doi.org/10.1016/j.envpol.2022.120561
14. Güven, O., Gökdağ, K., Jovanović, B., Kıdeyş, A. E. (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. *Environmental Pollution*, *223*, 286–294. https://doi.org/https://doi.org/10.1016/j.envpol.2017.01.025
15. Herlevi, H., Aarnio, K., Puntila, R., Bonsdorff, E. (2018). The food web positioning and trophic niche of the non-indigenous round goby: a comparison between two Baltic Sea populations. *Hydrobiologia*, *822*, 1–18. https://doi.org/10.1007/s10750-018-3667-z
16. Karachle, P. K., Stergiou, K. I. (2017). An update on the feeding habits of fish in the Mediterranean Sea (2002–2015). *Mediterranean Marine Science*, *18*(1), 43–52. https://doi.org/10.12681/mms.1968
17. Karami, A., Golieskardi, A., Ho, Y. B., Larat, V., Salamatinia, B. (2017). Microplastics in eviscerated flesh and excised organs of dried fish. *Scientific Reports*, *7*(1), 5473. https://doi.org/10.1038/s41598-017-05828-6
18. Koongolla, J. B., Lin, L., Yang, C.-P., Pan, Y.-F., Li, H.-X., Liu, S., Xu, X.-R. (2022). Microplastic prevalence in marine fish from onshore Beibu Gulf, South China Sea [Original Research]. *Frontiers in Marine Science*, *9*. https://doi.org/10.3389/fmars.2022.964461
19. Mee L.D. (2005). How to save the Black Sea. Your guide to the Black Sea strategic action plan.
20. Li, W. C. (2018). Chapter 5 - The Occurrence, Fate, and Effects of Microplastics in the Marine Environment. In E. Y. Zeng (Ed.), *Microplastic Contamination in Aquatic Environments* 133–173. Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-813747-5.00005-9
21. Lopes, C., Raimundo, J., Caetano, M., & Garrido, S. (2020). Microplastic ingestion and diet composition of planktivorous fish. *Limnology and Oceanography Letters*, *5*(1), 103–112. https://doi.org/https://doi.org/10.1002/lol2.10144
22. Lusher, A., Hollman, P., Mendoza-Hill, J. (2017). *Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety*. FAO.
23. McNeish, R. E., Kim, L. H., Barrett, H. A., Mason, S. A., Kelly, J. J., Hoellein, T. J. (2018). Microplastic in riverine fish is connected to species traits. *Sci Rep*, *8*(1), 11639. https://doi.org/10.1038/s41598-018-29980-9
24. Michishita, S., Gibble, C., Tubbs, C., Felton, R., Gjeltema, J., Lang, J., Finkelstein, M. (2023). Microplastic in northern anchovies (*Engraulis mordax*) and common murres (*Uria aalge*) from the Monterey Bay, California USA - Insights into prevalence, composition, and estrogenic activity. *Environmental Pollution*, *316*, 120548. https://doi.org/https://doi.org/10.1016/j.envpol.2022.120548
25. Mutlu, T., Gedik, K., Eryaşar, A. R. (2022). Investigation of Microplastic Accumulation in Horse Mackerel (*Trachurus mediterraneus*) Caught in the Black Sea. *Journal of Anatolian Environmental and Animal Sciences*, *4*, 561–567.
26. Neves, D., Sobral, P., Ferreira, J. L., Pereira, T. (2015). Ingestion of microplastics by commercial fish off the Portuguese coast. *Marine Pollution Bulletin*, *101*(1), 119–126. https://doi.org/https://doi.org/10.1016/j.marpolbul.2015.11.008
27. Ningrum, E. W., Mufti, P., Sedayu, A. (2019). Ingestion of microplastics by anchovies from Talisayan harbor, East Kalimantan, Indonesia. *Journal of Physics: Conference Series*, *1402*, 033072. https://doi.org/10.1088/1742-6596/1402/3/033072
28. Pattira, K., Wipavee, T. (2020). Microplastics ingestion by freshwater fish in the Chi River, Thailand. *Geomate Journal*, *18*(67), 114-119. https://geomatejournal.com/geomate/article/view/498
29. Pedersen, J. N. (2000). Food consumption and daily feeding periodicity: comparison between pelagic and demersal whiting in the North Sea. *Journal of Fish Biology*, *57*(2), 402–416. https://doi.org/10.1111/j.1095-8649.2000.tb02180.x
30. Phaksopa, J., Sukhsangchan, R., Keawsang, R., Tanapivattanakul, K., Thamrongnawasawat, T., Worachananant, S., Sreesamran, P. (2021). Presence and characterization of microplastics in coastal fish around the Eastern Coast of Thailand. *Sustainability*, *13*(23), 13110. https://www.mdpi.com/2071-1050/13/23/13110
31. Phillips, M. B., Bonner, T. H. (2015). Occurrence and amount of microplastic ingested by fishes in watersheds of the Gulf of Mexico. *Marine Pollution Bulletin*, *100*(1), 264–269. https://doi.org/https://doi.org/10.1016/j.marpolbul.2015.08.041
32. Pojar, I., Stanica, A., Stock, F., Kochleus, C., Schultz, M., & Bradley, C. (2021). Sedimentary microplastic concentrations from the Romanian Danube River to the Black Sea. *Scientific Reports*, *11*. https://doi.org/10.1038/s41598-021-81724-4
33. Polat, H., Ergün, H. (2008). Pelagic fish of Black Sea. *Aquaculture Studies*, *2008*(1).
34. Renzi, M., Specchiulli, A., Blašković, A., Manzo, C., Mancinelli, G., & Cilenti, L. (2019). Marine litter in stomach content of small pelagic fishes from the Adriatic Sea: sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus*). *Environ Sci Pollut Res Int*, *26*(3), 2771–2781. https://doi.org/10.1007/s11356-018-3762-8
35. Roch, S., Brinker, A. (2017). Rapid and efficient method for the detection of microplastic in the

gastrointestinal tract of fishes. *Environmental Science & Technology*, *51*(8), 4522–4530. https://doi.org/10.1021/acs.est.7b00364

36. Rummel, C. D., Löder, M. G. J., Fricke, N. F., Lang, T., Griebeler, E.-M., Janke, M., Gerdts, G. (2016). Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine Pollution Bulletin*, *102*(1), 134–141. https://doi.org/https://doi.org/10.1016/j.marpolbul.2015.11.043
37. Shaw, M. D., Diekmann, R., DerKooij, J. V., Milligan, S. B., Bromley, P. J., Righton, D. (2008). Assessment of the diets of cod *Gadus morhua* and whiting merlangius *Merlangus juveniles* in a frontal region close to the norwegian trench: Co-existence or Competition? *Journal of Fish Biology*, *73*(7), 1612–1634. https://doi.org/10.1111/j.1095-8649.2008.02035.x
38. Siddique, M. A. M., Shazada, N. E., Ritu, J. A., Turjo, K. E. Z., Das, K. (2024). Does the mouth size influence microplastic ingestion in fishes? *Mar Pollut Bull*, *198*, 115861. https://doi.org/10.1016/j.marpolbul.2023.115861
39. Simeonova, A., Chuturkova, R. (2020). Macroplastic distribution (Single-use plastics and some Fishing gear) from the northern to the southern Bulgarian Black Sea coast. *Regional Studies in Marine Science*, *37*, 101329. https://doi.org/https://doi.org/10.1016/j.rsma.2020.101329
40. Topçu, E. N., Tonay, A. M., Dede, A., Öztürk, A. A., & Öztürk, B. (2013). Origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. *Marine Environmental Research*, *85*, 21–28. https://doi.org/https://doi.org/10.1016/j.marenvres.2012.12.006
41. Tuik. (2022). *Fisheries Statistics of Republic of Turkey*. Retrieved 12.04.2024 from www.tuik.gov.tr
42. Veiga, J. M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., Galgani, F., Thompson, R.C., D., J., Gago, J., Sobral, P. and Cronin, R. (2016). *Identifying Sources of Marine Litter* (JRC Technical Report; EUR 28309;, Issue. M. G. T. M. L. T. Report.
43. Wang, W., Gao, H., Jin, S., Li, R., Na, G. (2019). The ecotoxicological effects of microplastics on aquatic food web, from primary producer to human: A review. *Ecotoxicology and Environmental Safety*, *173*, 110–117. https://doi.org/https://doi.org/10.1016/j.ecoenv.2019.01.113