ILMU KELAUTAN: Indonesian Journal of Marine Sciences *September 2022 Vol 27(3):199-214* *e-ISSN 2406-7598*

Microplastics in Organs of Commercial Marine Fishes from Five Fishing Ports in Java Island, Indonesia

Defri Yona[1,4,*], Mangesti Reza Evitantri[1], Danu Setia Wardana[1], Dyah Ajeng Pitaloka[1], Diana Ningrum[1], M. Arif Zainul Fuad[1,4], Yuniar Ponco Prananto[2], Ledhyane Ika Harlyan[3,4], Atsuhiko Isobe[5]

[1]Marine Science Department, Fisheries and Marine Science Faculty, Brawijaya University
[2]Department of Chemistry, Faculty of Science, Brawijaya University
[3]Fisheries Resources and Utilization Department, Fisheries and Marine Science Faculty, Brawijaya University
[4]Marine Resources Exploration and Management Research Group Brawijaya University
Jl. Veteran, Malang 65145 Indonesia
[5]Research Institute for Applied Mechanics, Kyushu University
6-1 Kasuga-Koen, Kasuga 816-8580, Japan
Email: defri.yona@ub.ac.id

Abstract

Microplastics have been found in the marine environment worldwide. Due to their very small size, it could be ingested by marine organisms from small size plankton to big size fish. The aim of this study is to assess the variability of microplastics in three different organs (gills, gastrointestinal tracts, and muscles) of commercial fishes in five different fishing ports in East Java Province, Indonesia. A total of 137 fish samples from 14 species were extracted to identify the types of microplastics. The microplastics found in the fish samples were mostly dominated by fiber, fragments, and a little quantity of film. In most species, the gills accumulated more microplastics compared to the gastrointestinal tracts and muscles. Gill is the organ that is highly exposed to the environmental conditions, therefore, it is more susceptible to the microplastic contamination. The results showed that there was an inverse relationship between the size of the fish and the occurrence of microplastics (P<0.05). Small size Sardinella lemuru contained more microplastics than bigger size fish such as Katsuwonus pelamis. The variability of microplastics found in this study showed important factors such as habitat, fish size, feeding behavior, and organ function which influenced the ingestion process of microplastic. This study also revealed the presence of microplastics were not only in the gills and gastrointestinal tracts of fish, but also in its muscles. Since this study targeted commercial fishes, further research is needed to know the possible impact on human consumption of fish containing microplastics.

Keywords: *Demersal fish, Eastern Indian Ocean, Java Sea, Pelagic fish, Plastic pollution*

Introduction

The increasing concentration of microplastics in the marine environment has become a major issue worldwide. It could be found in five main ocean compartments: on the surface, in the water column, seafloor, shoreline and in biota (GESAMP, 2016). The small size of microplastics make them easily transported by surface currents and winds between those compartments (Iwasaki *et al*., 2017; Welden and Lusher, 2017). The study of microplastics on the ocean surface has been conducted in various parts of the world (Cincinelli *et al.,* 2017; Isobe *et al.,* 2017; Pan *et al.,* 2019), in the water column (Choy *et al.,* 2019; Kanhai *et al.,* 2017; Tielman *et al.,* 2022), on the seafloor (Cauwenberghe *et al.,* 2013; Woodall *et al.,* 2014; Zobkov and Esiukova, 2017) and on the shoreline (Chae *et al.,* 2015; Chubarenko and Stepanova 2017; Sagawa *et al.,* 2018). In the marine biota, microplastics have been recorded in zooplankton (Frias *et al.,* 2014; Iliff *et al.,* 2020), benthic organisms (Scott *et al.,* 2019; Wang *et al.,* 2019; Webb *et al.,* 2019), fish (Abbasi *et al.,* 2018; Murphy *et al.,* 2017; Ory *et al.,* 2018; Sathish *et al.,* 2020), sea turtles (Caron *et al.,* 2018a; 2018b) and seabirds (Provencher *et al.,* 2018).

The presence of microplastics in commercial marine fish species have also been subjects to many studies (Neves *et al.,* 2015; Bessa *et al.,* 2018; Giani *et al.,* 2019; Karbalaei *et al.,* 2019; Pozo *et al.,* 2019; Su *et al.,* 2019). Fish is one of the most important sources of food to human because of its high nutritional quality. They are high in fatty acids (omega-3 and omega-6), contain high amino acid and important minerals and vitamins for human health

*) Corresponding author

https://ejournal.undip.ac.id/index.php/ijms
DOI: 10.14710/ik.ijms.27.3.199-214
Received : 18-05-2022
Accepted : 02-07-2022

(Pal *et al.,* 2018). Although there are still few studies on the effect of consuming fish that contains microplastics on human health, awareness should be raised since the presence of microplastics in the marine environment is increasing (Lusher *et al.,* 2017).

Microplastics have potential of being absorbed by different species of fish from many different habitats (Murphy *et al.,* 2017; Pereira *et al.,* 2020; Sathish *et al.,* 2020; Yona *et al.,* 2020). Furthermore, the accumulation of microplastics into their body mostly comes from the ingestion process, either directly or indirectly. The direct ingestion of microplastics occurs because the fish considered it as their natural food (Neves *et al.,* 2015), while indirect ingestion occurs through the ingestion of preys already containing it (Lusher *et al.,* 2017). In addition, the accumulation of microplastics also the result of the respiration process when the fish filters the seawater to obtain oxygen and directly absorbed it (Abbasi *et al.,* 2018). The presence of microplastics in commercial fishes have been conducted by many studies worldwide (Neves *et al.,* 2015; Rochman *et al.,* 2015; Bessa *et al.,* 2018; Karbalaei *et al.,* 2019; Su *et al.,* 2019; Daniel *et al.,* 2020). These study emphazied that the consumption of fish contained microplastics is the major route of human exposure to microplastics through food chain.

Depending on the absorption process, the fish could accumulate microplastics into their different organs such as gills, gastrointestinal tracts (GIT), muscles and liver. The gastrointestinal tract is the most studied organ regarding the accumulation of microplastics (Franzellitti *et al.,* 2019) and it supports the reason that fish often mistake it as its prey (Bessa *et al.,* 2018). The gills could also be considered as a vulnerable organ in accumulating microplastics directly from the environment (Abbasi *et al.,* 2018; Lin *et al.,* 2020; Yona *et al.,* 2020). In addition, Su *et al.* (2019) stated that the gastrointestinal tract and gills are exposed to different types of microplastics. Microplastics have been found in other organs, such as liver and muscles, and translocation process may be the reason for their occurrence (Franzellitti *et al.,* 2019; Su *et al.,* 2019). There are few studies that focus mainly on different organs in order to understand the accumulation of microplastics in fishes, especially in Indonesia. Most studies have also targeted gastrointestinal tracts to observed the presence of microplastics (Efadeswarni *et al*., 2019; Priscilla and Patria, 2020; Suwartiningsih *et al*., 2020). Therefore, this study aims to analyze the variability of the accumulation of microplastics of commercial fishes from five different fishing ports in Java Island, Indonesia. Three organs of fish were targeted, which are the gill and gastrointestinal tract as organs that have direct exposure to microplastics from the waters and the muscle that is consumed by human.

Materials and Methods

Study area and Fish samples collection

This study was conducted in the ports represent two different fishing grounds, namely the eastern Indian Ocean in the southern part (Fisheries Management Area 573) and the Java Sea in the northern part of the island (Fisheries Management Area 712). The fishs from three fishing ports from the FMA 573 include Sendang Biru in Malang, Prigi in Trenggalek and Tamperan in Pacitan were sampled. While the other two were from the FMA 712, include Brondong in Lamongan and Mayangan in Probolinggo (Figure 1.). These five fishing ports are located in the East Java Province. The main catches in the Java Sea are mostly demersal and small pelagic species (such as anchovy, mackerel and scads), while in the eastern Indian Ocean are large pelagic species (such as skipjack, bigeye and yellowfin tuna) (Andriyono 2018). Java Sea is a semi-enclosed shallow water with an average depth of 40 m (Siregar *et al.,* 2017) and surrounded by Indonesia`s main islands, *e.g* Java, Sumatra, Borneo (Kalimantan) and Sulawesi. It is one of the busiest seas in the country and vulnerable to marine pollution from human activities. The eastern Indian Ocean has deep waters with an average depth more than 1000 m (Ma'mun *et al.,* 2017).

Fish samples were collected from the local fishermen with 2 to 4 species representing each fishing port. The names of the species and morphometric data are presented in Table 1. There were 10 individuals for each species, except for *Priancanthus tayenus* from the Brondong fishing port that had only 7 individuals. The samples were collected from July to September 2020 and kept in the freezer for further analysis in the laboratory.

All fish samples were rinsed with filtered water on the surface to ensure there was no microplastic contamination from the sampling collection process. Contamination during microplastics extraction process in the laboratory was prevented by making sure all the apparatus used were rinsed at least three times using filtered water, and the cotton laboratory coat was worn during the process. Furthermore, the samples were always covered using aluminum foil when not in use. To ensure that there is no contamination from the airbone plastic particles, blank samples of ultra-pure water were prepared and placed in the working area. No evidence of contamination was found in the blank samples.

Microplastics extraction and identification

The total length (cm) and weight (g) of the fish samples were measured before the dissection process. The gills, gastrointestinal tracts and dorsal muscles were taken from dissected samples and weighted as wet weight. Microplastic extraction process was conducted following modified method of Masura and Foster (2015). Since some organs were rather big in size, in order to digest easily, each organ was crushed carefully. The same method have been conducted by Abassi *et al.* (2018) and Ory *et al.* (2018). The samples were then placed in a beaker and about 20 ml of H_2O_2 (30%) and Fe(II) were added. The digestion process was conducted overnight and homogenized on the hotplate stirrer at 75°C for approximately 30 minutes. The samples were then filtered through the Whatman GF/F filter paper and the filters were sealed in a petri dish.

A microscope (MICROS MCX100, Austria) was used in identifying the types of microplastic, namely fiber, fragment and film. Fiber is a long, elongated particle that is equally thick throughout the entire length and fragments is an irregular shape particle with sharp or broken edge. While film is a thin particle part of plastic bags (Dai *et al.,* 2018; Hidalgo-Ruz *et al.,* 2012; Yona *et al.,* 2019). The abundance of microplastics was counted in the number of particles for each individual and the number of particles per gram wet weight for each organ.

The polymer type of microplastics were identified using Fourier Transform Infrared Spectroscopy (Varian 1000 FTIR) on selected particles. Since most of the particle sizes were very small and difficult to retrieve for the polymer identification, only several particles were selected for the FTIR analysis. They have been correctly identified as plastics using visual microscopy according to its shape and color and tested using FTIR with a resolution that was set at 4 cm^{-1} in the range of 4000 to 650 cm^{-1}. Unfortunately, the spectra produced by FTIR could not be identified clearly as polymers because the samples were too small and also there was a possibility of contamination from the organic material during the FTIR reading. Previous studies have also found that the FTIR method is difficult to identify very small microplastic samples because the tool could not produce the spectra clearly (Baalkhuyur *et al.,* 2018; Sathish *et al.,* 2020). Polymer identification using FTIR has widely been used in microplastic studies since it could analyze the entire sample and require less sample preparation (Jung *et al.,* 2018). It was considered a simple, efficient and non-destructive method for identifying plastic polymers. However, the requirement to interpret the result with 50% or greater confidence level with the reference spectra (Lusher *et al.,* 2013) was not an easy task, especially for a very small sample.

Figure 1. The location of five fishing ports in this study. Sendang Biru-Malang, Prigi-Trenggalek and Tamperan-Pacitan with the fishing ground in the eastern Indian Ocean. Brondong-Lamongan and Mayangan-Probolinggo with the fishing ground in the Java Sea.

Table 1. Fish species and the average (±SD) of total length, total weight and the weight of each organ from each fishing port. Weight was measured as wet weight.

Species	Total length (cm)	Weight (g)	Organ weight (g)		
			Gill	GIT	Muscle
Eastern Indian Ocean					
Sendangbiru					
Sardinella lemuru	12.49±0.52	17.31±2.34	0.32±0.11	0.83±0.18	2.0±0.00
Katsuwonus pelamis	41.70±1.90	1161.00±199.83	52.80±5.99	107.70±36.10	9.20±0.92
Prigi					
Mullus surmuletus	14.36±0.84	45.87±9.69	1.02±0.21	2.95±1.90	5.04±0.04
Decapterus tabl	27.45±0.86	262.43±14.60	8.48±1.32	31.26±4.82	6.58±0.33
Trichiurus lepturus	74.50±2.86	236.75±41.01	4.31±1.69	15.51±11.77	6.90±0.07
Tamperan					
Caranx ignobilis	28.20±1.92	444.20±103.09	8.41±2.39	21.19±9.74	9.70±0.54
Trichiurus lepturus	72.10±3.69	217.60±23.68	3.58±1.10	9.53±3.74	3.95±0.05
Java Sea					
Brondong					
Selaroides leptolepis	14.75±0.59	38.20±2.88	0.78±0.11	1.47±0.61	5.08±0.05
Leiognathus equulus	12.89±0.42	35.54±3.46	0.64±0.11	1.09±0.45	5.06±0.03
Nemipterus virgatus	14.77±0.85	35.55±2.76	0.77±0.14	1.02±0.25	5.06±0.03
Priancanthus tayenus	11.14±1.07	23.86±10.96	0.68±0.28	1.39±0.86	2.56±0.51
Mayangan					
Nemipterus virgatus	19.35±0.88	88.32±5.45	3.66±0.59	4.16±0.81	3.61±0.14
Rastrelliger kanagurta	20.15±0.85	93.43±10.70	2.13±0.47	3.34±0.66	4.56±0.27
Caesio cuning	18.95±0.76	89.62±9.27	1.23±0.16	3.19±1.55	5.29±0.47

Statistical analysis

Statistical tests were performed using PAST 4.03 software. The variance analysis was tested to compare the average microplastic concentrations among the three different organs in each species and the total abundance of microplastics among the fishing ports. Furthermore, the correlation test was performed to identify the potential influence of fish size (length and weight), organ weight and microplastic concentrations. All data were tested for normality by Shapiro-Wilks test before conducting the variance and correlation analysis (P<0.05). Since the data did not comply with the assumptions of normality test, the Kruskal Wallis test was used to determine differences in microplastic concentrations among the three different organ. The Mann-Whitney test was conducted to test the difference of microplastics abundances between the two fishing ground areas (Java Sea and eastern Indian Ocean). Relationship between fish total length and body weight with microplastics abundance were tested using Pearson Correlation test. Significance level was set at P<0.05 for all statistical tests.

Results and Discussion

The abundance of microplastic

A total of 137 fish samples of 14 species were analyzed for microplastic contents. The highest number was from Sendang Biru (4 to 38 particle.fish^{-1}) followed by Brondong (2 to 27 particle.fish^{-1}), Tamperan (0 to 25 particle.fish^{-1}), Prigi (0 to 13 particle.fish^{-1}) and Mayangan (0 to 11 particle.fish^{-1}). The average number of microplastics found in the fish in every fishing port was shown in Figure 2. The Kruskal-Wallis test revealed that there was significant difference of microplastic in the fishes among the fishing ports (P<0.05). Furthermore, the Dunn`s post hoc test showed that microplastics in Sendang Biru were significantly different from the other four fishing ports. Prigi was different from Sendang Biru and Brondong, while Tamperan was only different from Sendang Biru. Furthermore, Brondong was different from Sendang Biru, Prigi and Mayangan, while Mayangan was different from Sendang Biru and Brondong. However, when the Mann-Whitney test was conducted to know whether the number of microplastics in the fishes caught in Java Sea and eastern Indian Ocean was different, the result showed no significant difference between the two fishing grounds (P>0.05).

The average concentrations of microplastics for each species in every fishing ports were presented in Figure 3. Two species from Sendang Biru fishing port were *S. lemuru* and *K. pelamis* and the microplastic concentrations between them were significantly different (Figure 3a.). *S. lemuru* had a very high amount microplastics compared to *K. pelamis.* Moreover, the species from Sendang Biru fishing port also contributed to the highest concentration compared to the others. *M. surmuletus* had the highest concentration of microplastics, followed by *T. lepturus* and *D. tabl* in Prigi fishing port (Figure 3b.). On the other hand, the concentration in *T. lepturus* was higher compared to *C. ignobilis* in Tamperan fishing port (Figure 3c.). In Brondong, three species had similar microplastic concentrations (*S. leptolepis, L. equulus* and *P. tayenus*) and the lowest was in *N. virgatus* (Figure 3d.). The highest concentration in Mayangan was observed in *C. cunning*, while for *N. virgatus* and *R. kanagurta* were found had similar numbers (Figure 3e.). The statistical test revealed that there was significant difference in the abundance of microplastics between the fishes in every fishing port (*P*<0.05).

Microplastics in fish organs

The accumulation of microplastics in the different organs of the fishes varied in every fishing port (Figure 4.). In Sendang Biru, the gills of *S. lemuru* had the highest microplastic particles, followed by the GITs and muscles. Furthermore, the highest concentration of microplastics in *K. pelamis* was observed in the muscles with little accumulation in the gills and GITs (Figure 4a.). Variability of microplastics particles were also recorded in Prigi, in which *M. surmuletus* had the highest concentration in the gills, followed by GITs and a very small numbers in the muscles. *Decapterus tabl* and *T. lepturus* had the same pattern because they both accumulated microplastics more in their muscles than in their gills and GITs (Figure 4b.). *C. ignobilis* and *T. lepturus* from Tamperan also had the same number microplastic particles in their muscles, gills and GITs (Figure 4c.). The four fish species from Brondong had similar pattern, and the highest particles number was seen in their gills, GITs and muscles (Figure 4d.). In Mayangan, different accumulation patterns were observed in different species. *C. cuning* accumulated a very high amount of microplastics in its gills and GITs, and a very small amount in the muscles. For *R. kanagurta*, the concentrations were in similar number between the gills and GITs, and the lowest amount was found in the muscles. Furthermore, the muscles of *N. virgatus* contained the highest number of microplastics, followed by the gills and GITs (Figure 4e.). Statistical analysis revealed that there was significant difference of microplastics accumulation among the organs for most of the species (*P*<0.05), except for *D. tabl* from Prigi and *C. ignobilis* from Tamperan (*P*>0.05).

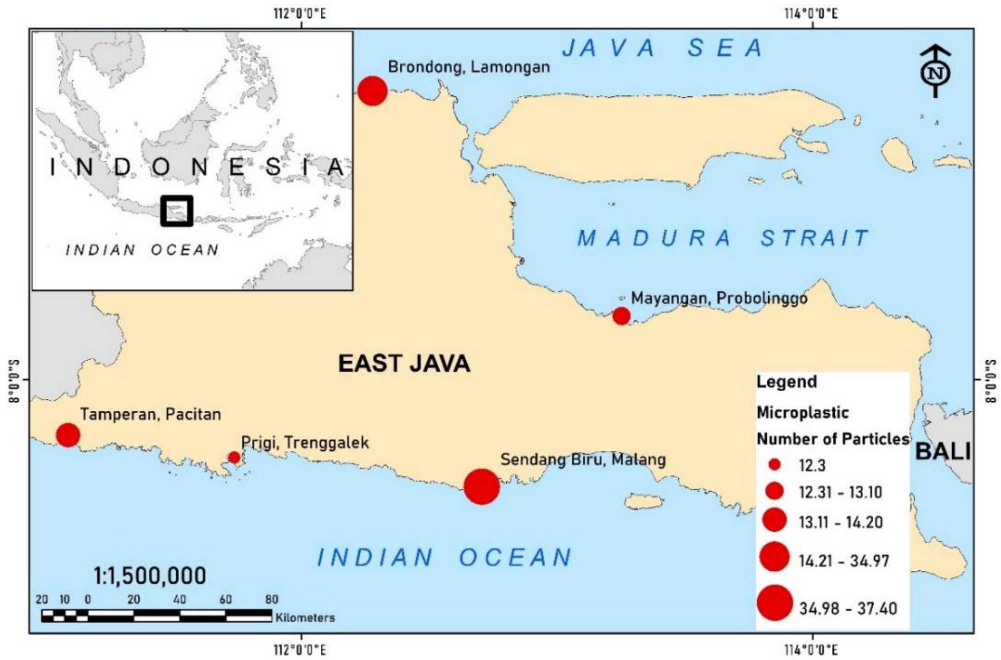

Figure 2. The average number of microplastics (particle/fish) found in the fish in every fishing port.

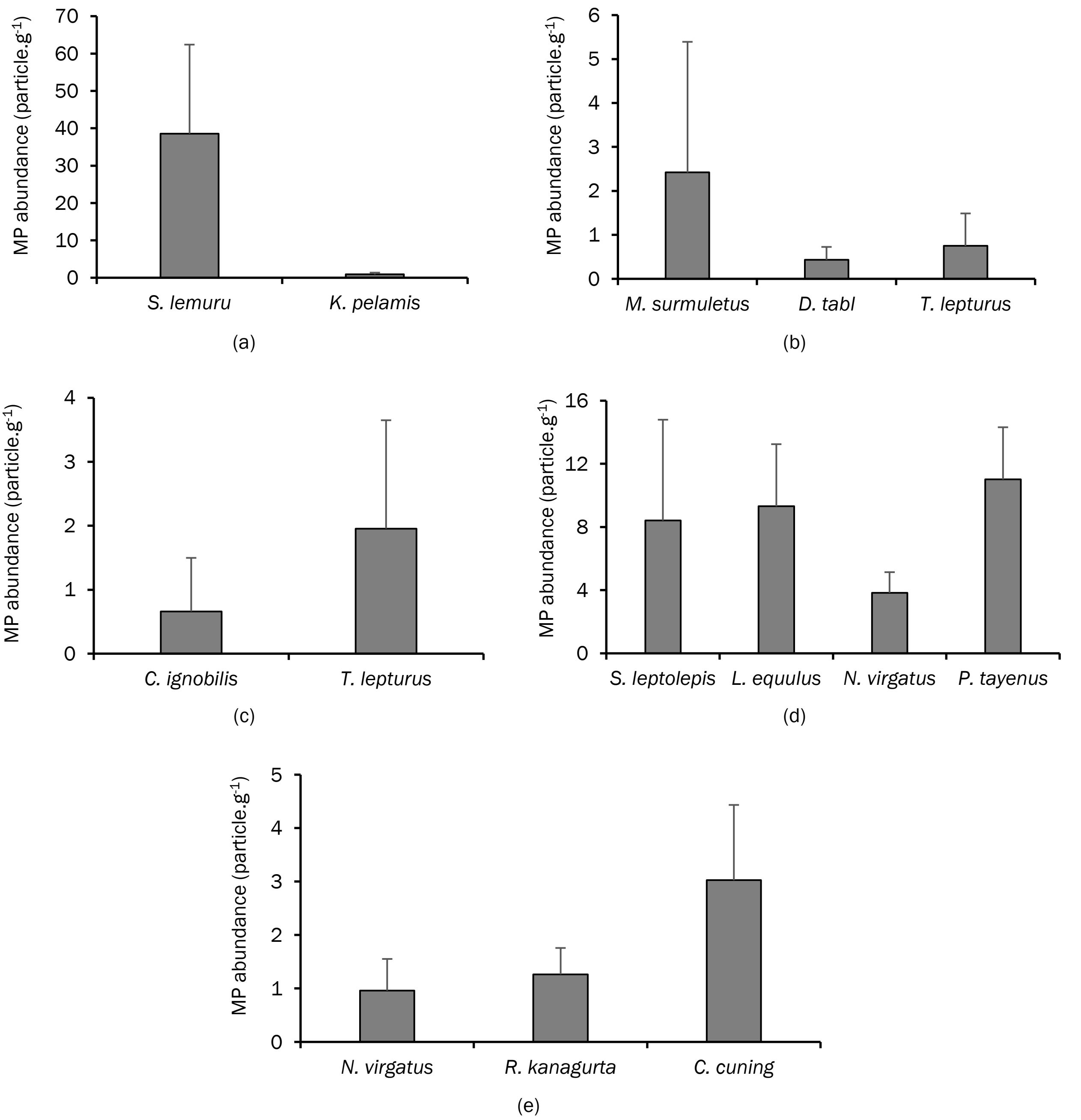

Figure 3. The abundance of microplastics (particle g^{-1}) in different fish species in (a) Sendang Biru, (b) Prigi, (c) Tamperan, (d) Brondong and (e) Mayangan.

Types of microplastic

Microplastics have been divided into several types, namely fiber, fragment, film, pellet, bead and foam. However, this study only found three types, *i.e.* fibers, fragments and films. The percentage compositions of the types of microplastics in the organs of every species were presented in Figure 5. Some had only fibers in their organs (*M. surmuletus* from Prigi and *N. virgatus* from Mayangan), while some had fibers in specific organ, such as in GITs and muscles of *T. lepturus* from Prigi, in GITs of *C. ignobilis* from Tamperan, in the gills and GITs of *R. kanagurta* from Mayangan, and in the muscles of *C. cuning* also from Mayangan. Most species had the highest accumulation of fibers in their organs, except for the gills of *S. lemuru* from Sendang Biru and muscles of *P. tayenus* from Brondong which accumulated more fragments. Furthermore, fiber, fragment and film were found in almost every organ of every fish species from Sendang Biru and Brondong.

Relationship of fish sizes and microplastic abundance

Pearson correlation test was used to test the relationship between the fish length and weight to the abundance of microplastics in every fishing port (Table 2.). There was a significant relationship between fish length and weight to microplastic abundance in most of fishing ports. It was found that the smaller the fish, the higher its microplastic content except for those in Tamperan that showed positive relationship between length and microplastic content.

Variability of microplastics in fish

The ingestion of microplastics by aquatic animals has been a major issue worldwide, including in the marine environment of Indonesia. In the study by Jambeck *et al*. (2015), it was stated that Indonesia is the second largest country with high mismanaged plastic wastes enters the ocean. Since then, the study of microplastics is also increasing. There have been studies that focused on the surface waters (Syakti *et al.,* 2017; 2018), the coastal sediment (Manalu *et al.,* 2017; Mauludy *et al.,* 2019; Firdaus *et al.,* 2020), deep water sediment (Cordova and Wahyudi, 2016), marine biota (Khoironi *et al.,* 2018) and fish (Hastuti *et al.,* 2019; Cordova *et al.,* 2020; Yona *et al.,* 2020).

In this study, 137 fish samples from 14 species were analyzed for their microplastic contents in three different organs, namely gills, gastrointestinal tracts and muscles. Out of the total samples, only seven individuals were identified without microplastics. This meant that almost 95% had absorbed microplastics into their body. The abundance of microplastic in fishes from this study were recorded in the range of 0.06 to 95.56 particle.g^{-1}. The highest was found in *S. lemuru* from Sendang Biru (38.59±23.80 particle.g^{-1}), while the lowest was found in *D. tabl* from Prigi fishing port (0.43±0.29 particle.g^{-1}). Although both species were collected from different fishing ports, the fishing ground may be the same, i.e. the northern part of Indian Ocean. Differences in the number of microplastics found in each species corroborated hypothesis that microplastic ingestion varies with different feeding strategies (Mizraji *et al.,* 2017; Justino *et al.,* 2021). *S. lemuru* is a filter feeder organism that feeds on phytoplankton and zooplankton (Pertami *et al.,* 2019; Sartimbul *et al.,* 2021), while *D. tabl* is a carnivorous fish and their principal diets are crustaceans and other fishes (Poojary *et al.,* 2010; Lubis *et al.,* 2019). Filter feeding is a less selective strategy than predation, thus the filter feeder fish are more sensitive to microplastics pollution (Rummel *et al.,* 2016).

Table 3 shows the comparison of microplastic abundances in the same species in terms of particle per individual and particle per g with other studies worldwide. It was found that the abundance of microplastics found in this study were higher compared

Table 2. Correlation of fish total length (cm) and body weight (g) with the abundance of microplastics (item g^{-1}) using Pearson Correlation test

	Correlation coefficient	
	Length	Weight
Sendang Biru		
Length		
Weight	0.99**	
Total abundance	-0.77**	-0.75**
Prigi		
Length		
Weight	0.58**	
Total abundance	-0.26	-0.47**
Tamperan		
Length		
Weight	-0.80**	
Total abundance	0.50*	-0.47*
Brondong		
Length		
Weight	0.70**	
Total abundance	-0.50**	-0.38*
Mayangan		
Length		
Weight	0.66**	
Total abundance	-0.40*	-0.11

** $P<0.01$; * $P<0.05$

Table 3. Comparison of microplastic abundances in the same species from other studies

Species	Study area	Total abundance		Reference
		Particle.ind^{-1}	Particle.g^{-1}	
S. lemuru	Northern Mindanao, Philippines	3.72 ± 3.97	–	Palermo *et al*. (2020)
	Bali Strait, Indonesia	7.03 ± 0.62	–	Sarasita *et al*. (2020)
	Eastern Indian Ocean, Indonesia	20.5 ± 8.2	38.59 ± 23.80	This study
K. pelamis	Southeast coast of India	0.2 ± 0.06	6.67E-05 ±0.0000001	Satish *et al*. (2020)
	Northeast Atlantic	0.16 ± 0.08	–	Pereira *et al*. (2020)
	Eastern Indian Ocean, Indonesia	16.9 ± 5.86	0.92 ± 0.45	This study
	Balcaric Islands, western Mediterranean	0.04 – 1.07	–	Alomar *et al*. (2017)
M. surmuletus	Eastern Indian Ocean, Indonesia	3.4 ± 3.24	2.42 ± 2.97	This study
T. lepturus	Bali Strait, Indonesia	3.83 ± 1.01	–	Sarasita *et al*. (2020)
	Eastern Indian Ocean, Indonesia	6.15 ± 5.51	1.35 ± 1.41	This study
S. leptolepis	Gulf of Thailand and Andaman Sea	0.05	–	Klangnurak and Chunniyom (2020)
	Eastern Indian Ocean, Indonesia	11.7 ± 6.70	8.41 ± 6.39	This study
L. equulus	Fengshan River, Taiwan Strait	62	–	Tien *et al*. (2020)
	Southeast coast of India	1	–	Karthik *et al*. (2018)
	Eastern Indian Ocean, Indonesia	9.70 ± 3.20	9.31 ± 3.93	This study
	Beibu Gulf, South China Sea	0.071	–	Koongolla *et al*. (2020)
N. virgatus	Java Sea	3.55 ± 1.64	2.39 ± 1.73	This study
R. kanagurta	Southeast coast of India	0.98 ± 0.32	0.13 ± 0.05	Satish *et al*. (2020)
	Bali Strait, Indonesia	5.03 ± 0.76	–	Sarasita *et al*. (2020)
	Eastern Indian Ocean, Indonesia	3.7 ± 1.57	2.33 ± 0.88	This study
C. cuning	Gulf of Thailand and Andaman Sea	0.09	–	Klangnurak and Chunniyom (2020)
	Eastern Indian Ocean, Indonesia	6 ± 2.49	5.76 ± 2.79	This study

to the others. This might be caused by several factors such as feeding habit, habitat, trophic level and anthropogenic activities as the source of microplastic pollution in the marine environment (Wieczorek *et al.,* 2018; Giani *et al.,* 2019). Those reasons may be used to explain the higher concentration of microplastics found in this study.

The ingestion of microplastics by fishes in this study varies among the species, fishing ports and fishing grounds. The highest microplastic concentration was observed in the fishes from Sendang Biru, followed by Brondong, Tamperan, Mayangan and Prigi. The abundance variability of microplastic among species shown by the differences among the fishing ports. Prigi, which had the lowest abundance of microplastics, was composed of all demersal species, while Mayangan with the second lowest number was composed of all pelagic species. Furthermore, higher microplastic abundance from Sendang Biru, Brondong and Tamperan were recorded from pelagic and demersal fish species. Therefore, it was concluded that the fish habitat were not significantly influenced the abundance of microplastics and this is in agreement with other studies (Lusher *et al.,* 2013; Klangnurak and Chunniyom, 2020). Different species of fish with its different feeding habits could significantly influence the abundance of microplastics (Mizraji *et al*., 2017; Justino *et al*., 2021).

In general, the negative relationship between the fish size and concentration of microplastics in most of the fish species were observed. It means that, the smaller fishes contained more microplastic particles than the larger ones. There have been many reports regarding the relationship of fish size and microplastic content. Some studies found that the fish body length did not correlate with the number of microplastics (Hastuti *et al.,* 2019; Palermo *et al.,* 2020; Yona *et al.,* 2020), while other reseachers found that the larger ones have more in their body (Akhbarizadeh *et al.,* 2018; McNeish *et al.,* 2018; Boerger *et al.,* 2010). Negative relationships were observed in the study of fish from the Yellow Sea (Sun *et al.,* 2019). In this study, small size fish such as *S. lemuru*, *P. tayenus* and *L. equulus* contained higher number of microplastics than the bigger size fishes such as *K. pelamis*, *T. lepturus* and *C. ignobilis*. According to Sun *et al.* (2019), this may be related to the different stages of fish growth and their physical condition. More investigation is needed to understand the relationship between fish morphology and microplastic content.

Variability of microplastics in different organs

There have been many studies on the variability of microplastics accumulation in different fish organs, and most of them focused on the organs that have direct contact with water, such as gastrointestinal tracts and gills (Neves *et al.,* 2015; Baalkhuyur *et al.,* 2018; Karbalaei *et al.,* 2019; Su *et al.,* 2019; Sathish *et al.,* 2020). However, other organs such as liver and muscle have also become the subject of microplastic accumulation (Abbasi *et al.,* 2018; Akhbarizadeh *et al.,* 2018; Daniel *et al.,* 2020). The accumulation of microplastics in the organs that do not have direct contact with seawater proves that there are translocation processes inside the body (Franzellitti *et al.,* 2019; Su *et al.,* 2019). Microplastics translocation can occur through the cellular pathways in which small size microplastics can be absorbed by muscle or other organs not directly related to the ingestion-digestion process through cell internalization (Carr *et al.,* 2012; Abbasi *et al.,* 2018; Messinetti *et al.,* 2019; Su *et al.,* 2019).

The accumulation of microplastics in this study occurred in gills, gastrointestinal tracts and muscles and there were variation in the concentration of each species. Furthermore,

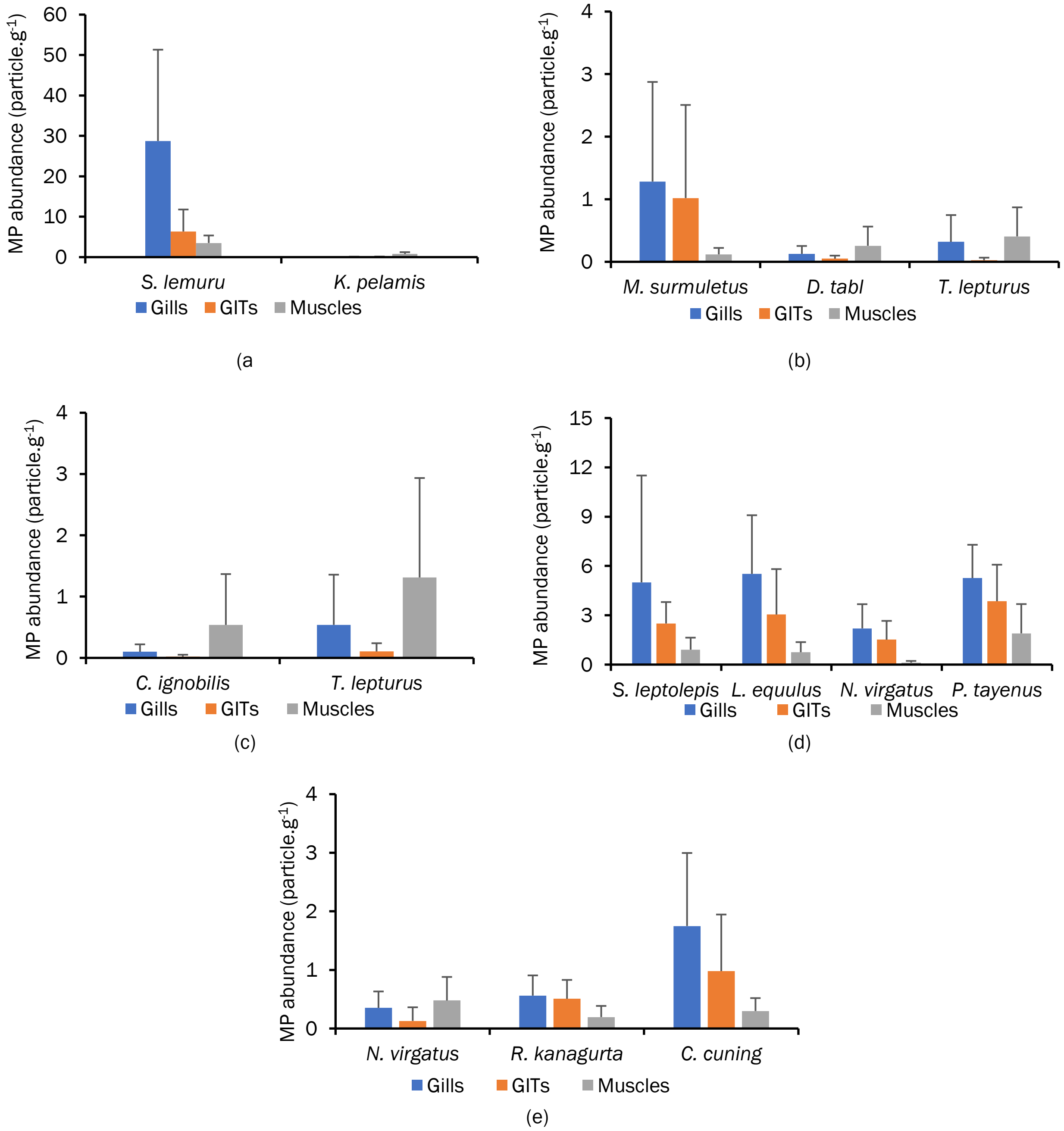

Figure 4. Microplastic abundances in different organs of fish species from each fishing port (a) Sendang Biru, (b) Prigi, (c) Tamperan, (d) Brondong and (e) Mayangan.

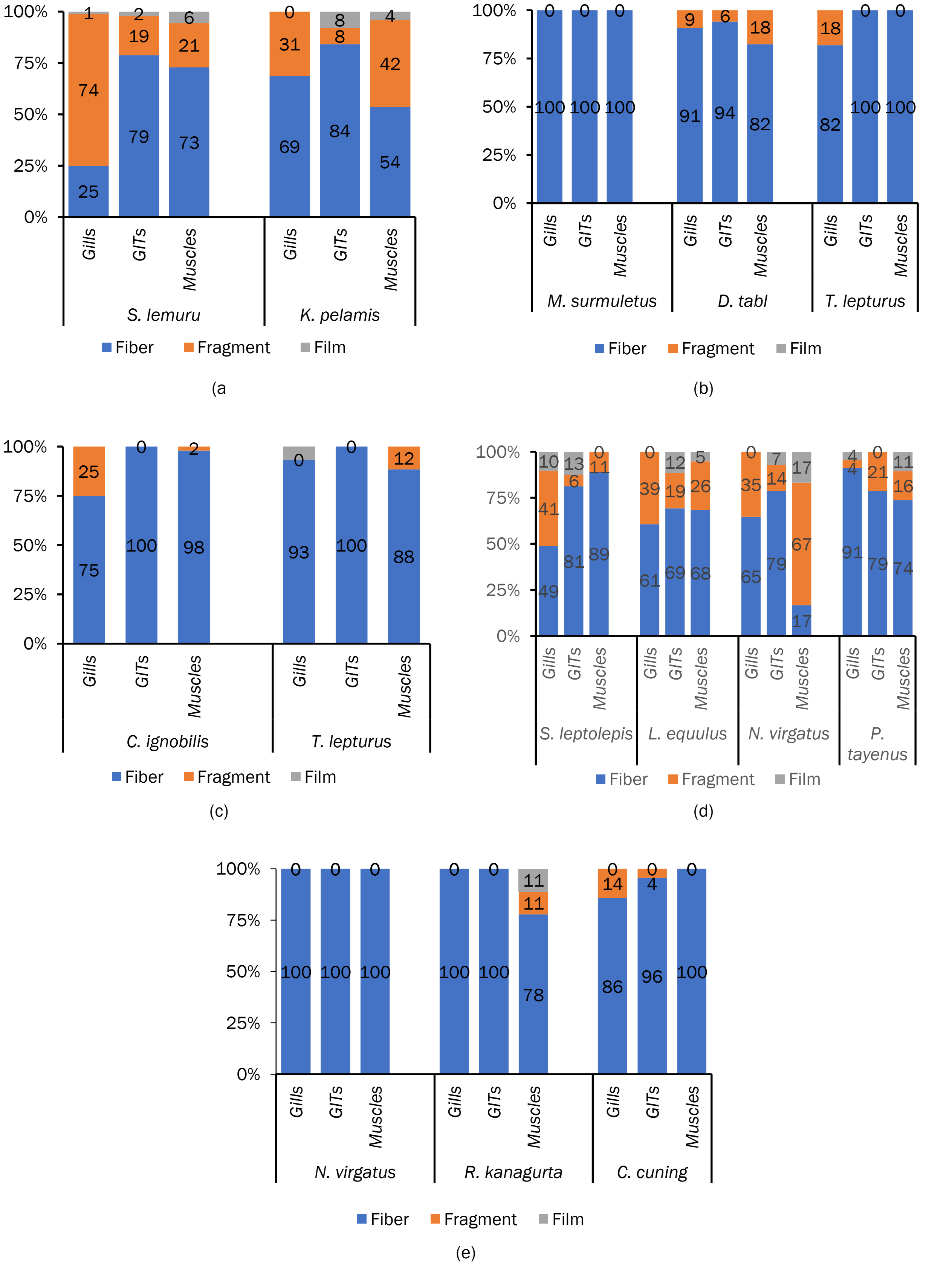

Figure 5. Percentage occurrence of microplastic types (fiber, fragment and film) in different organs of each fish from (a) Sendang Biru, (b) Prigi, (c) Tamperan, (d) Brondong and (e) Mayangan.

microplastics were higher in the gills than gastrointestinal tracts and muscles for some fish such as *S. lemuru, M. surmuletus, S. leptolepis, L. equulus, P. tayenus* and *C. cuning*. The gills are vulnerable to the accumulation of microplastics, because this organ is highly exposed to environmental contamination (Su *et al.,* 2019; Barboza *et al.,* 2020). Some studies found higher accumulation of microplastics in the gastrointestinal tracts compared to the other organs due to uptake via deliberate or incidental ingestion process (Huang *et al.,* 2020; Lin *et al.,* 2020), however, none was found in this study. Furthermore, higher microplastics were observed in the muscles of benthic fish such as *T. lepturus* and *C. ignobilis,* and this result is in agreement with the study of Abbasi *et al*. (2018) and Akhbarizadeh *et al*. (2018). There have been some assumptions on the availability of microplastics in fish muscle, such as microplastic internalization through endocytosis and uptake very small microplastics through the skin then entering into the blood circulation (Barboza *et al.,* 2018; 2020). Further studies are needed to understand the translocation process of microplastics inside the body of fish.

Fiber was the most dominant type of microplastics found in this study and the accumulation was comparable in each of the fish organ. The dominant type of microplastic found in their tissues depend on the amount in the seawater and waste management system in the region (Karbalaei *et al.,* 2019). Most studies recorded fiber as the dominant type found in fish (Bellas *et al.,* 2016; Bessa *et al.,* 2018; Sun *et al.,* 2019; Yona *et al.,* 2020), while few others found fragment as the dominant type (Garnier *et al.,* 2019; Karbalaei *et al.,* 2019). Furthermore, fiber is mostly found in study areas closer to the populated regions (Neves *et al.,* 2015; Bellas *et al.,* 2016; Bessa *et al.,* 2018) and it could be the reason for the result of this study. Java Island is the most populated island in Indonesia and anthropogenic activities could influence the presence of microplastics in the ocean. In addition, higher accumulation of fiber in the gills suggests that it is the dominant type of microplastic in seawaters since the gills have direct contact with it (Barboza *et al.,* 2020).

Conclusion

This study showed the variation of microplastics ingestion in different fish species and organs. Fiber was the dominant type of microplastics found in the most of fish organs. Some fish accumulated more microplastics in their gills, while others accumulated more in their muscles. The results showed that the accumulation of microplastics among the fish varied according to their habitat, feeding habit, and fish size. Since microplastics were also found in the muscle, there is the possibility that translocation of microplastics occurred between organs. However, more study is needed to explain detail process of the translocation of microplastics inside the body of fish. Furthermore, studies are needed to examine this process in order to understand the fate and transport of microplastics in commercial fishes as one of the important sources of food for humans.

Acknowledgement

This study was funded by a grant from Hibah Penelitian Unggulan (HPU) tahun 2020 Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas Brawijaya Nomor DIPA-042.01.400919/2020.

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.

Akhbarizadeh, R., Moore, F. & Keshavarzi, B. 2018. Investigating a Probable Relationship between Microplastics and Potentially Toxic Elements in Fish Muscles from Northeast of Persian Gulf. *Environ. Poll.* 232(5): 154–63. https://doi.org/10.1016/j.envpol.2017.09.028.

Alomar, C., Sureda, Capó, A.X., Guijarro, B., Tejada, S. & Deudero, S. 2017. Microplastic Ingestion by *Mullus surmuletus* Linnaeus, 1758 Fish and Its Potential for Causing Oxidative Stress. *Environ. Res.,* 159: 135–42. https://doi.org/10.1016/j.envres.2017.07.043.

Andriyono, S. 2018. Overview of Indonesia Fisheries Sector: Java and Bali Island. *Int. J. Life Sci. Earth Sci.,* 1(1): 39–48. https://doi.org/ 10.31295/ijle.v1n1.12.

Baalkhuyur, F.M., Bin Dohaish, E.A., Elhalwagy, M.E.A., Alikunhi, N.M., AlSuwailem, A.M., Røstad, A., Coker, D.J., Berumen, M.L. & Duarte, C.M. 2018. Microplastic in the Gastrointestinal Tract of Fishes along the Saudi Arabian Red Sea Coast. *Mar. Poll. Bull.,* 131: 407–15. https://doi.org/10.1016/j.marpolbul.2018.04.040.

Barboza, L.G.A., Lopes, C., Oliveira, P., Bessa, F., Otero, V., Henriques, B., Raimundo, J., Caetano, M., Vale, C. & Guilhermino, Lúcia. 2020. Microplastics in Wild Fish from North East Atlantic Ocean and Its Potential for Causing Neurotoxic Effects, Lipid Oxidative Damage, and

Human Health Risks Associated with Ingestion Exposure. *Sci. Total Environ.* 717: p.134625. https://doi.org/10.1016/j.scitotenv. 2019.134625.

Barboza, L.G.A., Vieira, L.R., Branco, V., Carvalho, C. & Guilhermino, L. 2018. Microplastics Increase Mercury Bioconcentration in Gills and Bioaccumulation in the Liver, and Cause Oxidative Stress and Damage in *Dicentrarchus labrax* Juveniles. *Sci. Rep.,* 8(1): p.15655. https://doi.org/10.1038/s41598-018-34125-z.

Bellas, J., Martínez-Armental, J., Martínez-Cámara, A., Besada, V. & Martínez-Gómez, C. 2016. Ingestion of Microplastics by Demersal Fish from the Spanish Atlantic and Mediterranean Coasts. *Mar. Poll. Bull.,* 109(1): 55–60. https://doi.org/10.1016/j.marpolbul.2016.06.026.

Bessa, F., Barria, P., Neto, J.M., Frias, J.P.G.L., Otero, V., Sobral, P. & Marques, J.C. 2018. Occurence of Microplastics in Commercial Fish from a Natural Estuarine Environment. *Mar. Poll. Bull.,* 128: 575–84.

Boerger, C.M., Lattin, G.L., Moore, S.L. & Moore, J.C. 2010. Plastic Ingestion by Planktivorous Fishes in the North Pacific Central Gyre. *Mar. Poll. Bull.* 60(12): 2275–78. https://doi.org/10.1016/j.marpolbul.2010.08.007.

Caron, A.G.M., Thomas, C.R., Berry, K.L.E., Motti, C.A., Ariel, E. & Brodie, J.E. 2018a. Validation of an Optimised Protocol for Quantification of Microplastics in Heterogenous Samples: A Case Study Using Green Turtle Chyme. *MethodsX,* 5: 812–23. https://doi.org/10.1016/j.mex.2018. 07.009.

Caron, A.G. M., Thomas, C.R., Berry, K.L.E., Motti, C.A., Ariel, E. & Brodie, J.E. 2018b. Ingestion of Microplastic Debris by Green Sea Turtles (*Chelonia mydas*) in the Great Barrier Reef: Validation of a Sequential Extraction Protocol. *Mar. Poll. Bull.,* 127: 743–51. https://doi.org/10.1016/j.marpolbul.2017.12.062.

Cauwenberghe, L.V., Vanreusel, A., Mees, J. & Janssen, C.R. 2013. Microplastic Pollution in Deep-Sea Sediments. *Environ. Poll.,* 182: 495–99. https://doi.org/10.1016/j.envpol.2013.08.013.

Chae, D.H., Kim, I.S., Kim, S.K., Song, Y.K. & Shim, W.J. 2015. Abundance and Distribution Characteristics of Microplastics in Surface Seawaters of the Incheon/Kyeonggi Coastal Region. *Arch. Environ. Contam. Toxicol.* 69(3): 269–78. https://doi.org/10.1007/s00244-01 5-0173-4.

Choy, C.A., Robison, B.H., Gagne, T.O., Erwin, B., Firl, E., Halden, R.U., Hamilton, J.A., Kakani, K., Lisin, S.E., Rolsky, C. & Van Houtan, K.S. 2019. The Vertical Distribution and Biological Transport of Marine Microplastics across the Epipelagic and Mesopelagic Water Column. *Sci. Rep.* 9(1): 1-9. https://doi.org/10.1038/s41598-019-44117-2.

Chubarenko, I. & Stepanova, N. 2017. Microplastics in Sea Coastal Zone: Lessons Learned from the Baltic Amber. *Environ. Poll.,* 224: 243–54. https://doi.org/10.1016/j.envpol.2017.01.085.

Cincinelli, A., Scopetani, C., Chelazzi, D., Lombardini, E., Martellini, T., Katsoyiannis, A., Fossi, M.C. & Corsolini, S. 2017. Microplastic in the Surface Waters of the Ross Sea (Antarctica): Occurrence, Distribution and Characterization by FTIR. *Chemosphere,* 175: 391–400. https://doi.org/10.1016/j.chemosphere.2017.02.024.

Cordova, M.R., Riani E. & Shiomoto, A. 2020. Microplastics Ingestion by Blue Panchax Fish (*Aplocheilus* sp.) from Ciliwung Estuary, Jakarta, Indonesia. *Mar. Poll. Bull.,* 161: 111763. https://doi.org/10.1016/j.marpolbul.2020.111763.

Cordova, M.R. & Wahyudi, A.J. 2016. Microplastic in the Deep-Sea Sediment of Southwestern Sumatran Waters. *Mar. Res. Indo.,* 41(1): 27. https://doi.org/10.14203/mri.v41i1.99.

Dai, Z., Zhang, H., Zhou, Q., Tian, Y., Chen, T., Tu, C., Fu, C. & Luo, Y. 2018. Occurrence of Microplastics in the Water Column and Sediment in an Inland Sea Affected by Intensive Anthropogenic Activities. *Environ. Poll.,* 242: 1557–65. https://doi.org/10.1016/j.envpol. 2018.07.131.

Daniel, D.B., Ashraf, P.M. & Thomas, S.N. 2020. Microplastics in the Edible and Inedible Tissues of Pelagic Fishes Sold for Human Consumption in Kerala, India. *Environ. Poll.,* 266: 115365. https://doi.org/10.1016/j.envpol.2020.115365.

Efadeswarni, Andriantoro, Azizah, N. & Saragih, G.S., 2019. Microplastics in digestive tracts of fishes from Jakarta Bay. *IOP Conf. Ser. Earth Environ. Sci.,* 407, 012008. https://doi.org/10.1088/1755-1315/407/1/012008

Firdaus, M., Trihadiningrum, Y. & Lestari, P. 2020. Microplastic Pollution in the Sediment of Jagir Estuary, Surabaya City, Indonesia. *Mar.Poll. Bull.,* 150: p.110790. https://doi.org/10.1016/j.marpolbul.2019.110790.

Franzellitti, S., Canesi, L., Auguste, M., Wathsala, R.H.G.R. & Fabbri, E. 2019. Microplastic Exposure and Effects in Aquatic Organisms: A Physiological Perspective. *Environ. Toxicol. Pharmacol.* 68: 37–51. https://doi.org/10.1016/j.etap.2019.03.009.

Frias, J.P.G.L., Otero, V. & Sobral, P. 2014. Evidence of Microplastics in Samples of Zooplankton from Portuguese Coastal Waters. *Mar. Environ. Res.* 95: 89–95. https://doi.org/10.1016/j. marenv res.2014.01.001.

Garnier, Y., Jacob, H., Guerra, A.S., Bertucci, F. & Lecchini, D. 2019. Evaluation of Microplastic Ingestion by Tropical Fish from Moorea Island, French Polynesia. *Mar. Poll. Bull.* 140: 165–70. https://doi.org/10.1016/j.marpolbul.2019.01.038.

GESAMP. 2016. Sources, Fate and Effects of Microplastics in the Marine Environment: Part Two of a Global Assessment. In: Kershaw, P. J., & Rochman, C. M. (Eds). IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. Rep. Stud. GESAMP No. 93, 220 p."

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. *Mar. Poll. Bull.* 140 : 129–37. https://doi.org/10.1016/j.marpolbul.2019.01.005.

Hastuti, A.R., Lumbanbatu, D.T. & Wardiatno, Y. 2019. The Presence of Microplastics in the Digestive Tract of Commercial Fishes off Pantai Indah Kapuk Coast, Jakarta, Indonesia. *Biodiversitas J. of Biological Diversity* 20 (5): 1233–42. https://doi.org/10.13057/biodiv/ d200513.

Hidalgo-Ruz, V., Gutow, L., Thompson, R.C. & Thiel, M. 2012. Microplastics in the Marine Environment: A Review of the Methods Used for Identification and Quantification. *Environ. Sci. Technol.,* 46 (6): 3060–75. https://doi.org/ 10.1021/es203 1505.

Huang, J.S., Koongolla, J.B., Li, H.X., Lin, L., Pan, Y.F., Liu, S., He, W.H., Maharana, D. & Xu, X.R. 2020. Microplastic Accumulation in Fish from Zhanjiang Mangrove Wetland, South China. *Sci. Total Environ.,* 708: p.134839. https://doi.org/10.1016/j.scitotenv.2019.134839.

Iliff, S.M., Wilczek, E.R., Harris, R.J., Bouldin, R. & Stoner, E.W. 2020. Evidence of Microplastics from Benthic Jellyfish (*Cassiopea xamachana*) in Florida Estuaries.*Mar. Poll. Bull.,* 159: 111521. https://doi.org/10.1016/j.marpolbul.2020.111521.

Isobe, A., Uchiyama-Matsumoto, K., Uchida, K. & Tokai, T. 2017. Microplastics in the Southern Ocean. *Mar. Poll. Bull.,* 114(1): 623–26. https://doi.org/10.1016/j.marpolbul.2016.09.037.

Iwasaki, S., Isobe, A., Kako, S., Uchida, K. & Tokai, T. 2017. Fate of Microplastics and Mesoplastics Carried by Surface Currents and Wind Waves: A Numerical Model Approach in the Sea of Japan. *Mar. Poll. Bull.,* 121(1–2): 85–96. https://doi.org/10.1016/j.marpolbul.2017.05.057.

Jambeck, J.R, Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R. & Law, K.L. 2015. Plastic Waste Inputs from Land into the Ocean. *Sci.,* 347(6223): 768–71.

Jung, M.R., Horgen, F.D., Orski, S.V., Rodriguez C.V., Beers, K.L., Balazs, G.H., Jones, T.T., Work, T.M., Brignac, K.C., Royer, S.J., Jensen, B.A. & Lynch, J.M.. 2018. Validation of ATR FT-IR to Identify Polymers of Plastic Marine Debris, Including Those Ingested by Marine Organisms. *Mar. Poll. Bull.,* 127: 704–16. https://doi.org/10.1016/j.marpolbul.2017.12.061.

Justino, A.K.S., Lenoble, V., Pelage, L., Ferreira, G.V.B., Passarone, R., Frédou, T. & Lucena Frédou, F. 2021. Microplastic contamination in tropical fishes: An assessment of different feeding habits. *Reg. Stud. Mar. Sci.,* 45:101857. https://doi.org/10.1016/j.rsma. 2021.101857

Kanhai, L.D.K., Officer, R., Lyashevska, O., Thompson, R.C. & O'Connor, I. 2017. Microplastic Abundance, Distribution and Composition along a Latitudinal Gradient in the Atlantic Ocean. *Mar. Poll. Bull.,* 115(1–2): 307–14. https://doi.org/10.1016/j.marpolbul.2016.12.025.

Karbalaei, S., Golieskardi, A., Hamzah, H.B., Abdulwahid, S., Hanachi, P., Walker, T.R. & Karami, A. 2019. Abundance and Characteristics of Microplastics in Commercial Marine Fish from Malaysia. *Mar. Poll. Bull.,* 148: 5–15. https://doi.org/10.1016/j.mar polbul.2019.07.072.

Karthik, R., Robin, R.S. ., Purvaja, R., Ganguly, D., Anandavelu, I., Raghuraman, R., Ramakrishna, G. & Ramesh, R. 2018. Microplastics along the

Beaches of Southeast Coast of India. *Sci. Total Environ.,* 645: 1388–99. https://doi.org/10.1016/j.scitotenv.2018.07.242.

Khoironi, A., Anggoro, S. & Sudarno. 2018. The Existence of Microplastic in Asian Green Mussels. *IOP Conf. Ser.Earth Environ. Sci.,* 131: 012050.

Klangnurak, W. & Chunniyom, S. 2020. Screening for Microplastics in Marine Fish of Thailand: The Accumulation of Microplastics in the Gastrointestinal Tract of Different Foraging Preferences. *Environ. Sci. Poll. Res.,* 27(21): 27161–27168. https://doi.org/10.1007/s11356-020-09147-8.

Koongolla, J.B., Lin, L., Pan, Y.F., Yang, C,P., Sun, D.R., Liu, S., Xu, X.R., Maharana, D., Huang, J.S. & Li, H.X. 2020. Occurrence of Microplastics in Gastrointestinal Tracts and Gills of Fish from Beibu Gulf, South China Sea. *Environ. Poll.,* 258:113734. https://doi.org/10.1016/j.envpol.2019.113734.

Lin, L., Ma, L.S., Li, H.X., Y Pan, Y.F., Liu, S., Zhang, L., Peng, J.P., Fok, L., Xu, X.R. & He, W.H. 2020. Low Level of Microplastic Contamination in Wild Fish from an Urban Estuary. *Mar. Poll. Bull.,* 160: 111650. https://doi.org/10.1016/ j.marpolbul.2020.111650.

Lubis, F., Ida Adharini, R., & Setyobudi, E. 2019. Food Preference of Shortfin Scad (*Decapterus macrosoma*) at the Southern Waters of Gunungkidul Yogyakarta, Indonesia. *J. Ilmiah Perikanan dan Kelautan*, 11(2): 19-28. https://doi.org/10.20473/jipk.v11i2.13927

Lusher, A.L., Hollman, P.C.H. & Mendoza-Hill, J. 2017. Microplastics in Fisheries and Aquaculture: Status of Knowledge on Their Occurrence and Implications for Aquatic Organisms and Food Safety. FAO Fisheries and Aquaculture Technical Paper 615. Rome: FAO Fisheries and Aquaculture Technical Paper. No. 615. Rome, Italy.

Lusher, A.L, McHugh, M. & Thompson, R.C. 2013. Occurrence of Microplastics in the Gastrointestinal Tract of Pelagic and Demersal Fish from the English Channel. *Mar. Poll. Bull.,* 67 (1–2): 94–99. https://doi.org/10.1016/j.marpolbul.2012.11.028.

Ma'mun, A., Priatna, A., Hidayat, T. & Nurulludin. 2017. Distribution and potential resources of pelagic fish in fisheries management area of the Republic Indonesia 573 (FMA 5730) Indian Ocean. *J. Penelitian Perikanan Indonesia,* 23(1): 47–56. https://doi.org/10.15578/ jppi.23.1.2017.47-56.

Manalu, A.A, Hariyadi, S. & Wardiatno, Y. 2017. Microplastics Abundance in Coastal Sediments of Jakarta Bay, Indonesia. *AACL Bioflux,* 10(5): 11.

Masura, B. & Foster, A. 2015. Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for Quantifying Synthetic Particles in Waters and Sediments. NOAA Technical Memoraandum NOS-OR&R-48.

Mauludy, M.S., Yunanto, A. & Yona, D. 2019. Microplastic Abundances in the Sediment of Coastal Beaches in Badung, Bali. *J. Perikanan Universitas Gadjah Mada,* 21(2): 73–78. https://doi.org/10.22146/jfs.45871.

Mizraji, R., Ahrendt, C., Perez-Venegas, D., Vargas, J., Pulgar, J., Aldana, M., Patricio Ojeda, F., Duarte, C. & Galbán-Malagón, C. 2017. Is the feeding type related with the content of microplastics in intertidal fish gut? *Mar. Poll. Bull.,* 116: 498–500. https://doi.org/10.1016/j.marpolbul.2017.01.008

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: 11639. https://doi.org/10.1038/ s41598-018-29980-9.

Murphy, F., Russell, M., Ewins, C. & Quinn, B. 2017. The Uptake of Macroplastic and Microplastic by Demersal and Pelagic Fish in the Northeast Atlantic around Scotland. *Mar. Poll. Bull.,* 122 (1–2): 353–59. https://doi.org/10.1016/j.marpolbul.2017.06.073.

Neves, D., Sobral, P., Ferreira, J.L. & Pereira, T. 2015. Ingestion of Microplastics by Commercial Fish off the Portuguese Coast. *Mar. Poll. Bull.,* 101(1): 119–26. https://doi.org/10.1016/ j.marpolbul.2015.11.008.

Ory, N., Chagnon, C., Felix, F., Fernández, C., Ferreira, J.L., Gallardo, C., Garces-Ordóñez, O., Henoztroza, A., Laaz, E., Mizraji, R., Mojica, H., Murilo Haro, V., Ossa Medina, V., Preciado, M., Sobral, P., Urbina, M.A. & Thiel, M. 2018. Low Prevalence of Microplastic Contamination in Planktivorous Fish Species from the Southeast Pacific Ocean. *Mar. Poll. Bull.,* 127: 211–16. https://doi.org/10.1016/j.marpolbul.2017.12.016.

Pal, J., Shukla, B.N., Maurya, A.K., Verma, H.O., Pandey, G. & Amitha. 2018. A Review on Role of Fish in Human Nutrition with Special Emphasis to Essential Fatty Acid. *Int. J. Fish. Aquat. Sci.,* 6 (2): 427–30.

Palermo, J.D.H., Labrador, K.L., Follante, J.D., Agmata, A.B., Pante, M.J.R., Rollon, R.N. & David, L.T. 2020. Susceptibility of *Sardinella lemuru* to Emerging Marine Microplastic Pollution. *Global J. Environ. Sci. Manag.,* 6(3): 373–84. https://doi.org/10.22034/gjesm.20 20.03.07.

Pan, Z., Sun, X., Guo, H., Cai, S., Chen, H., Wang, S., Zhang, Y., Lin, H. & Huang, J. 2019. Prevalence of Microplastic Pollution in the Northwestern Pacific Ocean. *Chemosphere,* 225: 735–44. https://doi.org/10.1016/j.chemosphere.2019. 03.076.

Pereira, J.M., Rodríguez, Y., Blasco-Monleon, S., Porter, A., Lewis, C. & Pham, C.K. 2020. Microplastic in the Stomachs of Open-Ocean and Deep-Sea Fishes of the North-East Atlantic. *Environ. Poll.,* 265: 115060. https://doi.org/10. 1016/j.envpol.2020.115060.

Pertami, N. D., Rahardjo, M. F., Damar, A., & Nurjaya, I. W. 2019. Food and feeding habit of Bali Sardinella, *Sardinella lemuru* Bleeker, 1853 in Bali Strait waters. *J. Iktiologi Indonesia*, 19(1): 143-155. https://doi.org/10.32491/jii.v19i1. 444

Poojary, N., Tiwari, L. R., & Jaiswar, A. K. 2010. Food and feeding habits of the Indian scad, *Decapterus russelli* (Ruppell, 1830) from Mumbai waters, north-west coast of India. *Indian J. Fish.*, *57*(4): 93–99.

Pozo, K., Gomez, V., M., Vera, L., Nuñez, D., Oyarzún, P., Mendoza, G., Clarke, B., Fossi, M.C., Pribylova, P., Klanova, J. 2019. Presence and Characterization of Microplastics in Fish of Commercial Importance from the Biobío Region in Central Chile. *Mar. Poll. Bull.,* 140: 315–19. https://doi.org/10.1016/j.marpolbul.2019.01. 025.

Priscilla, V., Patria, M.P. 2020. Comparison of microplastic abundance in aquaculture ponds of milkfish *Chanos chanos* (Forsskål, 1775) at Muara Kamal and Marunda, Jakarta Bay. *IOP Conf. Ser. Earth Environ. Sci.,* 404: 012027. https://doi.org/10.1088/1755-1315/404/1/ 012027

Provencher, J.F., Vermaire, J.C., Avery-Gomm, S., Braune, B.M. & Mallory, M.L. 2018. Garbage in Guano? Microplastic Debris Found in Faecal Precursors of Seabirds Known to Ingest Plastics. *Sci. Total Environ.,* 644: 1477–84. https://doi.org/10.1016/j.scitotenv.2018.07.101.

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F., Werorilangi, S. & Teh, S.J., 2015. Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption. *Nat. Sci. Rep.,* 5(1): 1–10.

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. *Mar. Poll. Bull.*, 102(1), 134–141. https://doi.org/10. 1016/j.marpolbul.2015.11.043

Sagawa, N., Kawaai, K. & Hinata, H. 2018. Abundance and Size of Microplastics in a Coastal Sea: Comparison among Bottom Sediment, Beach Sediment, and Surface Water. *Mar. Poll. Bull.,* 133: 532–42. https://doi.org/ 10.1016/j.marpolbul.2018.05.036.

Sarasita, D., Yunanto, A. & Yona, D. 2020. Microplastics Abundance in Four Different Species of Commercial Fishes in Bali Strait. *J. Iktiologi Indonesia,* 20(1): 1–12. https://doi.org/10.32491/jii.v20i1.508.

Sathish, M.N., Jeyasanta, I. & Patterson, V. 2020. Occurrence of Microplastics in Epipelagic and Mesopelagic Fishes from Tuticorin, Southeast Coast of India. *Sci. Total Environ.* 720: p.137614. https://doi.org/10.1016/j.scitotenv. 2020.137614.

Scott, N., Porter, A., Santillo, D., Simpson, H., Lloyd-Williams, S. & Lewis, C. 2019. Particle Characteristics of Microplastics Contaminating the Mussel *Mytilus edulis* and Their Surrounding Environments. *Mar. Poll. Bull.,* 146: 125–33. https://doi.org/10.1016/j.marpolbul.2019.05. 041.

Siregar, S.N., Sari, L.P., Purba, N.P., Pranowo, W.S. & Syamsuddin, M.L. 2017. Pertukaran massa air di Laut Jawa terhadap periodisitas monsun dan Arlindo pada tahun 2015. *Depik,* 6(1): 44–59. https://doi.org/10.13170/depik.6.1.5523.

Su, L., Deng, H., Li, B., Chen, Q., Pettigrove, V., Wu, C. & Shi, H. 2019. The Occurrence of Microplastic in Specific Organs in Commercially Caught Fishes from Coast and Estuary Area of East China. *J. Hazard. Mater.,* 365: 716–24. https://doi.org/10.1016/j.jhazmat.2018.11.024.

Sun, X., Li, Q., Shi, Y., Zhao, Y., Zheng, S., Liang, J., Liu, T. & Tian, Z. 2019. Characteristics and Retention of Microplastics in the Digestive Tracts of Fish from the Yellow Sea. *Environ. Poll.,* 249: 878–85. https://doi.org/10.1016/ j.envpol.2019.01. 110.

Suwartiningsih, N., Setyowati, I., Astuti, R. 2020. Microplastics in Pelagic and Demersal Fishes of Pantai Baron, Yogyakarta, Indonesia. *J. Biodjati* 5: 33–49. https://doi.org/10.15575/biodjati. v5i1.7768

Sartimbul, A., Kasitowati, R. D., ‘Izza, M. K. & Fauzia, S. S. 2021. High catch of *Sardinella lemuru* (Bleeker, 1853) and plankton abundance in Prigi Waters: Case study in 2017 and 2019. *IOP Conf. Ser. Earth Environ. Sci.*, 744(1): 012071. https://doi.org/10.1088/1755-1315 /744/1/ 012071

Syakti, A.D., Bouhroum, R., Hidayati, N.V., Koenawan, C.J., Boulkamh, A., Sulistyo, I., Lebarillier, S., Akhlus, S., Doumenq, P. & Wong-Wah-Chung, P. 2017. Beach Macro-Litter Monitoring and Floating Microplastic in a Coastal Area of Indonesia. *Mar. Poll. Bull.,* 122(1–2): 217–25. https://doi.org/10.1016/j.marpolbul.2017.06. 046.

Syakti, A.D., Hidayati, N.V., Jaya, Y.V., Siregar, S.H., Yude, R., Suhendy, Asia, L., Wong-Wah-Chung, P. & Doumenq, P. 2018. Simultaneous Grading of Microplastic Size Sampling in the Small Islands of Bintan Water, Indonesia.*Mar. Poll. Bull.,* 137: 593–600.https://doi.org/10.1016/j.marpolbul. 2018.11.005.

Tielman, E.M., Indriana, L.F., Widowati, I. & Ambariyanto, A., 2022. Presence of Microplastics in Windowpane Oyster *Placuna placenta* and the waters from the Tambak Lorok Coastal Area in Central Java, Indonesia. *Ilmu Kelautan: Indonesian Journal of Marine Sciences*, 27(1): 53-60. https://doi.org10. 14710/ik.ijms.27.1.53-60

Tien, C.J., Wang, Z.X. & Chen, C.S. 2020. Microplastics in Water, Sediment and Fish from the Fengshan River System: Relationship to Aquatic Factors and Accumulation of Polycyclic Aromatic Hydrocarbons by Fish. *Environ. Poll.,* 265: 114962. https://doi.org/10.1016/j.env pol.2020.114962.

Wang, J., Wang, M., Ru, S. & Liu, X. 2019. High Levels of Microplastic Pollution in the Sediments and Benthic Organisms of the South Yellow Sea, China. *Sci. Total Environ.,* 651: 1661–69. https://doi.org/10.1016/j.scitotenv. 2018.10.007.

Webb, S., Ruffell, H., Marsden, I., Pantos, O. & Gaw, S. 2019. Microplastics in the New Zealand Green Lipped Mussel *Perna canaliculus*. *Mar. Poll. Bull.,* 149: 110641. https://doi.org/10.1016/ j.mar polbul.2019.110641.

Welden, N.A.C. & Lusher, A.L. 2017. Impacts of Changing Ocean Circulation on the Distribution of Marine Microplastic Litter: Changing Ocean Circulation and Marine Microplastic Litter. *Integr. Environ. Assess. Manag.,* 13(3): 483–87. https://doi.org/10.1002/ieam.1911.

Wieczorek, A.M., Morrison, L., Croot, P.L., Allcock, A.L., MacLoughlin, E., Savard,O., Brownlow, H. & Doyle, T.K. 2018. Frequency of Microplastics in Mesopelagic Fishes from the Northwest Atlantic. *Front. Mar. Sci.,* 5: p.39 https://doi.org/10.33 89/fmars.2018.00039.

Woodall, L.C., Sanchez-Vidal, A., Canals, M., Paterson, G.L.J., Coppock, R., Sleight, V., Calafat, A., Rogers, A.D., Narayanaswamy, B.E. & Thompson, R.C. 2014. The Deep Sea Is a Major Sink for Microplastic Debris. *Royal Soc. Open Sci.,* 1(4): 140317. https://doi.org/ 10.1098/rsos.1403 17.

Yona, D., Maharani, M.D., Cordova, M.R., Elvania, Y. & Dharmawan, I.W.E. 2020. Microplastics Analysis in the Gill and Gastrointestinal Tract of Coral Reef Fishes from Three Small Outer Island of Papus, Indonesia: A Preliminary Study. *J. Ilmu Teknol. Kel. Tropis,* 12(2): 497–507. https:// doi.org/doi.org/10.29244/jitkt.v12i2. 25971.

Yona, D., Sari, S.H.J., Iranawati, F., Bachri, S. & Ayuningtyas, W.C. 2019. Microplastics in the Surface Sediments from the Eastern Waters of Java Sea, Indonesia. *F1000 Research,* 8: 98. https://doi.org/10.12688/f1000research.171 03.1.

Zobkov, M. & Esiukova, E. 2017. Microplastics in Baltic Bottom Sediments: Quantification Procedures and First Results. *Mar. Poll. Bull.,* 114(2): 724–32. https://doi.org/10.1016/ j.marpolbul.2016.10.060.