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RESEARCH PAPER

Microplastic Pollution at Different Trophic Levels of Freshwater Fish in a Variety of Türkiye's Lakes and Dams

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Abstract

Information on the occurrence of microplastic (MP; particles smaller than 5 mm) in freshwater fish biota in the Türkiye is limited. In this study, the microplastic contaminations of seven fish species (*Cyprinus carpio*, *Carassius gibelio*, *Alburnus* spp., *Scardinius erythrophthalmus*, *Vimba vimba*, *Neogobius fluviatilis*, and *Perca fluviatilis*) collected from Lake Manyas, Lake Uluabat, Lake Gala, Lake Gökgöl, Alaçatı Dam, Beydağ Dam, Tahtalı Dam, and Karaidemir Dam were examined. A total of 610 MP particles were extracted from the gastrointestinal systems of all fish species (n: 406). The ingested MPs were only fibers with the dominant plastic color being blue. The length of microplastics ranged from 0.10 to 4.85 mm. Mean MP length size in *C. carpio* species 1.40±0.90 mm, in *C. gibelio* species 1.32±0.88 mm, in *Alburnus* spp. 1.23±0.90 mm, in *S. erythrophthalmus* species 0.94±0.79 mm, in *V. vimba* species 1.11±0.69 mm, in *P. fluviatilis* species 1.34±0.89 mm, in *N. fluviatilis* species 1.25±0.97 mm.
Among the studied species, the most fiber microplastic was found in *P. fluviatilis*. According to habitat and feeding features the highest number of microplastics was found in benthopelagic and invertivore fish. This data is anticipated to form the basis for new research and decision-making processes.

Introduction

Plastics are high molecular-weight polymers produced through the addition or condensation polymerization of monomers as the starting substance. The main sources of these monomers are coal, natural gas, and petroleum. Due to their special qualities, plastics are frequently employed in a variety of sectors, including industry, agriculture, and daily life, which results in a significant amount of plastic trash being produced (PlasticsEurope, 2019). Future trends in consumer behavior and demographics are all pointed to rising plastic consumption. Only 5% of plastic garbage gets recycled in communities, and a sizeable fraction of these products are nonbiodegradable after their useful lives, leading to plastic buildup and environmental damage (Tanaka & Takada, 2016). There are currently approximately 30 000 different types of polymers, both natural and synthetic. When choosing and utilizing specific types of polymers, it is crucial to understand the species and any potential negative effects on ecosystems and human health (Bratovčić et al., 2015). The researchers found microplastic in human blood (Ha et al., 2022), lung tissue (Jenner et al., 2022), placenta (Ragusa et al., 2021), and colectomy specimens (Ibrahim et al., 2021). The most widely used bisphenol compound, bisphenol A, has been linked to numerous human diseases and has been shown to have an estrogen-like impact. Due to the widespread pollution of inland surface waters by microplastics and bisphenol analogs, there is a significant chance for their coexistence (Mu et al., 2022).

The degree to which microplastics damage an organism is most likely dependent on the type of polymer, size, shape, and chemical mixtures involved. Some types of polymers are more harmful than others, depending on the monomers or chemical additives that make them up. Several scientists disagree on whether organisms will be negatively or neutrally impacted by exposure to microplastics. The literature provides evidence to support both sides of this argument. Many studies have found that exposure to microplastics adversely affects an organism's gene expression, survival, or reproduction (Rochman et al., 2019; Seltenrich, 2015). Studies on the ecotoxicity of microplastics have primarily used marine creatures (77%) as compared to freshwater organisms (23%) (de Sá et al., 2018).

Plastics, whether identifiable primary objects or secondary fragmented fragments, make up the bulk of litter in terms of both mass and quantity, and they enter the ocean through rivers, litter discharge, runoff from the land, and ship spills through discharges at sea (Andrady, 2011; Barnes et al., 2009; Gregory & Andrady, 2003; Moore, 2008). Globally, the harm posed by microplastic particles (MP; particles smaller than 5 mm) to human health and the environment is on the rise. The origin, distribution patterns, transport routes, and effects of MPs in the freshwater environment are still largely unknown, despite the fact that research on MPs and their sources, concentrations, transport paths, environmental fates, and effects on biota is fast expanding (Wang et al., 2021).

Microplastics (MPs) may be the most serious ecosystem-scale contaminant due to their global distribution, tiny size, concentrated surface area, abundance, and extensive biogeochemical mobility (Liang et al., 2023). The rising presence of macro- and microplastics in aquatic ecosystems poses a severe environmental problem. Microplastics have the capacity to take in poisons and pollutants from the surrounding environment, which might then transfer those pollutants through the food chain (Bergmann et al., 2022; Koelmans et al., 2016). Microplastics and their dangerous by products can go up the food chain to various trophic levels, endangering both human health and the stability of the marine ecosystem (Diepens & Koelmans, 2018; Miller et al., 2020). MPs are everywhere in the environment, for instance in the air (Dris et al., 2015; Mbachu et al., 2020), sediment (Egessa et al., 2020; Uddin et al., 2021, 2021), drinking water (De Frond et al., 2022), sugar, honey, refreshing beverage, beer, and milk (Diaz-Basantes et al., 2020; Kosuth et al., 2018; Liebezeit & Liebezeit, 2013), white wine (Prata et al., 2020), tea bag (Afrin et al., 2022), and egg (Liu et al., 2022). MPs are primarily introduced into the food chain through aquatic food products. These food products are usually fish (Abbasi et al., 2018; Baalkhuyur et al., 2020; Bessa et al., 2018; Galafassi, Sighicelli, et al., 2021; Halstead et al., 2018; Reboa et al., 2022), canned fish products (Akhbarizadeh et al., 2020; Gündoğdu & Köşker, 2023; Karami et al., 2018), mussels (Gedik & Eryaşar, 2020; Li, et al., 2018a), and seaweed (Li et al., 2020a; Sundbæk et al., 2018).

Türkiye has 25 river basins, 320 natural lakes, and 861 dams, according to the General Directorate of Nature Conservation and National Parks (DSI- General Directorate of State Hydraulic Works, 2023). Due to unsustainable irrigation practices, drought, and increasing pollution levels, Türkiye's freshwater ecosystems are experiencing declining water levels (Çevik et al., 2022). Türkiye's geographic location offers several advantages, including a wealth of aquatic species and resources for fishing. Catching fish in freshwater (20%) and the sea (80%) has contributed to the majority of the production in recent years (Harlioğlu, 2011). According to Béné et al. (2015), more than half of the world's population relies on fish and other aquaculture products for food. Although there has been a problem with microplastic contamination since the 1970s (Carpenter & Smith, 1972), evidence of fish consumption of microplastics was only recently discovered in 2010 when the stomach contents of different marine fish species from the North Pacific Central Gyre were examined (Boerger et al., 2010).

Plastic interacts with about 700 aquatic animals, and it has been discovered in fish's digestive systems, according to research (Hossain et al., 2019). According to Galafassi et al. (2021), only 38% of the 443 original research articles on MPs ingestion by fish described freshwater species exclusively; the majority (62% of the articles described marine species). Despite the increasing attention this research field has received and the sizeable body of evidence that has been built in the last decade, the level of MPs ingested by freshwater fish is still poorly studied when compared to marine species. In contrast to the 48% of publications that looked at marine species, only 14% of all publications were about freshwaters.

Recently, studies on microplastic pollution in marine fish species (Aytan et al., 2022; Güven et al., 2017; Kiliç, 2022; Koraltan et al., 2022) and freshwater fish species have been increasing, especially in Türkiye. But the freshwater fish species and the number of fish species studied are limited. In terms of research on the stomach content of fish in Türkiye; in rivers (Atamanalp et al., 2022; Kılıç et al., 2022), lakes (Atici et al., 2021) and dams (Özhan Turhan, 2021), can be given as examples.

With this research, the presence of microplastics was investigated in fish species caught in different freshwater habitats lakes: (Manyas, Uluabat, Gala, and Gökgöl), and dams (Alaçatı, Beydağ, Tahtalı, and Karaidemir) in Türkiye. This research aims to provide basic data for microplastic studies. Observations on MPs contamination in fish could form the basis for future prevention of microplastic contamination.

Materials & Methods

Study Areas and Fish Sampling

Freshwater fishes of the Cyprinidae, Leuciscidae, Gobiidae, and Percidae families were collected in 2014,2016, and 2018. Where fish are caught in Lake Manyas, Lake Uluabat, Lake Gala, Lake Gökgöl and Alaçatı (Kutlu Aktaş) Dam, Beydağ Dam, Tahtalı Dam, Karaidemir Dam (Table 1, Table 2, and Figure 1).

The fish examined (the 406 fish samples) were supplied from collections consisting of different field studies within TAGEM-15, AR-GE/29 project, etc. These samples were caught by fishermen using various nets in previous years, fixed with 4% formaldehyde, and stored.

Laboratory Processing

Each fish's total and standard length (TL and SL - cm), total body weight (g), and gastrointestinal tract weight (GIT - g) were measured. The GITs of the fish specimens were then dissected and transferred to a petri dish (European Commission, 2013). Organic materials were chemically digested. To accomplish this, each GIT content was separately treated with 30 ml of 35% hydrogen peroxide (H_2O_2) at room temperature for five days. Then, the contents of the petri dish were filtered using a mesh (26 µm) with vacuum filtration. MPs were visually detected in the samples using a Leica MZ6 stereomicroscope (minimum 0.63X and maximum 4.0X) equipped with a Leica DFC320 digital microscope camera. Photographs of detected MPs were taken, and particle lengths were measured using ImageJ software program (https://imagej.nih.gov/ij/). In the end, MPs were categorized according to their physical appearance (fiber, film, etc.) and color (blue, red, green, etc.).

The hot needle test was used to determine if the suspected items were made of plastic or not. The hot needle test was chosen as one of the physical form

Figure 1. Sampling stations on the map of Türkiye.

Table 1. Information on sampling stations.

Basin	Sampling stations	City name of Türkiye	Collection date
Susurluk	Lake Manyas	Balıkesir	2018
Susurluk	Lake Uluabat	Bursa	2016 and 2018
Meriç-Ergene	Lake Gala	Edirne	2016
Konya	Lake Gökgöl	Konya	2016
Küçük Menderes	Alaçatı (Kutlu Aktaş) Dam	İzmir	2014
Küçük Menderes	Beydağ Dam	İzmir	2014
Küçük Menderes	Tahtalı Dam	İzmir	2014
Meriç-Ergene	Karaidemir Dam	Tekirdağ	2016

Table 2. Taxonomic classification of the analyzed fish is available via Fishbase and Glansis (*Fishbase*, 2023; *Glansis NOAA*, 2023).

Family	Scientific name	Common name	Living habitat	Feeding features	Trophic level
Cyprinidae	*Cyprinus carpio* (Linnaeus, 1758)	Common carp	Benthopelagic	Omnivore	3.1
Cyprinidae	*Carassius gibelio* (Bloch, 1782)	Prussian carp	Benthopelagic	Omnivore	2.5
Leuciscidae	*Alburnus* spp.	Bleak	Benthopelagic	Omnivore	2.7
Leuciscidae	*Scardinius erythrophthalmus* (Linnaeus, 1758)	Rudd	Benthopelagic	Omnivore	2.9
Leuciscidae	*Vimba vimba* (Linnaeus,1758)	Vimba bream	Benthopelagic	Invertivore	3.3
Gobiidae	*Neogobius fluviatilis* (Pallas, 1814)	Monkey goby	Benthopelagic	Invertivore	3.4
Percidae	*Perca fluviatilis* (Linnaeus, 1758)	European perch	Demersal	Piscivore	4.4

verification tests for MP identification (Cutroneo et al., 2020; Hermsen et al., 2018; Wootton et al., 2021).

Fourier Transform Infrared Spectroscopy (FTIR) Analysis of Microplastics

Randomly six particles were chosen for FTIR spectroscopy (Thermo Fisher, Nicolet is50) analysis to confirm that the collected microplastic particles were indeed plastic polymers. It was too expensive to use FTIR analysis on a big sample number. Also, sample type and size are also important. However, only three samples could be examined because of MPs size. Micro-FTIR spectroscopy is more efficient because it can test smaller parts but is also more expensive. Particle spectra were analyzed, and their results were compared to library data.

Contamination Control of Microplastics

To prevent MP contamination, clean cotton laboratory coats and single-use gloves were worn at all stages of the procedure. The dissection materials and all work surfaces were cleaned with 70% ethanol. In addition, a petri dish containing pure water was used for contamination control. The control petri dish was checked for the presence of microplastics under a stereo microscope after filtration. The contamination blanks did not contain plastic.

Statistical Analysis

All statistical analyses were performed using the IBM-SPSS (International Business Machines-Software Package for Social Sciences) Statistics, Version 23.0 (Armonk, New York). The data were summarized by frequency tables and descriptive statistics. The normality of data was analyzed by Kolmogorov-Smirnov test and depending on this distributional violation, nonparametric statistical analyses were used. Mann-Whitney U and Kruskal-Wallis tests were used for the comparison of the two and more than two groups in terms of fish quantitative measurements, respectively. A Poisson regression analysis was performed to analyze the relationship between MP density and fish characteristics. The relationships between MP density and fish characteristics were also analyzed by Spearman's Rho correlation coefficient. The significance level was set to 0.05.

Results

Fish Measurements Data and Microplastic Characterization (type, color, and size)

In the present research, microplastic was categorized based on its type, color, and size in all study areas.

The gastrointestinal systems of *Alburnus* spp. (n:19), *V. vimba* (n:14), and *N. fluviatilis* (n:30) species, (a total of 63 fish) from Lake Manyas fauna, were investigated for the presence of microplastics. The highest number of microplastics was found in *N. fluviatilis* at 22 microplastics. The mean number of plastic particles was found as 1.5±0.67, 1.42±0.53, and 1.37±0.80 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-3, 1-2, and 1-4 MPs/individual, respectively.

From the fauna of Lake Uluabat, (total of 60 fish) belonging to the 2016 sampling *Alburnus* spp. (n:30) and *V. vimba* (n:30) species were examined for the presence of microplastics in the gastrointestinal tract. The highest number of microplastics was found in *V. vimba* with 35 microplastics. The mean number of plastic particles was found as 1.76±0.72, and 1.75±0.91 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-3, and 1-4 MPs/individual, respectively.

The gastrointestinal tracts of *V. vimba* (n:32) and *N. fluviatilis* (n:26) species, (a total of 58 fish) belonging to the 2018 sampling, were examined for the presence of microplastics. The most abundant microplastic was found in *V. vimba* at 68 microplastics. The mean number of plastic particles was found as 2.26±1.20, and 1.6±1.05 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-5, and 1-5 MPs/individual, respectively. As a result of the analysis, it was determined that the number of microplastics in the fish samples caught in the changing years increased, but the species containing the most microplastics did not change.

The gastrointestinal tract of *S. erythrophthalmus* species (n:30), from the fauna of Lake Gala, was investigated for the presence of microplastics 61 microplastics were found. The mean number of plastic particles was found as 2.44±1.08 MPs/individual. The minimum and maximum number of plastic particles were found as 1-5 MPs/individual.

The gastrointestinal systems of *C. carpio* (n:11) and *C. gibelio* (n:10) species, (a total of 21 fish) from the fauna of Lake Gökgöl, were investigated for the presence of microplastics. The most abundant microplastic were found in *C. gibelio* as 21 microplastics. The mean number of plastic particles was found as 2.00±0.94, and 2.10±0.87MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-4, and 1-3 MPs/individual, respectively.

The gastrointestinal systems of *C. carpio* (n:21) and *C. gibelio* (n:2) species, (a total of 23 fish) from Alaçatı Dam fauna, were investigated for the presence of microplastics. A total of 23 microplastics were found in the gastrointestinal tract of 16 of 21 *C. carpio*. The mean number of plastic particles was found as 1.43±0.72 MPs/individual at *C. Carpio.* The minimum and maximum number of plastic particles were found as 1-3 MPs/individual, at *C. Carpio.*

The gastrointestinal tracts of *C. gibelio* (n:32) and *P. fluviatilis* (n:28) species, (a total of 60 fish) from the Beydağ Dam fauna, were investigated for the presence of microplastics. A total of 60 microplastics were found in the gastrointestinal tract of 28 *C. gibelio*. The mean number of plastic particles was found as 2.14±1.32, and 2.57±1.38 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-5, and 1-6 MPs/individual, respectively.

The gastrointestinal tracts of *C. carpio* (n:1), *C. gibelio* (n:13) and *P. fluviatilis* (n:30) species, (a total of 44 fish) from the Tahtalı Dam fauna, were investigated for the presence of microplastics. A total of 62 microplastics were found in the gastrointestinal tract of *P. fluviatilis*. The mean number of plastic particles was found as 2.62±0.91, and 2.38±1.42 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 2-4, and 1-7 MPs/individual, respectively (without *C. carpio*).

The gastrointestinal systems of *C. gibelio* (n:10), *Alburnus* spp.(n:14), *V. Vimba* (n:8), and *P. fluviatilis* (n:15) species from the Karaidemir Dam fauna (total of 47 fish) were investigated for the presence of microplastics. A total of 31 microplastics were found in the gastrointestinal tract of *Alburnus* spp. The mean number of plastic particles was found as 2.33±1.00, 3.1±1.37, 2.14±1.06, and 2.44±1.33 MPs/individual, respectively. The minimum and maximum number of plastic particles were found as 1-4, 1-5, 1-4, and 1-5 MPs/individual, respectively.

Summarizes and shows each sampling site and caught fish and their metrics data, and MPs information (color information is not included in the table as the dominant color in all study areas is blue) (Table 3 and Table 4). Additionally, in the current research, microplastic was categorized by type, color, and size in fish samples from all study areas. 610 fiber particles (from 292 fish samples) were visually identified (Figure 2). Different colors of MP fibers were identified and classified into three colors such as blue, red, and green (Figure 3). Based on the size, MP was found in various size ranges, with a minimum of 0.10 and a maximum of 4.85 mm (Table 5). The difference between species in terms of mean MP length size was analyzed by the Kruskal-Wallis test. Test results showed that the effect of species on MP length size was found statistically significant ($p<0.05$). According to the pairwise comparisons, the mean MP length size for *S. erythrophthalmus* was found smaller than most of the other species such as *P. fluviatilis*, *C. carpio*, and *C. gibelio*.

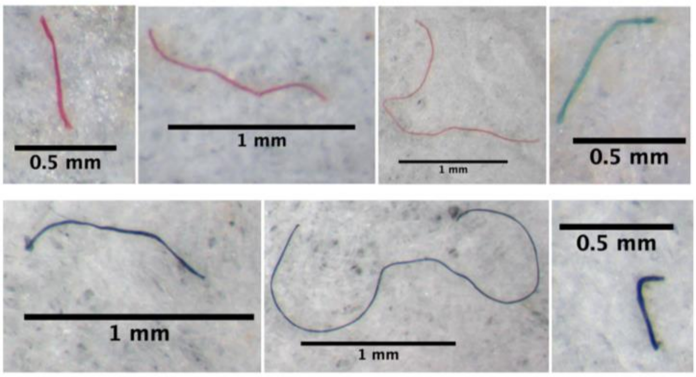

Figure 2. Morphology examples of fiber microplastics detected in fish.

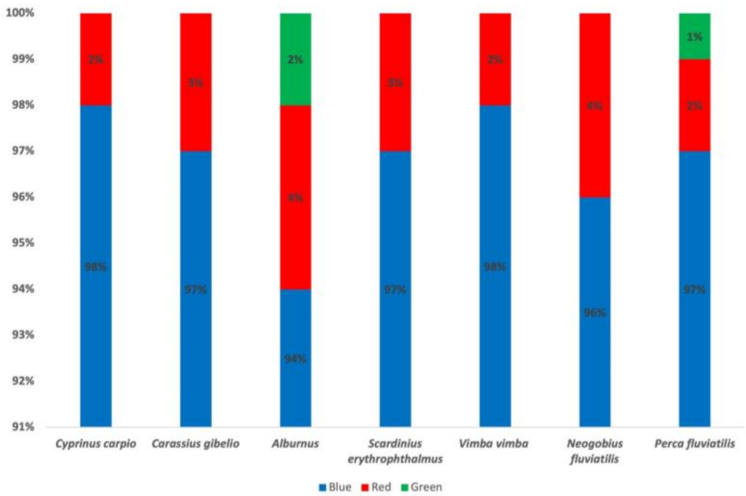

Figure 3. The chromatic classification percentages of MPs in the gastrointestinal tract (GIT) of fish were combined from across all sampling sites.

Table 3. Collected and examined omnivore fish from lakes and dams and their characteristics.

	Omnivore										
	Alburnus spp.			*S.erythrophthalmus*	*C. carpio*		*C. gibelio*				
	Manyas	*Uluabat*	*Karaidemir*	*Gala*	*Gökgöl*	*Alaçatı*	*Gökgöl*	*Alaçatı*	*Beydağ*	*Tahtalı*	*Karaidemir*
n	19	30 [a]	14	30	11	21	10	2	32	13	10
Mean TL ± SD (cm)	10.61±1.77	9.13±0.96[a]	12.12±1.55	17.69±4.08	23.45±2.00	10.88±3.09	14.12±3.09	16.75±6.01	14.71±2.74	17.23±3.28	20.07±4.60
Min. and max. TL size (cm)	6.7-14.3	7.3-10.7 [a]	10.5-15.0	13-27	20.6-26.5	6.5-15.9	7.8-18.4	12.5-21.0	9.6-19.7	14-23.5	14-26.2
Mean body weight (g)	9.15±4.79	5.17±1.65[a]	12.49±4.95	79.10±66.78	186.92±44.34	23.23±18.77	57.99±28.86	87.5±89.80	55.81±34.49	110.79±76.89	122.03±97.91
Mean GIT weight (g)	0.46±0.24	0.26±0.09	0.40±0.18	2.78±2.54	8.05±1.40	1.72±1.31	4.07±2.38	3.1±3.11	1.97±0.81	2.63±1.77	3.3±2.37
Percentage of fish with MP	63.2	43.3	71.4	83.3	90.9	76.2	100.0	50.0	87.5	61.5	90.0
Number of MPs items found by optical analysis	18	23 [a]	31	61	20	23	21	4	60	21	21
Mean MP length size (mm)	1.03±0.89	1.24±0.66[a]	1.34±1.05	0.94±0.79	1.13±0.70	1.63±1.00	1.01±0.57	1.48±1.15	1.19±0.86	1.51±0.91	1.70±1.02
Min. and max. MP length size (mm)	0.18-3.54	0.33-2.68 [a]	0.22-4.6	0.14-3.75	0.19-2.62	0.38-4.03	0.26-2.13	0.4-2.75	0.22-4.5	0.29-3.92	0.32-4.08

Table 4. Collected and examined piscivore and invertivore fish from lakes and dams and their characteristics.

	Piscivore			Invertivore				
	P. fluviatilis				*V. vimba*		*N. fluviatilis*	
	Beydağ	*Tahtalı*	*Karaidemir*	*Manyas*	*Uluabat*	*Karaidemir*	*Manyas*	*Uluabat*
n	28	30	15	14	30 [a] / 32 [b]	8	30	26 [b]
Mean TL ± SD (cm)	10.13±3.04	13.00±3.22	10.27±4.00	8.72±1.04	11.72±3.98 [a] / 11.56±1.95 [b]	12.62±2.23	9.86±2.08	10.78±1.91 [b]
Min. and max. TL size (cm)	7.8-21.6	8.7-21.9	6.4-16.2	7.2-10.6	7.9-20.2 [a] / 8.1-16.3 [b]	10.3-15.7	6.9-15.6	8-14.9 [b]
Mean body weight (g)	17.97±31.28	32.27±31.10	18.71±20.07	5.69±2.23	15.92±16.71 [a] / 16.05±9.31 [b]	18.35±11.02	11.57±10.89	16.16±11.19 [b]
Mean GIT weight (g)	0.53±0.56	1.08±0.89	1.00±1.36	0.3±0.10	0.7±0.72 [a] / 0.84±0.61 [b]	0.71±0.48	0.31±0.23	0.30±0.24 [b]
Percentage of fish with MP	67.9	86.7	60.0	50.0	66.6/93.8	87.5	53.3	61.5
Number of MPs items found by optical analysis	49	62	22	10	35 [a] / 68 [b]	15	22	24 [b]
Mean MP length size (mm)	1.36±0.95	1.43±0.94	1.04±0.48	1.17±1.20	1.09±0.53 [a]/ 1.12±0.71 [b]	1.03±0.48	1.19±0.99	1.30±0.97 [b]
Min. and max. MP length size (mm)	0.15-4.8	0.27-4.85	0.48-2.18	0.1-4.22	0.42-2.85 [a]/ 0.2-3.19 [b]	0.45-1.92	0.18-4.20	0.28-4.38 [b]

The analyzed fish were three categorized into habitat and feeding features. These are: benthopelagic and omnivorous, benthopelagic and invertivore, and lastly demersal and piscivore. The highest amount of microplastics was recorded from Lake Uluabat benthopelagic and invertivore fish (2018 sampling) (Table 6).

The effects of feeding and living habitat on MP measurements were analyzed by Kruskal-Wallis and Mann-Whitney U tests, respectively. The difference between three different feeding features in terms of the number of MP was found statistically significant ($p<0.05$). In piscivores, the number of MP was found higher compared to invertivores. Similarly, the difference between the two habitats in terms of the number of MP was also found statistically significant ($p<0.05$). The number of MP in the demersal habitat was found higher than the benthopelagic. For MP length size, the effects of feeding and living habitat were found statistically non-significant ($p>0.05$) (Table 7).

A Poisson regression analysis was performed to examine the effects of fish characteristics on MP density. The effect of fish length on the number of MP was found statistically significant ($\beta=0.110$, $p=0.000$). According to Spearman's Rho coefficient, the correlation between the number of MP and length was found as 0.34 ($p=0.000$) (Figure 4).

Fourier Transform Infrared Spectroscopy (FTIR)

The polymer type was determined by comparing absorbance spectra to different reference libraries and open-source libraries. In this study, polymer analysis results from the FTIR study found varying matches in different library searches. According to the Open Specy Library, the first example is polyethylene chlorinated, the second is polystyrene and the third is polychloroprene (Figure 5).

Discussion

This study found that of the 406 fish examined, 292 (72%) contained varying amounts of MPs (total MPs n:610). Among the fish species examined, the highest amount of microplastic was detected in *P. fluviatilis* (fish n:73, swallowed MP n:133 pieces), and the least amount of microplastic was detected in *C. carpio* species (fish n:33, swallowed MP n:43 pieces).

This study is one of several demonstrating the consumption of MPs by freshwater organisms. Fiber, determined as the single type of MP result of the study and supported by the previous study results from marine (Aytan et al., 2022; Güven et al., 2017; Koraltan et al., 2022) and freshwater environments of Türkiye (Atamanalp et al., 2022; Atici et al., 2021; Özhan Turhan, 2021) and also from different countries (Jabeen et al.,

Table 5. The size distribution of MPs in the gastrointestinal tracts (GIT) of fish combined from across all sampling sites.

	C. carpio	*C. gibelio*	*Alburnus* spp.	*S. erythrophthalmus*	*V. vimba*	*P. fluviatilis*	*N. fluviatilis*
MP length size (mm) (Mean ± SD)	1.40±0.90	1.32±0.88	1.23±0.90	0.94±0.79	1.11±0.69	1.34±0.89	1.25±0.97
Min. and max. MP length size (mm)	0.19-4.03	0.22-4.5	0.18-4.6	0.14-3.75	0.10-4.22	0.15-4.85	0.18-4.38

Table 6. Grouping of the collected fish according to fish habitat and feeding features.

	Lake Manyas	Lake Uluabat*[a]	Lake Uluabat*[b]	Lake Gala	Lake Gökgöl	Alaçatı Dam	Beydağ Dam	Tahtalı Dam	Karaidemir Dam
Benthopelagic and omnivore	Fish n: 19 MP n: 18	Fish n: 30 MP n: 23		Fish n:30 MP n: 61	Fish n: 21 MP n: 41	Fish n: 23 MP n: 27	Fish n: 32 MP n: 60	Fish n: 14 MP n: 21	Fish n: 24 MP n: 52
Benthopelagic and invertivore	Fish n: 44 MP n: 32	Fish n: 30 MP n: 35	Fish n: 58 MP n: 92						Fish n: 8 MP n: 15
Demersal and piscivore							Fish n: 28 MP n: 49	Fish n: 30 MP n: 62	Fish n: 15 MP n: 22

*[a] Data for 2016, [b] Data for 2018

Table 7. Comparisons of feeding features and fish habitats in terms of number of MP and MP length size.

		Number of MP (Mean ± SD)	p-value	MP length size (mm) (Mean ± SD)	p-value
Feeding	Invertivore	1.81 ± 1.02	[a] 0.003*	1.19 ± 0.77	[a] 0.189
	Omnivore	2.10 ± 1.08		1.23 ± 0.69	
	Piscivore	2.54 ± 1.46		1.38 ± 0.73	
Living Habitat	Benthopelagic	1.98 ± 1.06	[b]0.009*	1.21 ± 0.72	[b]0.081
	Demersal	2.54 ± 1.46		1.38 ± 0.73	

[a]Kruskal-Wallis test [b]Mann-Whithey U test *significant at the 0.05 level

2017; Morgana et al., 2018; Rochman et al., 2015; Vendel et al., 2017).

The smallest MP size was measured in *V. vimba* (0.10 mm), and the largest in *P. fluviatilis* (4.85 mm). Among fibers, the blue color of plastic was the most dominant. The results of this research are in line with the dominant color results in other studies (Atici et al., 2021; Bessa et al., 2018; Dantas et al., 2020; Güven et al., 2017). However by contrast other studies found different dominant colors (Atamanalp et al., 2022; Aytan et al., 2022). The ability of blue to withstand ultraviolet ray deterioration may explain why blue fibers are more common (Martí et al., 2020). This different result may be due to the varying anthropogenic pressures in the regions.

Herbivores and filter-feeding fish living in the upper-middle layer, therefore, do not take food from the sediment and have no raw lumps or fragments in

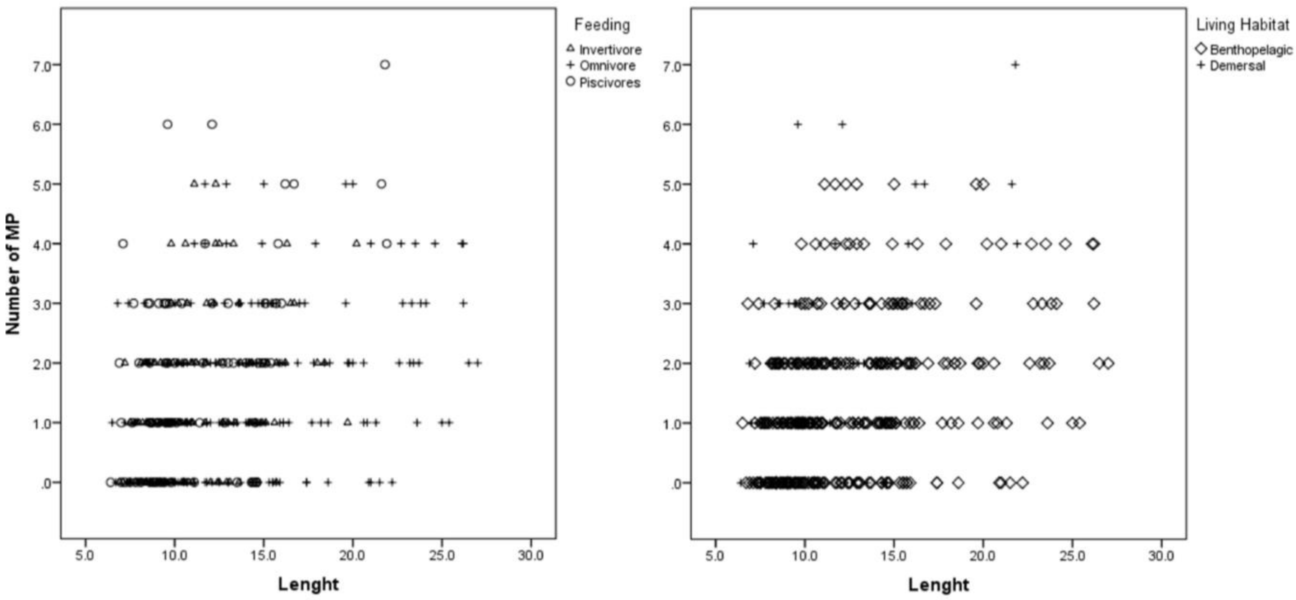

Figure 4. A Poisson regression analysis showing the effects of fish characteristics on MP density.

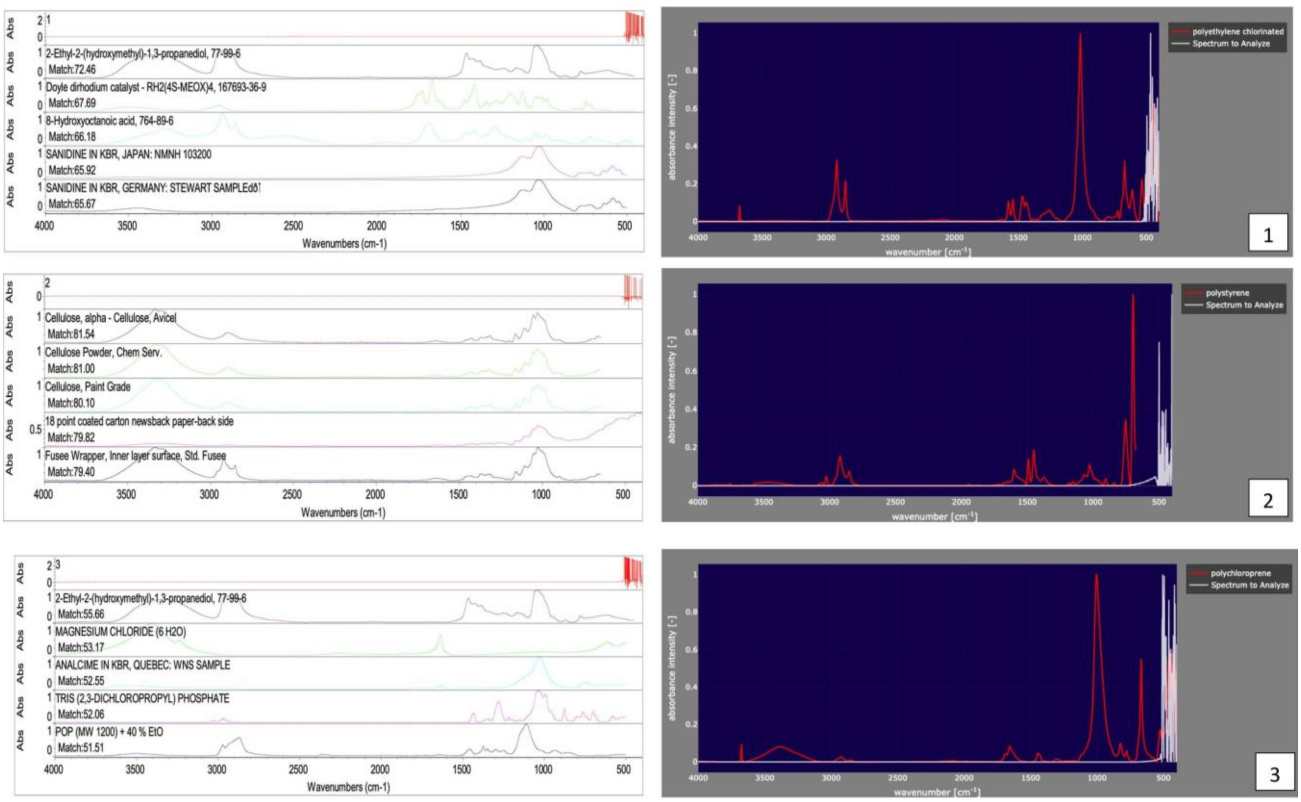

Figure 5. Examples of Fourier transform infrared spectroscopy microplastic analyze. (Left side others library results, right side Open Specy's results)

their bodies. Omnivorous fish, which live mostly in the lower water layer, usually seek benthic food sources above the sediment. This feeding behavior gives fish more chances to capture or ingest microplastics in the sediment (Li et al., 2020b). This is perhaps attributed to the different feeding and living habits of different fish species, resulting in the distinct distribution of MPs in fishes (Silva-Cavalcanti et al., 2017). The highest number of microplastics was found in benthopelagic and invertivore fish belonging to the 2018 sampling in Lake Uluabat (Table 5). This variation may be related to water pollution degree, MPs characteristics, and behavioral and feeding characteristics of fish species.

Spectroscopy is an important step in identifying the polymer of microplastics (Brander et al., 2020; Primpke et al., 2020). In this study, polymer analysis results from the FTIR study found varying matches in different library searches. Maybe this result is related to spectral data classification tools. According to Cowger et al. (2021), spectral matching tools are frequently inaccurate for microplastic identification and are expensive. The lack of precision can be attributed to the large number of microplastic pollutants that are not reflected in spectral libraries.

The majority of microplastics formed in aquatic environments result from the breakdown of bigger plastics resulting in secondary microplastics (Waller et al., 2017). The textile sector and products like clothes, fishing lines and nets, and plastic bags are the principal sources of fibers (Ríos et al., 2022). Microplastic pollution has been introduced to freshwater habitats as a result of inadequate waste management (Issac & Kandasubramanian, 2021). Freshwaters can amass a lot of microplastic fibers and particles, but less work has been done to detect them there than in marine waters. There are certain freshwater lakes and rivers that are near heavily populated areas where microplastic quantity is higher. Studies on microplastic in freshwater ecosystems are characterized by relatively small sample sizes (Li et al., 2018b). Due to their propensity to entangle and linger in the stomach for extended periods, which causes physiological stress, MP fibers can impair eating rates and body mass in marine species (Jeyasanta et al., 2023). It has recently been proposed that adherence provides an additional means for fibrous (with a few angular) microplastics to associate with organs other than the digestive system, similar to how seaweeds accumulate plastics (Gutow et al., 2016). Fibers, like other forms of microplastic, have the potential to ingest harmful substances like polychlorinated biphenyls, arsenic, and methylmercury into a person's body. Cancer, DNA damage, and problems with reproduction have all been linked to such prolonged exposures (Mahu et al., 2023). MPs without additives do not pose a chemical threat to aquatic life, but they do cause physical issues like intestine blockages (Udayakumar et al., 2021). Therefore, MPs are a threat to both aquatic life and public health due to their potential impacts. It is important to monitor them to determine the anthropogenic pressure and it is the association with the microplastic distribution.

In general terms, there are many variables that prevent a meaningful comparison of the results of this study with the results of other studies. Especially plastic diversity, plastic source, and distribution, differences in water, soil, and climatic conditions, seasonal differences, diversity of carriers, socio-economy of the country can be counted among these. On the other hand, fish species, bio-ecology, feeding type, lifespan, growth rate, breeding times, habitat preferences, height, and weight differences are among the variables that make comparisons difficult.

Conclusion

These days, microplastics are a common sight in the environment. As particle size is reduced, the surface area to volume ratio increases. Therefore, the characteristics of small particles' surface area have a greater impact on their chemical behavior than do the components of their composition.

Therefore, it is impossible to extrapolate the interactions between microplastics and the environment from the behavior of macroplastics. To be able to assess the degree of food contamination, it is crucial to comprehend the pathways via which microplastics are contaminating foods and beverages. Given the commercial interest in some small-scale fisheries markets for lake fish, the potential impact on human consumption and health should be investigated.

This study was carried out on freshwater fish samples of different trophic statuses in different regions. All the fish species examined had fiber microplastic, which shows how commonplace it is in freshwater ecosystems. More extensive research is needed to observe the current anthropogenic effects in the study areas.

In this regard, urgent action must be taken at the national and international levels to solve the microplastic problem. Politically and socio-economically feasible preventative microplastics contamination actions should be implemented.

Ethical Statement

Formal consent is not needed for this kind of research.

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Author Contribution

S.V.Y.: conceptualization, investigation, visualization, supervision, funding acquisition, writing original draft S.B.: investigation, data curation, visualization, writing original draft

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References

Abbasi, S., Soltani, N., Keshavarzi, B., Moore, F., Turner, A., & Hassanaghaei, M. (2018). Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere, 205, 80–87. https://doi.org/10.1016/j.chemosphere.2018.04.076

Afrin, S., Rahman, Md. M., Akbor, Md. A., Siddique, Md. A. B., Uddin, Md. K., & Malafaia, G. (2022). Is there tea complemented with the appealing flavor of microplastics? A pioneering study on plastic pollution in commercially available tea bags in Bangladesh. Science of The Total Environment, 837, 155833. https://doi.org/10.1016/j.scitotenv.2022.155833

Akhbarizadeh, R., Dobaradaran, S., Nabipour, I., Tajbakhsh, S., Darabi, A. H., & Spitz, J. (2020). Abundance, composition, and potential intake of microplastics in canned fish. Marine Pollution Bulletin, 160, 111633. https://doi.org/10.1016/j.marpolbul.2020.111633

Andrady, A. L. (2011). Microplastics in the marine environment. Marine Pollution Bulletin, 62(8), 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Atamanalp, M., Köktürk, M., Parlak, V., Ucar, A., Arslan, G., & Alak, G. (2022). A new record for the presence of microplastics in dominant fish species of the Karasu River Erzurum, Turkey. Environmental Science and Pollution Research, 29(5), 7866–7876. https://doi.org/10.1007/s11356-021-16243-w

Atici, A. A., Sepil, A., & Sen, F. (2021). High levels of microplastic ingestion by commercial, planktivorous Alburnus tarichi in Lake Van, Turkey. Food Additives & Contaminants: Part a, 38(10), 1767–1777.

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). https://www.trjfas.org/abstract.php?lang=en&id=14878

Baalkhuyur, F. M., Qurban, M. A., Panickan, P., & Duarte, C. M. (2020). Microplastics in fishes of commercial and ecological importance from the Western Arabian Gulf. Marine Pollution Bulletin, 152, 110920. https://doi.org/10.1016/j.marpolbul.2020.110920

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Béné, C., Barange, M., Subasinghe, R., Pinstrup-Andersen, P., Merino, G., Hemre, G.-I., & Williams, M. (2015). Feeding 9 billion by 2050 – Putting fish back on the menu. Food Security, 7(2), 261–274. https://doi.org/10.1007/s12571-015-0427-z

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G. W., Provencher, J. F., Rochman, C. M., van Sebille, E., & Tekman, M. B. (2022). Plastic pollution in the Arctic. Nature Reviews Earth & Environment, 3(5), 323–337. https://doi.org/10.1038/s43017-022-00279-8

Bessa, F., Barría, P., Neto, J. M., Frias, J. P. G. L., Otero, V., Sobral, P., & Marques, J. C. (2018). Occurrence of microplastics in commercial fish from a natural estuarine environment. Marine Pollution Bulletin, 128, 575–584. https://doi.org/10.1016/j.marpolbul.2018.01.044

Boerger, C. M., Lattin, G. L., Moore, S. L., & Moore, C. J. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Marine Pollution Bulletin, 60(12), 2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007

Brander, S. M., Renick, V. C., Foley, M. M., Steele, C., Woo, M., Lusher, A., Carr, S., Helm, P., Box, C., Cherniak, S., Andrews, R. C., & Rochman, C. M. (2020). Sampling and Quality Assurance and Quality Control: A Guide for Scientists Investigating the Occurrence of Microplastics Across Matrices. Applied Spectroscopy, 74(9), 1099–1125. https://doi.org/10.1177/0003702820945713

Bratovčić, A., Odobašić, A., Ćatić, S., & Šestan, I. (2015). Application of polymer nanocomposite materials in food packaging. Croatian Journal of Food Science and Technology, 7(2), 86–94. https://doi.org/10.17508/CJFST.2015.7.2.06

Carpenter, E. J., & Smith, K. L. (1972). Plastics on the Sargasso sea surface. Science (New York, N.Y.), 175(4027), 1240–1241. https://doi.org/10.1126/science.175.4027.1240

Çevik, C., Kıdeyş, A. E., Tavşanoğlu, Ü. N., Kankılıç, G. B., & Gündoğdu, S. (2022). A review of plastic pollution in aquatic ecosystems of Turkey. Environmental Science and Pollution Research, 29(18), 26230–26249. https://doi.org/10.1007/s11356-021-17648-3

Cowger, W., Steinmetz, Z., Gray, A., Munno, K., Lynch, J., Hapich, H., Primpke, S., De Frond, H., Rochman, C., & Herodotou, O. (2021). Microplastic Spectral Classification Needs an Open Source Community: Open Specy to the Rescue! Analytical Chemistry, 93(21), 7543–7548. https://doi.org/10.1021/acs.analchem.1c00123

Cutroneo, L., Reboa, A., Besio, G., Borgogno, F., Canesi, L., Canuto, S., Dara, M., Enrile, F., Forioso, I., Greco, G., Lenoble, V., Malatesta, A., Mounier, S., Petrillo, M., Rovetta, R., Stocchino, A., Tesan, J., Vagge, G., & Capello, M. (2020). Correction to: Microplastics in seawater: sampling strategies, laboratory methodologies, and identification techniques applied to port environment. Environmental Science and Pollution Research, 27(16), 20571–20571. https://doi.org/10.1007/s11356-020-08704-5

Dantas, N. C. F. M., Duarte, O. S., Ferreira, W. C., Ayala, A. P., Rezende, C. F., & Feitosa, C. V. (2020). Plastic intake does not depend on fish eating habits: Identification of microplastics in the stomach contents of fish on an urban beach in Brazil. Marine Pollution Bulletin, 153, 110959. https://doi.org/10.1016/j.marpolbul.2020.110959

De Frond, H., Thornton Hampton, L., Kotar, S., Gesulga, K., Matuch, C., Lao, W., Weisberg, S. B., Wong, C. S., & Rochman, C. M. (2022). Monitoring microplastics in drinking water: An interlaboratory study to inform effective methods for quantifying and characterizing microplastics. Chemosphere, 298, 134282. https://doi.org/10.1016/j.chemosphere.2022.134282

de Sá, L. C., Oliveira, M., Ribeiro, F., Rocha, T. L., & Futter, M. N. (2018). Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? Science of The Total Environment, 645, 1029–1039. https://doi.org/10.1016/j.scitotenv.2018.07.207

Diaz-Basantes, M. F., Conesa, J. A., & Fullana, A. (2020). Microplastics in Honey, Beer, Milk and Refreshments in Ecuador as Emerging Contaminants. Sustainability, 12(14), Article 14. https://doi.org/10.3390/su12145514

Diepens, N. J., & Koelmans, A. A. (2018). Accumulation of Plastic Debris and Associated Contaminants in Aquatic Food Webs. Environmental Science & Technology, 52(15), 8510–8520. https://doi.org/10.1021/acs.est.8b02515

Dris, R., Gasperi, J., Rocher, V., Saad, M., Renault, N., & Tassin, B. (2015). Microplastic contamination in an urban area: A case study in Greater Paris. Environmental Chemistry, 12(5), 592–599. https://doi.org/10.1071/EN14167

DSI- General Directorate of State Hydraulic Works. (2023). https://www.dsi.gov.tr/Sayfa/Detay/754

Egessa, R., Nankabirwa, A., Basooma, R., & Nabwire, R. (2020). Occurrence, distribution and size relationships of plastic debris along shores and sediment of northern Lake Victoria. Environmental Pollution (Barking, Essex: 1987), 257, 113442. https://doi.org/10.1016/j.envpol.2019.113442

European Commission. (2013). Guidance on monitoring of marine litter in European seas. Publications Office. https://data.europa.eu/doi/10.2788/99475

Fishbase. (2023). https://www.fishbase.se/search.php

Galafassi, S., Campanale, C., Massarelli, C., Uricchio, V. F., & Volta, P. (2021). Do Freshwater Fish Eat Microplastics? A Review with A Focus on Effects on Fish Health and Predictive Traits of MPs Ingestion. Water, 13(16), Article 16. https://doi.org/10.3390/w13162214

Galafassi, S., Sighicelli, M., Pusceddu, A., Bettinetti, R., Cau, A., Temperini, M. E., Gillibert, R., Ortolani, M., Pietrelli, L., Zaupa, S., & Volta, P. (2021). Microplastic pollution in perch (*Perca fluviatilis*, Linnaeus 1758) from Italian south-alpine lakes. Environmental Pollution, 288, 117782. https://doi.org/10.1016/j.envpol.2021.117782

Gedik, K., & Eryaşar, A. R. (2020). Microplastic pollution profile of Mediterranean mussels (*Mytilus galloprovincialis*) collected along the Turkish coasts. Chemosphere, 260, 127570. https://doi.org/10.1016/j.chemosphere.2020.127570

Glansis NOAA. (2023). https://www.glerl.noaa.gov/glansis/

Gregory, M. R., & Andrady, A. L. (2003). Plastics in the Marine Environment. In Plastics and the Environment (pp. 379–401). John Wiley & Sons, Ltd. https://doi.org/10.1002/0471721557.ch10

Gündoğdu, S., & Köşker, A. R. (2023). Microplastic contamination in canned fish sold in Türkiye. PeerJ, 11, e14627. https://doi.org/10.7717/peerj.14627

Gutow, L., Eckerlebe, A., Giménez, L., & Saborowski, R. (2016). Experimental Evaluation of Seaweeds as a Vector for Microplastics into Marine Food Webs. Environmental Science & Technology, 50(2), 915–923. https://doi.org/10.1021/acs.est.5b02431

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/10.1016/j.envpol.2017.01.025

Ha, L., Mjm, van V., Sh, B., Ad, V., Jj, G.-V., & Mh, L. (2022). Discovery and quantification of plastic particle pollution in human blood. Environment International, 163. https://doi.org/10.1016/j.envint.2022.107199

Halstead, J. E., Smith, J. A., Carter, E. A., Lay, P. A., & Johnston, E. L. (2018). Assessment tools for microplastics and natural fibres ingested by fish in an urbanised estuary. Environmental Pollution (Barking, Essex: 1987), 234, 552–561. https://doi.org/10.1016/j.envpol.2017.11.085

Harlioğlu, A. G. (2011). Present status of fisheries in Turkey. Reviews in Fish Biology and Fisheries, 21(4), 667–680. https://doi.org/10.1007/s11160-011-9204-z

Hermsen, E., Mintenig, S. M., Besseling, E., & Koelmans, A. A. (2018). Quality Criteria for the Analysis of Microplastic in Biota Samples: A Critical Review. Environmental Science & Technology, 52(18), 10230–10240. https://doi.org/10.1021/acs.est.8b01611

Hossain, M. S., Sobhan, F., Uddin, M. N., Sharifuzzaman, S. M., Chowdhury, S. R., Sarker, S., & Chowdhury, M. S. N. (2019). Microplastics in fishes from the Northern Bay of Bengal. The Science of the Total Environment, 690, 821–830. https://doi.org/10.1016/j.scitotenv.2019.07.065

Ibrahim, Y. S., Tuan Anuar, S., Azmi, A. A., Wan Mohd Khalik, W. M. A., Lehata, S., Hamzah, S. R., Ismail, D., Ma, Z. F., Dzulkarnaen, A., Zakaria, Z., Mustaffa, N., Tuan Sharif, S. E., & Lee, Y. Y. (2021). Detection of microplastics in human colectomy specimens. JGH Open, 5(1), 116–121. https://doi.org/10.1002/jgh3.12457

Issac, M. N., & Kandasubramanian, B. (2021). Effect of microplastics in water and aquatic systems. Environmental Science and Pollution Research, 28(16), 19544–19562. https://doi.org/10.1007/s11356-021-13184-2

Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., & Shi, H. (2017). Microplastics and mesoplastics in fish from coastal and fresh waters of China. Environmental Pollution, 221, 141–149. https://doi.org/10.1016/j.envpol.2016.11.055

Jenner, L. C., Rotchell, J. M., Bennett, R. T., Cowen, M., Tentzeris, V., & Sadofsky, L. R. (2022). Detection of microplastics in human lung tissue using μFTIR spectroscopy. Science of The Total Environment, 831, 154907. https://doi.org/10.1016/j.scitotenv.2022.154907

Jeyasanta, K. I., Laju, R. L., Patterson, J., Jayanthi, M., Bilgi, D. S., Sathish, N., & Edward, J. K. P. (2023). Microplastic pollution and its implicated risks in the estuarine environment of Tamil Nadu, India. Science of The Total Environment, 861, 160572. https://doi.org/10.1016/j.scitotenv.2022.160572

Karami, A., Golieskardi, A., Choo, C. K., Larat, V., Karbalaei, S., & Salamatinia, B. (2018). Microplastic and mesoplastic contamination in canned sardines and sprats. Science of The Total Environment, 612, 1380–1386. https://doi.org/10.1016/j.scitotenv.2017.09.005

Kiliç, E. (2022). Microplastic Occurrence in the Gill and Gastrointestinal Tract of Chelon ramada (Mugilidae) in a Highly Urbanized Region, İskenderun Bay, Türkiye. Marine Science and Technology Bulletin, 11(Early View), 309–319. https://doi.org/10.33714/masteb.1162225

Kılıç, E., Yücel, N., & Mübarek Şahutoğlu, S. (2022). First record of microplastic occurence at the commercial fish from Orontes River. Environmental Pollution, 307, 119576. https://doi.org/10.1016/j.envpol.2022.119576

Koelmans, A. A., Bakir, A., Burton, G. A., & Janssen, C. R. (2016). Microplastic as a Vector for Chemicals in the Aquatic Environment: Critical Review and Model-Supported

Reinterpretation of Empirical Studies. Environmental Science & Technology, 50(7), 3315–3326. https://doi.org/10.1021/acs.est.5b06069

Koraltan, İ., Mavruk, S., & Güven, O. (2022). Effect of biological and environmental factors on microplastic ingestion of commercial fish species. Chemosphere, 303, 135101. https://doi.org/10.1016/j.chemosphere.2022.135101

Kosuth, M., Mason, S. A., & Wattenberg, E. V. (2018). Anthropogenic contamination of tap water, beer, and sea salt. PLOS ONE, 13(4), e0194970. https://doi.org/10.1371/journal.pone.0194970

Li, B., Su, L., Zhang, H., Deng, H., Chen, Q., & Shi, H. (2020b). Microplastics in fishes and their living environments surrounding a plastic production area. Science of The Total Environment, 727, 138662. https://doi.org/10.1016/j.scitotenv.2020.138662

Li, J., Green, C., Reynolds, A., Shi, H., & Rotchell, J. M. (2018a). Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. Environmental Pollution, 241, 35–44. https://doi.org/10.1016/j.envpol.2018.05.038

Li, J., Liu, H., & Paul Chen, J. (2018b). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Research, 137, 362–374. https://doi.org/10.1016/j.watres.2017.12.056

Li, Q., Feng, Z., Zhang, T., Ma, C., & Shi, H. (2020a). Microplastics in the commercial seaweed nori. Journal of Hazardous Materials, 388, 122060. https://doi.org/10.1016/j.jhazmat.2020.122060

Liang, W., Li, B., Jong, M.-C., Ma, C., Zuo, C., Chen, Q., & Shi, H. (2023). Process-oriented impacts of microplastic fibers on behavior and histology of fish. Journal of Hazardous Materials, 130856. https://doi.org/10.1016/j.jhazmat.2023.130856

Liebezeit, G., & Liebezeit, E. (2013). Non-pollen particulates in honey and sugar. Food Additives & Contaminants. Part A, Chemistry, Analysis, Control, Exposure & Risk Assessment, 30(12), 2136–2140. https://doi.org/10.1080/19440049.2013.843025

Liu, Q., Chen, Z., Chen, Y., Yang, F., Yao, W., & Xie, Y. (2022). Microplastics contamination in eggs: Detection, occurrence and status. Food Chemistry, 397, 133771. https://doi.org/10.1016/j.foodchem.2022.133771

Mahu, E., Datsomor, W. G., Folorunsho, R., Fisayo, J., Crane, R., Marchant, R., Montford, J., Boateng, M. C., Edusei Oti, M., Oguguah, M. N., & Gordon, C. (2023). Human health risk and food safety implications of microplastic consumption by fish from coastal waters of the eastern equatorial Atlantic Ocean. Food Control, 145, 109503. https://doi.org/10.1016/j.foodcont.2022.109503

Martí, E., Martin, C., Galli, M., Echevarría, F., Duarte, C. M., & Cózar, A. (2020). The Colors of the Ocean Plastics. Environmental Science & Technology, 54(11), 6594–6601. https://doi.org/10.1021/acs.est.9b06400

Mbachu, O., Jenkins, G., Pratt, C., & Kaparaju, P. (2020). A New Contaminant Superhighway? A Review of Sources, Measurement Techniques and Fate of Atmospheric Microplastics. Water, Air, & Soil Pollution, 231(2), 85. https://doi.org/10.1007/s11270-020-4459-4

Miller, M. E., Hamann, M., & Kroon, F. J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. PLOS ONE, 15(10), e0240792. https://doi.org/10.1371/journal.pone.0240792

Moore, C. J. (2008). Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research, 108(2), 131–139. https://doi.org/10.1016/j.envres.2008.07.025

Morgana, S., Ghigliotti, L., Estévez-Calvar, N., Stifanese, R., Wieckzorek, A., Doyle, T., Christiansen, J. S., Faimali, M., & Garaventa, F. (2018). Microplastics in the Arctic: A case study with sub-surface water and fish samples off Northeast Greenland. Environmental Pollution (Barking, Essex: 1987), 242(Pt B), 1078–1086. https://doi.org/10.1016/j.envpol.2018.08.001

Mu, X., Qi, S., Liu, J., Yuan, L., Huang, Y., Xue, J., Qian, L., Wang, C., & Li, Y. (2022). Toxicity and behavioral response of zebrafish exposed to combined microplastic and bisphenol analogues. Environmental Chemistry Letters, 20(1), 41–48. https://doi.org/10.1007/s10311-021-01320-w

Özhan Turhan, D. (2021). Evaluation of Microplastics in the Surface Water, Sediment and Fish of Sürgü Dam Reservoir (Malatya) in Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 22(Special Issue). https://doi.org/10.4194/TRJFAS20157

PlasticsEurope, E. (2019). Plastics—The facts 2019. An analysis of European plastics production, demand and waste data. PlasticEurope Https://Www. Plasticseurope. Org/En/Resources/Publications/1804-Plastics-Facts-2019.

Prata, J. C., Paço, A., Reis, V., da Costa, J. P., Fernandes, A. J. S., da Costa, F. M., Duarte, A. C., & Rocha-Santos, T. (2020). Identification of microplastics in white wines capped with polyethylene stoppers using micro-Raman spectroscopy. Food Chemistry, 331, 127323. https://doi.org/10.1016/j.foodchem.2020.127323

Primpke, S., Christiansen, S. H., Cowger, W., De Frond, H., Deshpande, A., Fischer, M., Holland, E. B., Meyns, M., O'Donnell, B. A., Ossmann, B. E., Pittroff, M., Sarau, G., Scholz-Böttcher, B. M., & Wiggin, K. J. (2020). Critical Assessment of Analytical Methods for the Harmonized and Cost-Efficient Analysis of Microplastics. Applied Spectroscopy, 74(9), 1012–1047. https://doi.org/10.1177/0003702820921465

Ragusa, A., Svelato, A., Santacroce, C., Catalano, P., Notarstefano, V., Carnevali, O., Papa, F., Rongioletti, M. C. A., Baiocco, F., Draghi, S., D'Amore, E., Rinaldo, D., Matta, M., & Giorgini, E. (2021). Plasticenta: First evidence of microplastics in human placenta. Environment International, 146, 106274. https://doi.org/10.1016/j.envint.2020.106274

Reboa, A., Cutroneo, L., Consani, S., Geneselli, I., Petrillo, M., Besio, G., & Capello, M. (2022). Mugilidae fish as bioindicator for monitoring plastic pollution: Comparison between a commercial port and a fishpond (north-western Mediterranean Sea). Marine Pollution Bulletin, 177, 113531. https://doi.org/10.1016/j.marpolbul.2022.113531

Ríos, J. M., Teixeira de Mello, F., De Feo, B., Krojmal, E., Vidal, C., Loza-Argote, V. A., & Scheibler, E. E. (2022). Occurrence of microplastics in Fish from Mendoza River: First Insights into Plastic Pollution in the Central Andes, Argentina. Water, 14(23), Article 23. https://doi.org/10.3390/w14233905

Rochman, C. M., Brookson, C., Bikker, J., Djuric, N., Earn, A., Bucci, K., Athey, S., Huntington, A., McIlwraith, H., Munno, K., De Frond, H., Kolomijeca, A., Erdle, L., Grbic, J., Bayoumi, M., Borrelle, S. B., Wu, T., Santoro, S., Werbowski, L. M., … Hung, C. (2019). Rethinking microplastics as a diverse contaminant suite. Environmental Toxicology and Chemistry, 38(4), 703–711. https://doi.org/10.1002/etc.4371

Rochman, C. M., Tahir, A., Williams, S. L., Baxa, D. V., Lam, R., Miller, J. T., Teh, F.-C., Werorilangi, S., & Teh, S. J. (2015). Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports, 5(1), Article 1. https://doi.org/10.1038/srep14340

Seltenrich, N. (2015). New Link in the Food Chain? Marine Plastic Pollution and Seafood Safety. Environmental Health Perspectives, 123, A34-41. https://doi.org/10.1289/ehp.123-A34

Silva-Cavalcanti, J. S., Silva, J. D. B., França, E. J. de, Araújo, M. C. B. de, & Gusmão, F. (2017). Microplastics ingestion by a common tropical freshwater fishing resource. Environmental Pollution, 221, 218–226. https://doi.org/10.1016/j.envpol.2016.11.068

Sundbæk, K. B., Koch, I. D. W., Villaro, C. G., Rasmussen, N. S., Holdt, S. L., & Hartmann, N. B. (2018). Sorption of fluorescent polystyrene microplastic particles to edible seaweed Fucus vesiculosus. Journal of Applied Phycology, 30(5), 2923–2927. https://doi.org/10.1007/s10811-018-1472-8

Tanaka, K., & Takada, H. (2016). Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. Scientific Reports, 6(1), Article 1. https://doi.org/10.1038/srep34351

Udayakumar, K. V., Gore, P. M., & Kandasubramanian, B. (2021). Foamed materials for oil-water separation. Chemical Engineering Journal Advances, 5, 100076. https://doi.org/10.1016/j.ceja.2020.100076

Uddin, S., Fowler, S. W., Uddin, Mohd. F., Behbehani, M., & Naji, A. (2021). A review of microplastic distribution in sediment profiles. Marine Pollution Bulletin, 163, 111973. https://doi.org/10.1016/j.marpolbul.2021.111973

Vendel, A. L., Bessa, F., Alves, V. E. N., Amorim, A. L. A., Patrício, J., & Palma, A. R. T. (2017). Widespread microplastic ingestion by fish assemblages in tropical estuaries subjected to anthropogenic pressures. Marine Pollution Bulletin, 117(1), 448–455. https://doi.org/10.1016/j.marpolbul.2017.01.081

Waller, C. L., Griffiths, H. J., Waluda, C. M., Thorpe, S. E., Loaiza, I., Moreno, B., Pacherres, C. O., & Hughes, K. A. (2017). Microplastics in the Antarctic marine system: An emerging area of research. Science of The Total Environment, 598, 220–227. https://doi.org/10.1016/j.scitotenv.2017.03.283

Wang, Z., Zhang, Y., Kang, S., Yang, L., Shi, H., Tripathee, L., & Gao, T. (2021). Research progresses of microplastic pollution in freshwater systems. Science of The Total Environment, 795, 148888. https://doi.org/10.1016/j.scitotenv.2021.148888

Wootton, N., Reis-Santos, P., & Gillanders, B. M. (2021). Microplastic in fish – A global synthesis. Reviews in Fish Biology and Fisheries, 31(4), 753–771. https://doi.org/10.1007/s11160-021-09684-6