Microplastic Exposure and Distribution in the Coastal Aquaculture Input System

APEC Oceans and Fisheries Working Group

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Produced by

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Executive Summary

Microplastic pollution is becoming a major issue due to the recent detection of microplastics in most ecosystems, with elevated concentrations detected in marine areas. Microplastics in the environment are expected to double in the coming years if there are no adequate mitigation measures. Microplastics, which are tiny plastic particles measuring less than 5 mm in length, have been found to have significant negative impacts on both human health and the environment, particularly aquatic ecosystems, as they can accumulate and leach toxic organic and inorganic pollutants and heavy metals. Microplastics are also known for their stability and inability to degrade, meaning they can persist in the environment for decades. Consequently, microplastics enter the food chain of aquatic organisms and bioaccumulate in their tissues, gradually working their way up the trophic levels via zooplankton, small fish, larger fish, and other organisms that consume them. Digesting these pollutants has been shown to have toxic effects on aquatic life. Microplastics have the potential to directly affect human health, as they can enter the human food chain through the consumption of contaminated fish or other aquatic organisms. In addition to carrying toxic chemicals, microplastics can adsorb various contaminants, including antibiotics, due to their large surface area, further exacerbating the problem of microplastic toxicity. Currently, there is a lack of coherent regulatory frameworks and consistent standard methods for defining microplastics in aquaculture systems. In addition, the available data on concentrations of microplastics in the coastal aquaculture input chain are limited and there is no systematic mitigation plan to reduce macro/microplastics in coastal aquaculture systems regionally and/or internationally. Therefore, a systematic and integrated joint effort between economies is needed to deal with this form of marine debris pollution. APEC's strategic role is to encourage initiatives to find solutions to this problem so that the market share of seafood products exported by most APEC economies is not impeded.

This report addresses the technical requirements to deliver the second output of the project "Determining Microplastics Distribution in Coastal Aquaculture Input Systems and Developing a Mitigation Plan towards Seafood Safety" about research

based on information on the level and distribution of microplastics in the input system of coastal aquaculture. Two large sampling campaigns were conducted in Indonesia (4 consecutive days, from 30 July to 2 August 2023) and in Viet Nam (4 consecutive days, from 10 to 13 August 2023). The sampling campaign in Indonesia was carried out in Lampung Bay, Padang Cermin sub-district, Pesawaran district, Lampung province. The second sampling campaign was conducted in Hai Phong located on the east coast of Viet Nam. In total, 268 samples were collected, including 60 farmed fish, 20 farmed shrimp, 40 wild carnivorous fish, 40 trash fish, 36 commercial feeds, 24 fishmeal, 12 seawater from net cages and ponds, 18 sediment from net cages and beaches, 18 sediments from shrimp ponds. They were divided into two fractions: 0.3-1 mm and 1-5 mm, with a total of 536 samples analyzed. Different approved sample preparation and treatment procedures were applied to different types of samples such as water, sediment, GIT of fish and shrimp, commercial feed and meal. The analyses of microplastics were performed using a stereo microscope, FT-IR, micro-FT-RT, SEM, and EDX mapping. All the sample preparation/treatment and analyses were conducted within the laboratories of Viet Nam National University, Hanoi.

The results showed that blue, green, black, yellow and white are among the most abundant colors of microplastics collected in water, sediment, fish, shrimp, feed and meal samples in Hai Phong, Viet Nam and Lampung, Indonesia. Fragment and fiber were the most abundant forms, which accounted for 11.3-85.5% (for fragment) and 11.9-77.1% (for fiber), while pellet was the least representative form of microplastics with less than 2% of all forms in all samples. Water, feed and fishmeal contained significantly more microplastics than fish/shrimp samples, which were mainly PET and PA. Microplastics were presented in two fractions (0.3-1 mm and 1-5 mm) and relatively comparable for most of the samples in terms of number of microplastics. In general, water samples contained the most microplastics, with a typical value of 0.45 particles/m^3, varying from 0.1702 particles/m^3 to 1.031 particles/m^3. The number of microplastics in fishmeal was highest, while sediment samples were ranked the second in terms of the number of microplastics, which were about 20 times greater than in fish and shrimp samples (~ 0.2 particles/g of dried sediment vs. about 0.01 particles/g of fish). Commercial feed samples had concentrations of microplastics that were 10 times

higher than fish and shrimp samples. Trash and wild fish seemed to contain more microplastics than fed fish.

Based on the interconnection, similar farming technologies and input products, the context of this research in the selected sites could be similar in other APEC economies. Firstly, the interconnected marine environments allow the distribution of microplastics in waterways of APEC economies where coastal aquaculture takes place. Secondly, most APEC economies practice similar farming technologies and use similar or the same input products that are contaminated by microplastics. However, the specific nature of microplastics and the level of contamination may be different from one place to another due to factors like different levels of marine plastic pollution management and physical geography.

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Abbreviations

ATR: Attenuated Total Reflectance

CL: Cellulose

CP: Cellophane

CPP: Cast Polypropylene

EDX: Energy Dispersive X-Ray Spectroscopy

EV: Ethyl vinyl acetate

EVOH: Ethylene vinyl alcohol

EVOH: Ethylene vinyl alcohol copolymer

FT-IR: Fourier Transformed Infrared Spectroscopy

GIT: Gastrointestinal tracts.

HDPE: High Density Polyethylene

LLDPE: Linear Low Density Polyethylene

MUF: Melamine-urea-formaldehyde

PA: Polyamide

PA: Polyamide (Nylon 66)

PAK: Polyacrylates

PAM: Polyacrylamide

PCL: polycaprolactone

PE: Polyethylene

PEI: Polyethylenimine

PES: Polyester.

PET: Polyethyleneterephthalate

PEVA: Poly(ethylene-vinyl acetate)

PFAS: Polyfluoroalkyl substances

PLEXAR: anhydride-modified polyolefins

PNB: Norbornene or Polynorbornene

POF: Polyolefin

PP: Polypropylene

PPA: Polyphthalamide

PPE: Polyphenylene Ether

PS: Polystyrene

PU: Polyurethane

PVA: Polyvinyl alcohol

PVC: Polyvinyl chloride

PVC: Polyvinylchloride

PVDF: Polyvinylidene fluoride

Pyr-GC–MS: pyrolysis-gas chromatography–mass spectrometry

SEM: Scanning Electron Microscopy

URF: Polyureformaldehyde

WWTPs: Wastewater Treatment Plants

µ-FT-IR: Microscopy coupled with Fourier Transformed Infrared Spectroscopy

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1. Description of the sampling sites in Indonesia and Viet Nam

1.1. Sampling sites in Indonesia

The sampling campaigns were conducted during 4 consecutive days from 30 July to 2 August 2023. Indonesian sampling sites were located in Lampung Bay, Padang Cermin Sub-district, Pesawaran district, Lampung province. The sample collection was carried out by an Indonesian research counterpart appointed by the contractor and supported by the technicians from the Ministry of Marine Affairs and Fisheries. The collection of seawater and sediment in and around net cages was conducted in proximity to Durian village, where there are about 1,600 inhabitants. The coordinates are 5.617417 S, 105.178028 E (Fig. 1). Water in the surveyed area was quite clean and apparently with no visible significant floating fragments except for leaf and tree branch litter. No significant plankton blooms were observed during the sampling campaigns (Fig. 2).

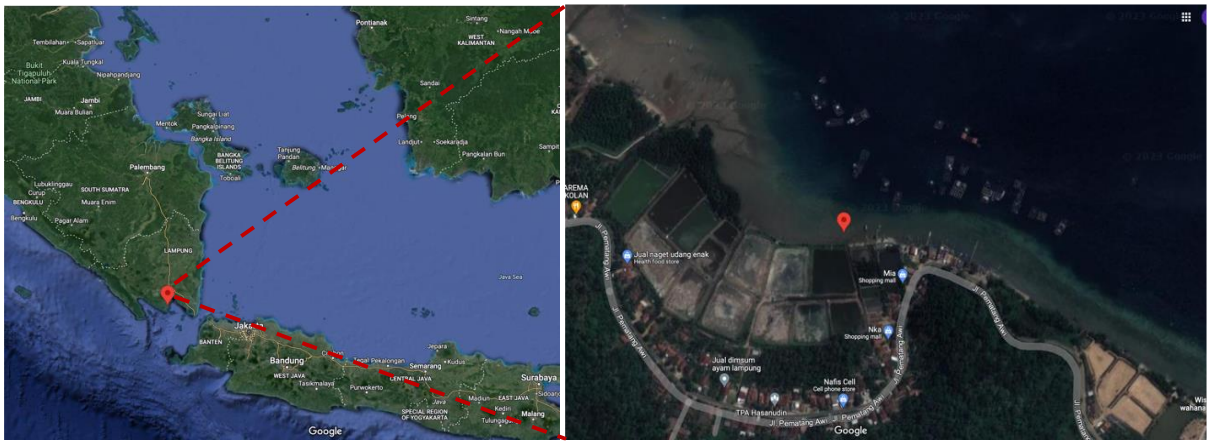


Fig. 1. Location of the surveyed net cages in Indonesia.

Fig. 2. Appearance of surface water in net cage area in Indonesia.

There were about 40 net cages and no maritime traffic in the surveyed area. The sea currents were not measured. The sampling spots were about 150-200 m from shorelines; the beach was not suitable for recreational activities due to muddy sediments thus not frequently visited by locals and/or tourists.

The examined shrimp farm was located in the same village about 3 km South of the net cages, with the coordinates of 5.641889 S, 105.188139 E (Fig. 3). The surveyed shrimp pond belongs to a company that has more than 30 ponds with an average surface area of about 4,500 m^2/pond. The shrimp farm was not frequently visited by locals and tourists. No significant industries, agriculture, and tourism were observed in the surveyed area.

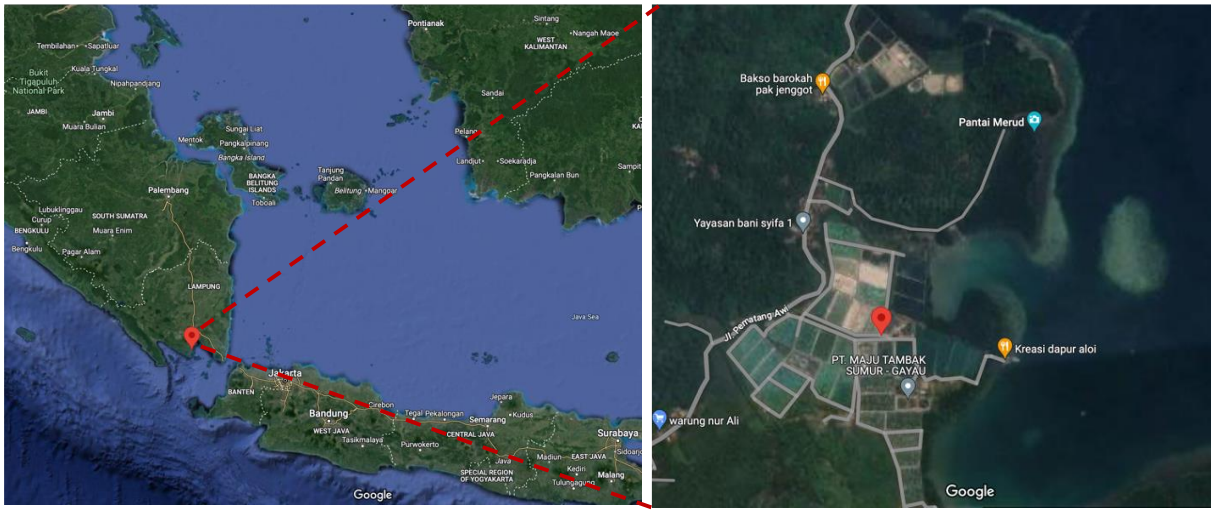


Fig. 3. Location of the surveyed shrimp ponds in Lampung, Indonesia.

1.2. Sampling sites in Viet Nam

The sampling campaigns were conducted during 4 consecutive days from 10 August to 13 August, 2023. Sampling sites were located in Cat Ba Island, Cat Hai district, Hai Phong city. The collection of seawater and sediment in and around net cages was conducted in proximity to Van Chai fishing village, where there are about 450 houses and an economy based on fishing and aquaculture. The coordinates are 20.738435 N, 107.062856 E (Fig. 4). Floating materials, including plastic bottles, were observed at this location (Fig. 5). No significant plankton blooms were observed during the sampling campaigns.

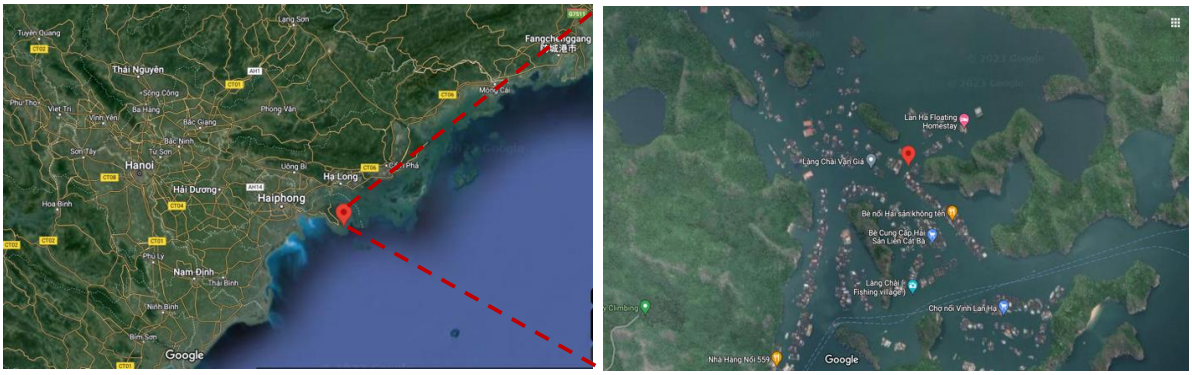


Fig. 4. Location of the surveyed net cages in Viet Nam.

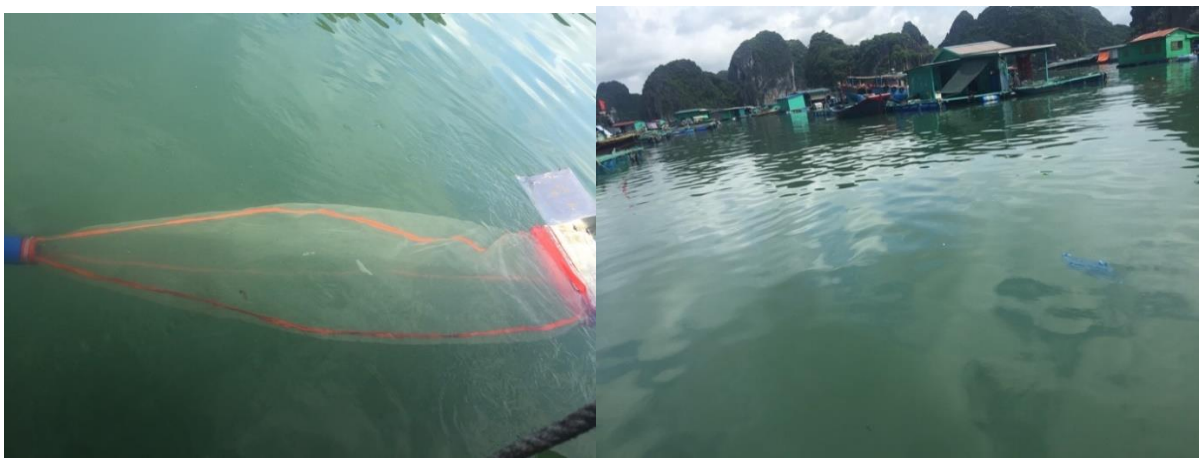


Fig. 5. Appearance of surface water in net cage area in Viet Nam.

Each family had at least one net cage system containing more than 10 to 100 individual net cages. There was maritime traffic for tourism and fishing activities in the surveyed area. The sea currents were not observed. The sampling spots were about 100 m to 1,000 m from shorelines, while beaches were not used for swimming due to deep cliffs and sharp rocks. The surveyed spots were frequented by fishers and/or tourists.

The surveyed shrimp farm was located in Cat Hai district about 16 km North West of the net cages, with the coordinates of 20.804920 N, 106.933194 E (Fig. 3). The surveyed shrimp were owned by a company which has more than 130 ponds with an average surface area of about 1,600 m^2/pond. The shrimp farm locality was not frequently visited by locals and tourists. No significant industries, agriculture, and tourism were observed in proximity to the surveyed area.

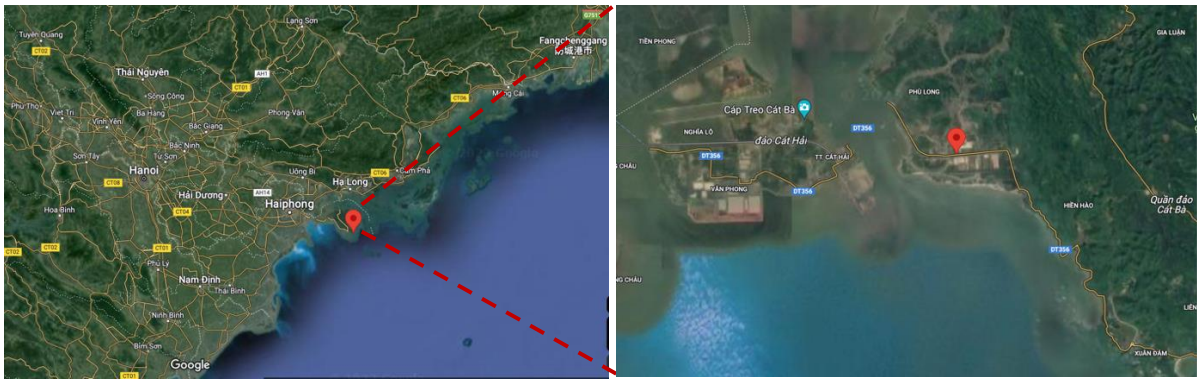


Fig. 6. Location of the surveyed shrimp ponds in Viet Nam.

2. Sampling campaigns in Indonesia and Viet Nam

2.1. Sampling campaigns in Indonesia

2.1.1. Sediment and seawater sampling campaigns in net cage areas

Surface water was collected by using a Manta net which has a center box of 30 cm x 40 cm x 30 cm (LxWxH) made of inox (stainless steel) 304, a 0.3 mm mesh made of nylon. The nylon net length is 2 m (Fig. 7). Three surface seawater samples were collected around 40 net cages containing about 15 sections each, with a volume of 3x3x3 m^3 (Fig. 8). The volume of water sampled for the three samples was respectively 77 m^3, 83 m^3 and 94 m^3.

Fig. 7. Surface water sampling around net cages by a Manta net.

All the net cages farmed two cycles of fish per year with common species of grouper (local name: Kerapu Tikus), barramundi (local name: Kakap Putih), and Silver

pompano. Locals usually use 1.8 tons of commercial feed per cycle for a typical yield of about 600 kg of fish. The used fish feed consisted of commercial feed or trash fish with different application methods and feed ratios between fish farms. The commercial fish feed used in the area was purchased from the same company (Matahari Sakti brand).

Fig. 8. Surface water sampling itineraries around net cages in Lampung province, Indonesia.

An Ekman Sediment grab sampler, sized 6 x 6 x 8 inches (LxWxH) was deployed to collect three sediment samples at one selected net cage, three sediment samples in the middle of net cages and beaches, and three sediment samples on the beach. In total, nine sediment samples were collected at the net cage area (Fig. 9, 10, and 11).

Fig. 9. Sediment sampling around net cages in Lampung province, Indonesia.

Fig. 10. Sediment sampling in the middle of net cages and beach in Lampung province, Indonesia.

Fig. 11. Sediment sampling on beach in Lampung province, Indonesia.

2.1.2. Sediment and seawater sampling campaigns in shrimp pond areas

As mentioned previously, the surveyed shrimp farm belongs to a company which has more than 30 ponds with an average surface area of about 4,500 m^2/pond. The selected pond was rectangular sized (60 m x 70 m). In total, 9 sediment samples were collected in the center (3 samples) and around the banks (6 samples) with a distance of > 3 m from the banks. The water samples were collected at the center and two opposite corners of the pond so that the distance from the sampling points to the banks was 3 m at the minimum. In a typical procedure, 100 L of H_2O was sampled and filtered through a plankton net with a mesh size of 200 microns to capture microplastics and fragments > 200 microns. The microplastics were then collected using two 0.3 mm and 5.0 mm sieves, as presented in section 3.2. In total, three water samples were collected in the middle of each examined pond (Fig. 12 and 13).

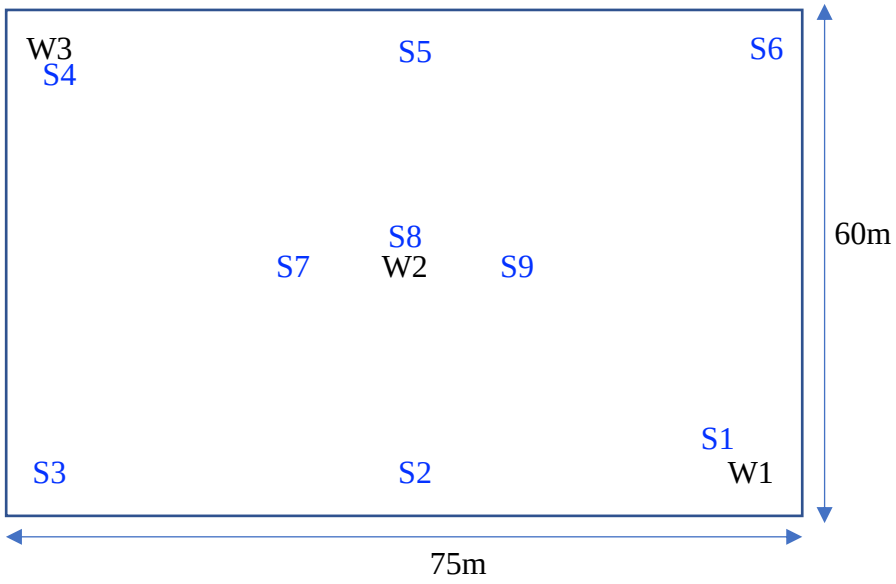


Fig. 12. Sediment and water sampling points in a shrimp pond in Lampung province, Indonesia. S (sediment samples), W (water samples).

Fig. 13. Sediment and water sampling in a shrimp pond in Lampung province, Indonesia.

2.1.3. Fish and shrimp GITs

Fish and shrimp were purchased from net cages and shrimp ponds in the surveyed areas. There were 10 Humpback Groupers (local name: Kerapu Tikus), 10 Barramundi (local name: Kakap Putih), and 10 Silver Pompano (local name: Bawal Bintang) fed with commercial feed, 12 whiteleg shrimp (*Litopenaeus vannamei*) fed with commercial feed, 20 wild carnivorous fish associated with net cages ((10 Giant trevally (*Caranx ignobilis*) + 10 Rabbitfish (local name: Baronang)) and 20 trash fish (10 Moon

fish + 10 Yellow tail) collected in the surveyed area (Fig. 14). Total length and weight of each fish and shrimp were measured with the aid of a balance with a scale of 0-5,000 g and a resolution of 0.1g, and a ruler (0-30 cm).

The data of weight, size, and GIT's weight of Humpback Groupers, Barramundis, Silver Pompano, Giant trevally, Rabbitfish, Moonfish, and Yellow tail are presented in Table 1.

Table 1. Data summary of fish samples collected in Lampung, Indonesia.

No	Name of fish	Weight (g)		Total length (cm)		GIT's weight (g)	
		Average ± Std	Min – Max	Average ± Std	Min – Max	Average ± Std	Min – Max
1	Humpback Grouper	686 ± 75	751 – 758	34 ± 1.3	32.5 – 35	40 ± 6.9	31 – 48
2	Silver Pompano	664 ± 115	577 – 829	35 ± 2.7	31 – 38	38 ± 12	22 – 50
3	Barramundi	575 ± 43	527 – 613	30.7 ± 0.9	26 – 39	34.4 ± 5.1	26 – 39
4	Giant trevally	432 ± 37	388 – 472	29.5 ± 0.5	29 – 30.6	34.6 ± 3.4	29 – 38
5	Rabbitfish	91.6 ± 28	66 – 126	15.8 ± 8	2 – 21	5 ± 1	4 – 6
6	Yellow tail	71.8 ± 9.5	58 – 83	17.8 ± 0.9	17 – 19	2.8 ± 0.4	2 – 3
7	Moon fish	22.6 ± 4.5	16 – 27	10.6 ± 0.8	9.5 – 11.5	0.6 ± 0.2	0.4 – 0.7
8	Shrimps	10.8± 1.9	9 – 12	11.6 ± 0.5	11 – 12.5	3*	-

*) All the GIT of collected shrimps were grouped to have a total weight (g) as the GIT's weight of shrimps are very low.

The average weight of Humpback Groupers, Barramundis, Giant trevally, Silver Pompano, Rabbitfish, Yellow tail, and Moon fish was respectively 686 ± 75 g, 575 ± 43 g, 432 ± 37 g, 664 ± 115 g, 91.6 ± 28 g, 71.8 ± 9.5 g, 22.6 ± 4.5 g. The corresponding total length of each fish was 34 ± 1.3 cm, 30.7 ± 0.9 cm, 29.5 ± 0.5 cm, 35 ± 2.7 cm, 15.8 ± 8 cm, 17.8 ± 0.9 cm, 10.6 ± 0.8 cm, while their average GIT weight was 40 ± 6.9 g, 34.4 ± 5.1 g, 34.6 ± 3.4 g, 38 ± 12 g, 5 ± 1 g, 2.8 ± 0.4 g, 0.6 ± 0.2 g, respectively

Regarding the collected shrimp (*Litopenaeus vannamei*), their total length varied in the range of 11 – 12.5 cm (11.6 ± 0.5) while their weight is within the range of 9 – 12 g. As the weights of shrimp GITs were very small, we grouped all the GITs of collected shrimp into 2 samples (shrimp number 1 – 6 and 7 – 12) which respectively have a total weight of 3 g each.

Fig. 14. Fish and shrimps collected in netcage area of Lampung province, Indonesia.

The fish were rinsed with filtered water from a Reverse Osmosis (RO) water filtration system, dissected, and the gastrointestinal tracts (GIT) were collected. The

entire GIT was weighed, rinsed in filtered water, and placed in individual previously cleaned glass petri disks (Fig. 15). Dissected GITs were transferred and stored in sealed aluminium foil bags, and transported to the laboratory until further processing.

Fig. 15. GIT of fish and shrimps collected in Lampung province, Indonesia.

2.1.4. Fish and shrimp fed feed and fishmeal

Nine commercial feeds (freshly produced) and nine commercial feeds (stored on farm at least 2-4 months post-date production) were purchased in the surveyed area, which were from two fish feed brands and 1 shrimp feed brand. Five fishmeal samples were collected; 4 were imported from the UK, Germany, Estonia, Thailand, and the other was from an Indonesian producer.

Fig. 16. Commercial feeds for fish and shrimps and fishmeal collected in Lampung province, Indonesia.

2.2. Sampling campaigns in Viet Nam

2.2.1. Sediment and seawater sampling campaigns in net cage areas

Surface water was collected using a Manta net consisting of a center box of 30 cm x 40 cm x 30 cm (LxWxH) made of Inox (stainless steel) 304 and a 0.3 mm mesh made

of nylon 2 m long. Three surface seawater samples were collected in the coastal area where a cluster of small-scale net cages was located (Fig. 17). The volume of water sampled for the three samples was respectively 65 m^3, 68 m^3 and 82 m^3.

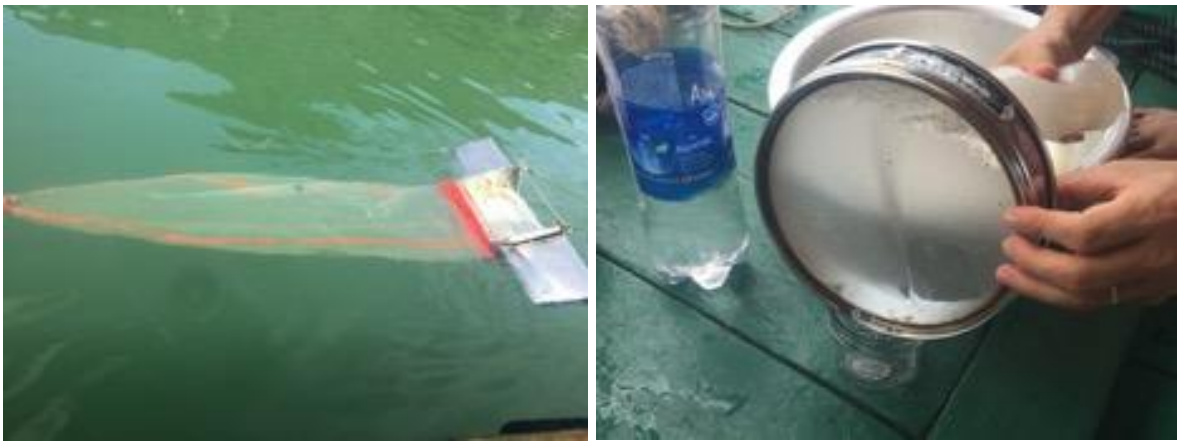


Fig. 17. Surface water sampling around net cages by a Manta net in Cat Hai district, Hai Phong city, Viet Nam.

Two cycles of fish were farmed per year in all the net cages. Locals usually spend 1.8-2.0 tons of commercial feed per cycle per farm. The fed feeds for different farms and net cages were purchased from different companies.

Fig. 18. Surface water sampling itineraries around net cages in Cat Hai district, Hai Phong City, Viet Nam.

An Ekman Sediment grab sampler, sized 6 x 6 x 8 inches (LxWxH), was deployed to collect three sediment samples each at the selected net cage, the halfway distance from the net cage and the beach, and on the beach. In total, nine sediment samples were collected at netcage area (Fig. 19, 20, and 21).

Fig. 19. Sediment sampling around net cages in Hai Phong city, Viet Nam.

Fig. 20. Sediment sampling in the middle of net cages and beach in Hai Phong province, Viet Nam.

Fig. 21. Sediment sampling on the beach in Hai Phong province, Viet Nam.

2.2.2. Sediment and seawater sampling campaigns in shrimp pond areas

The surveyed shrimp pond is one of 180 ponds owned by a company, each sized around 2,400 m^2/pond. The selected pond was rectangular, sized 60 m x 40 m. In total,

9 sediment samples were collected in the center (3 samples) and around the banks (6 samples) with a distance of > 3 m from the banks. Three water samples were collected with a volume of 100 L each. The water samples were collected at the center and two opposite corners of the pond so that the distance from the sampling points to the banks was minimum 3 m (Fig. 22 and 23).

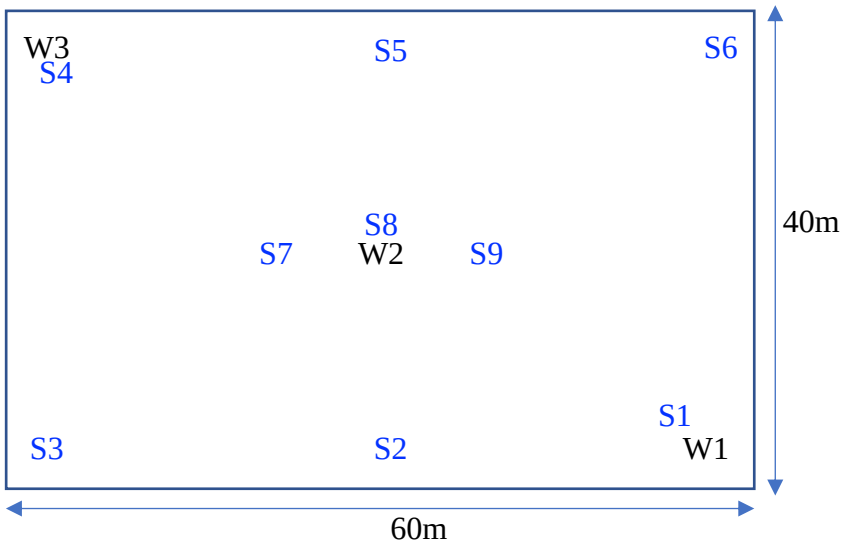


Fig. 22. Sediment and water sampling points in a shrimp pond in Hai Phong province, Viet Nam. S (sediment samples), W (water samples).

Fig. 23. Sediment and water sampling in a shrimp pond, Hai Phong province, Viet Nam

2.2.3. Fish and shrimp GITs

Fish and shrimp were purchased from the net cages and shrimp farmers in the surveyed areas. There were 10 Groupers (local name: cá song, cá mú), 10 Barramundi (local name: cá vược) and 22 shrimp all fed with commercial feed, 10 Bronze Croaker fish (local name: cá sủ) fed with trash feed, 30 wild carnivorous fish (10 Diamond Trevallies (local name: cá ông lão) + 10 Golden Rabbit fish (local name: cá bông dìa) + 10 Star Snappers (local name: cá nốt)) and 20 trash fish (10 *Scatophagus argus* (local name: cá nâu hói) + 10 Halfbeaks (local name: cá kìm) collected in the surveyed area (Fig. 24). Size and weight of each fish and shrimp were measured with the aid of a balance with a scale of 0-5,000 g, a resolution of 0.1 g, and a ruler (0-30 cm). As Halfbeaks were small in size and weight, only their GITs were used for further analyses.

The data for weight, total length, and GIT's weight of Groupers, Barramundis, Bronze Croaker fish, Diamond Trevallies, Golden Rabbitfish, Star Snappers, and *Scatophagus argus* are presented in Table 2.

Table 2. Data summary of fish samples collected in Hai Phong, Viet Nam.

No	Name of fish	Weight (g)		Total length (cm)		GIT's weight (g)	
		Average±Std	Min–Max	Average±Std	Min–Max	Average±Std	Min–Max
1	Groupers	2,580 ± 519	1,900 – 3,136	55 ± 5	48 – 60	166 ± 42	105 – 198
2	Barramundis	11,089 ± 47	1,031 – 1,145	43 ± 2	41 – 46	95 ± 22	74 – 126
3	Bronze Croaker fish	2,262 ± 183	2,078 – 2,475	60 ± 3	56 – 64	87 ± 10	75 – 98
4	Diamond Trevallies	615 ± 114	475 – 770	39 ± 2	37 – 42	35 ± 14	21 – 58
5	Golden Rabbitfish	140 ± 36	109 – 208	20 ± 2	18 – 23	10 ± 2	8 – 12
6	Star Snappers	67 ± 30	38 – 125	13 ± 1	12 – 15	8 ± 4	3 – 13
7	Scatophagus argus	15 ± 2	11 – 17	15 ± 4	8 – 18	2 ± 0.5	1 – 2
8	Shrimps	31.6±0.8	30.5 – 32.3	12.8±1.3	11-14	18*	

*) All the GITs of collected shrimps were grouped as the total weight (g) due to their small sizes.

Fig. 24. Fish and shrimps collected in net cage area of Hai Phong province, Viet Nam

The fish were rinsed with filtered water from a Reverse Osmosis (RO) water filtration system, dissected, and the GITs were collected. The entire GITs were weighed, rinsed in filtered water, and placed in individual previously cleaned (with filtered water) glass petri disks (Fig. 25). Dissected gastrointestinal tracts were stored in sealed aluminium foil bags kept in laboratories until further processing.

Fig. 25. GITs of fish and shrimps collected in Hai Phong province, Viet Nam

2.2.4. Fish and shrimp fed feed and fishmeal

Nine commercial feed (freshly produced) and nine commercial feed (stored on farm at least 2-4 months post-date production) were purchased in the surveyed area, which were from two fish feed brands and 1 shrimp feed brand. Fifteen fishmeal samples were collected, including 12 imported from France; Peru; Russia; Spain; Thailand, and three others from a Vietnamese producer.

Fig. 26. Commercial feeds for fish and shrimps and fishmeal collected in Hai Phong, Viet Nam (left) and Lampung, Indonesia (right).

3. Sample storage, preparation, and analysis

3.1. Sample storage

All samples of fish and shrimp GITs and sediment samples were dried in an oven at 60 °C for at least 24 h at the Lampung Mariculture Development Center, Lampung, Indonesia, then kept in aluminium foil bags to contain odor and avoid biochemical decomposition processes during the transport. All water samples were kept in glass jars and dried in an oven at 60 °C for at least 24 h before being transported to Viet Nam. All fish/shrimp commercial feed and fishmeal samples were collected and kept in aluminium foil bags for transport to Viet Nam.

A similar procedure was applied to all samples collected in Viet Nam, that the collected samples were directly transported to laboratories after the end of the sampling campaigns and dried at 60 °C for at least 24 h in laboratories. Water samples were kept in glass jars with metallic caps. Sediment samples, commercial fish/shrimp feeds and fishmeal were kept in aluminium foil bags, while fish and shrimp GIT samples were stored in glass petri dishes.

All samples collected in Indonesia and Viet Nam were stored and analyzed at the laboratories of Viet Nam National University, Hanoi, in which all commercial fish/shrimp feeds, fishmeal, and sediment samples were stored in refrigerators with an average temperature of < 4 °C while GIT samples were stored in a −10 °C freezer. All of those samples were subjected to sample preparation and analyses of size, color,

number, morphology, and nature of microplastics according to the procedures approved by the PO of the project and VNU key laboratories.

3.2. Sample preparation

3.2.1. Water sample preparation

The preparation of water samples was conducted using modified procedures previously published [1-6]. In a typical procedure, water samples kept in glass jars were filtered through a 0.3 mm mesh sieve made of Inox (stainless steel) 304 to collect all fragments > 0.3 mm. The fragments obtained in each glass jar were then transfered into a 500 mL glass beaker containing 250 mL of 30% H_2O_2 solutions (Sigma-Aldrich). Subsequently, the glass beaker was covered with aluminium foil and the mixture was shaken in the dark for 5 min at a speed of 200 rpm with the aid of a shaker model KS 260 S, IKA, Italia, then put in an oven at 65 °C for 48 h. The mixture was then poured into 2 superposed sieves of 1 mm (up) and 0.3 mm (down) meshes to collect two fractions of microplastics: 1-5 mm and 0.3-1 mm. The fragments on two sieves (0.3 and 1 mm meshes) were then transferred to two different glass beakers (500 mL) containing 250 mL of 1.6 g/mL $ZnCl_2$ solutions, which were prepared from $ZnCl_2$ salt (Sigma-Aldrich) for separation process which allows to collect all plastic materials.

Fig. 27. Organic material digestion (left) and filtration to collect floating fragments (right)

Floating materials (microplastics) were filtered through a glass filter of 5 µm in pore size and 47 mm in diameter (Whatman), then washed using a vacuum pump and DI water. Microplastics on glass filters were kept in a glass petri dish (60 mm in diameter) and dried at 60 °C for 48 h in an oven; the glass petri dish containing the filter

was then stored in a desiccator in an air-conditioned room (25°C, 50% RH) for further analyses. The fragments in the other glass jars were also subjected to the treatment procedure above to obtain microplastics of 0.3-1 mm and 1-5 mm. All microplastics corresponding to a sample with a known water volume were later used to calculate the number of microplastics in water (particles/m^3).

3.2.2. Sediment sample preparation

The preparation procedure for sediment samples was used based on previous reports [7-12] with some modifications. Briefly, sediment samples collected and stored in aluminium foil bags were transferred to 250 mL glass beakers and then dried in an oven at 65 °C for 48 h. In each sample, 20 g of dried sediment was transferred to a glass beaker (500 mL) containing 250 mL of 1.6 g/mL $ZnCl_2$ solution for separation, which allowed the collection of all plastic materials. Floating materials (microplastics) in a sample were filtered through a 0.3 mm mesh sieve to collect all fragments > 0.3 mm, then transferred into a 500 mL glass beaker containing 250 mL of 30% H_2O_2 solution. Subsequently, the glass beaker was covered with aluminium foil and the mixture was shaken at a speed of 200 rpm in the dark for 5 min with the aid of a shaker model KS 260 S, IKA, Italia, then put in an oven at 65 °C for 48 h. The mixture was then poured into 2 superposed sieves of 1 mm (up) and 0.3 mm (down) meshes to collect two fractions of microplastics: 0.3-1 mm and 1-5 mm. The microplastics collected on 0.3 mm and 1 mm mesh sieves were transferred and filtered through two different glass filters of 5 μm in pore size and 47 mm in diameter, then washed using a vacuum pump and DI water to collect clean microplastics of two fractions (0.3-1 and 1-5 mm). Microplastics on glass filters were kept in a glass petri dish (60 mm in diameter) and dried at 60 °C for 48 h in an oven; the glass petri dish containing the filter was then stored in a desiccator in an air-conditioned room (25°C, 50% RH) for further analyses. Some preparation steps can be seen in Fig. 28.

Fig. 28. Dried sediment (left) and shaking process on a shaker (right)

3.2.3. Fish and shrimp sample preparation

The GITs of each fish and shrimp stored in aluminium foil bags, as presented in sub-sections 2.1.3 and 2.2.3, were put in a 500 mL glass beaker containing 250 mL of 30% H_2O_2. The mixture was shaken in the dark by a shaker model KS 260 basic, IKA, Italia at a speed of 200 rpm for 5 min, then put in an oven at 65 ℃ for 48 h [13, 14]. The mixture was manually stirred regularly using a glass rod while kept in the oven. More 30% H_2O_2 solution will be added if the GIT is not entirely dissolved. Once the GIT was dissolved, the solution was subjected to filtration through two sieves of 1 and 0.3 mm, a separation process by using 1.6 g/mL $ZnCl_2$ solution and drying to collect microplastics of 0.3-1 mm and 1-5 mm as presented in sections 3.2.1 and 3.2.2. Examples of GIT digestion by 30% H_2O_2 solution and separation process using 1.6 g/mL $ZnCl_2$ solution are shown in Fig. 29 left and right, respectively. The processes mentioned above were deployed using previously published work, with some modifications [13-16].

Fig. 29. GIT dissolution (left) and density separation process (right).

3.2.4. Feed and fishmeal sample preparation

Feed and meal samples were prepared according to previously published procedures with some modifications to have better recovery of microplastics [17-19]. 20 g of feed and meal samples previously stored in aluminium foil bags were transferred to 500 mL glass beakers containing 250 mL of 30% H_2O_2 solutions to dissolve the organic materials. As previously presented, the dissolution process was conducted at 65 ℃ for 48 h. In case feed and meal samples were not completely dissolved, an additional 30% H_2O_2 solutions were added. The mixture was then subjected to filtration through two sieves of 1 and 0.3 mm, a separation process by using 1.6 g/mL $ZnCl_2$ solution and drying to collect microplastics of 0.3-1 mm and 1-5 mm as presented in sections 4.2.1 and 4.2.4. Fig. 30 presented examples of filters before (left) and after (right) filtration process for separating and collecting microplastics in feed and meal samples.

Fig. 30. Filters before (left) and after (right) the filtration process.

3.3. Sample analysis

3.3.1. Stereo microscope analyses

The color, morphology, size, and number of microplastics collected on the glass filters were analyzed using a Stereo Microscope Carl Zeiss, Stemi 508 within the premises of the VNU key laboratories. Some pictures of the facilities, including a Stereo Microscope, are presented in Fig. 31. The magnification was adjusted according to the size of microplastics, and it was within the range of 0.5 to 10.0 x.

Fig. 31. Facilities and Stereo Microscope deployed for preparation and analysis of microplastics

3.3.2. FT-IR and micro FT-IR, and SEM/EDX mapping analyses

Chemical functional groups were identified using Fourier-Transform Infrared Spectroscopy (FT-IR) with Attenuated Total Reflection (ATR) mode, model 4600, JASCO, Japan, and Micro-Fourier Transform Infrared Spectrometry (Micro-FTIR) combining a microscope with an FT-IR instrument, model NICOLET iN10, Thermo Scientific, USA, providing even more information about the chemical fingerprints for both organic and inorganic compounds that are components in small quantity and/or signal intensity that the conventional FT-IR could not measure. For a feasible application, FT-IR- ATR was deployed for the analysis of large microplastic fragments (2-5 μm), while micro FT-IR was deployed for the analysis of small microplastic fragments (< 2 μm) which do not allow FT-IR to identify the polymer of each microplastic particle due to too small size [20-21].

By comparing the sample spectra with known spectra from the database (JASCO (for FT-IR) and THERMO Scientific (for μ FT-IR) polymer spectral libraries), the

polymer in the sample can be determined. The spectral quality and matching score (>70 %) with the reference FT-IR library were taken into account.

Fig. 32. FT – IR Spectroscopy JASCO 4600 (a), μ FT – IR NICOLET iN10, Thermo Scientific, USA (b), Scanning Electron Microscopy (SEM) coupled with Energy-dispersive X-ray spectroscopy (EDX) (c), and preparation room (d)

The detailed morphology of very nano-plastics, which were defined as synthetic polymers with dimensions below 1 μm [22, 23], and their chemical composition were examined using a Scanning Electron Microscopy, TM4000Plus, Hitachi, Japan, while the composition and distribution of elements in nanoplastics was analyzed by an Energy-dispersive X-ray spectroscopy mapping, AZtecLive, Oxford, UK.

4. Quality assurance and statistical analysis

It is extremely important to prevent any cross-contamination from preparation to analysis processes. The laboratory and exposed surfaces were cleaned regularly. The glass flasks and beakers were always covered with aluminium foil during the preparation and analytical processes. Three blank Whatman filter papers directly taken from 3 packets (1 per packet) were subjected to stereo microscope, micro-FT-IR and SEM analyses to check the filter's purity and contamination. Three Whatman filter papers were subjected to the exact sample preparation and treatment for each type of

sample (Fish and shrimp, sediment, water, feed, and meals) but without the samples (only 30% H_2O_2, DI water, and $ZnCl_2$ solutions) to examine the contamination during the sample preparation and analyses. In total, 18 filters were analyzed to check the contamination. The outcomes are presented in Annexe 1.

Kruskal–Wallis test was conducted to analyze the difference in the quantity of microplastic in different types of samples, forms, sizes, and colors of microplastics. In contrast, ANOVA tests were applied to nominal variables such as the number of microplastics/g of sediment, fish, shrimp, feed, and fish feed. The Pearson correlation coefficient was calculated to determine the correlation between the number of microplastics found in the samples. The statistical calculation was conducted in Minitab 16.

5. Results and discussion

5.1. Colors and forms of microplastics

Colors and forms of microplastics were counted and defined as presented in Fig. 33, 34. Visibly, one can see different forms and colors of microplastics found in seawater samples. The results revealed that blue, green, black, yellow and white are among the most abundant colors of microplastics collected in water, sediment, fish, shrimp, feed and meal samples in Hai Phong, Viet Nam and Lampung, Indonesia. Grey, pink and red were not significantly representative of the colors of the collected microplastics (Table 1 and 2).

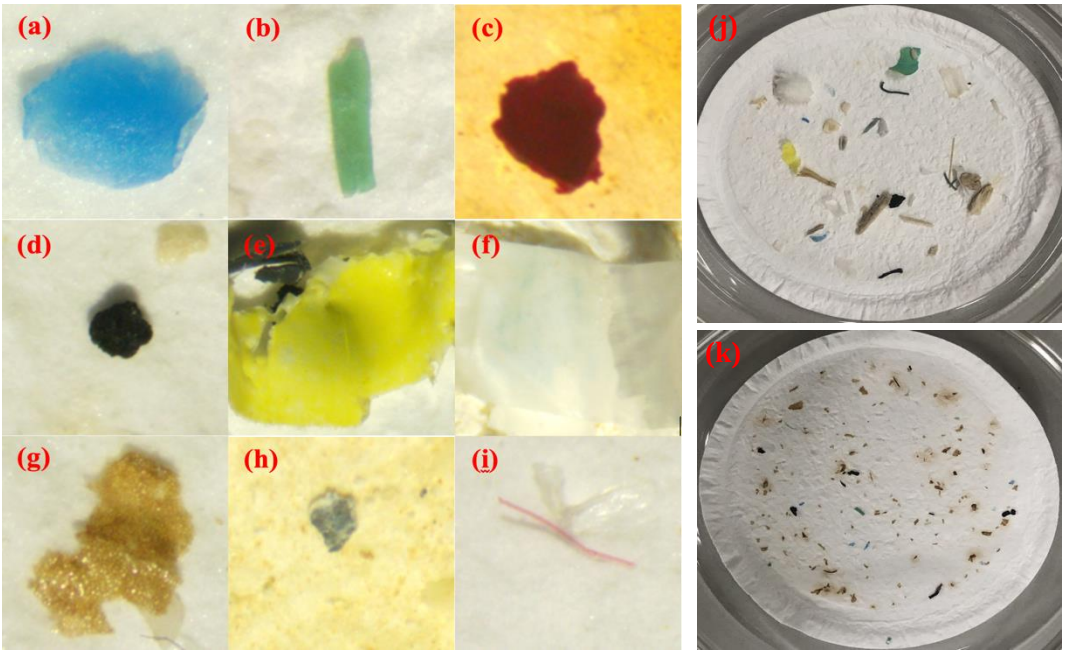


Fig. 33. Different colors of microplastics (a)Blue, (b) Green, (c) Red, (d) Black, (e) Yellow, (f) White, (g) Brown, (h) Grey, (i) Pink, (j) microplastics (1-5 mm) and (k) microplastics (0.3-1 mm) in a seawater sample collected in Lampung, Indonesia

Microplastic size was measured using a Stereo Microscope Carl Zeiss, Stemi 508. Fig. 34 presents an example of microplastic size measurement. It is noted that the figures presented in Fig. 34 were in pixels, and they should be converted to mm by a factor of 1/90 (1 mm = 90 px). For other microplastic sizes, please refer to Annexe 1 for more details.

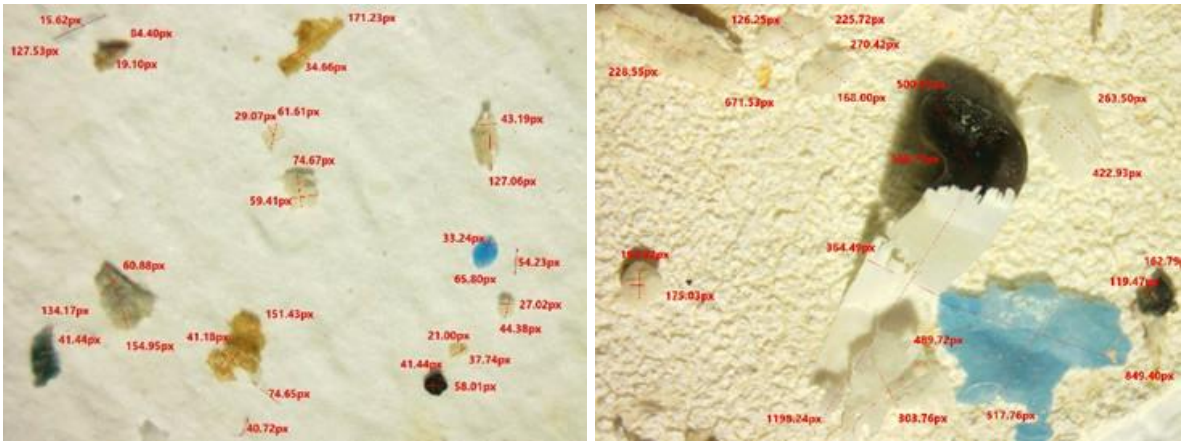


Fig. 34. Determination of microplastics' size, with a conversion factor 1 mm = 90 px

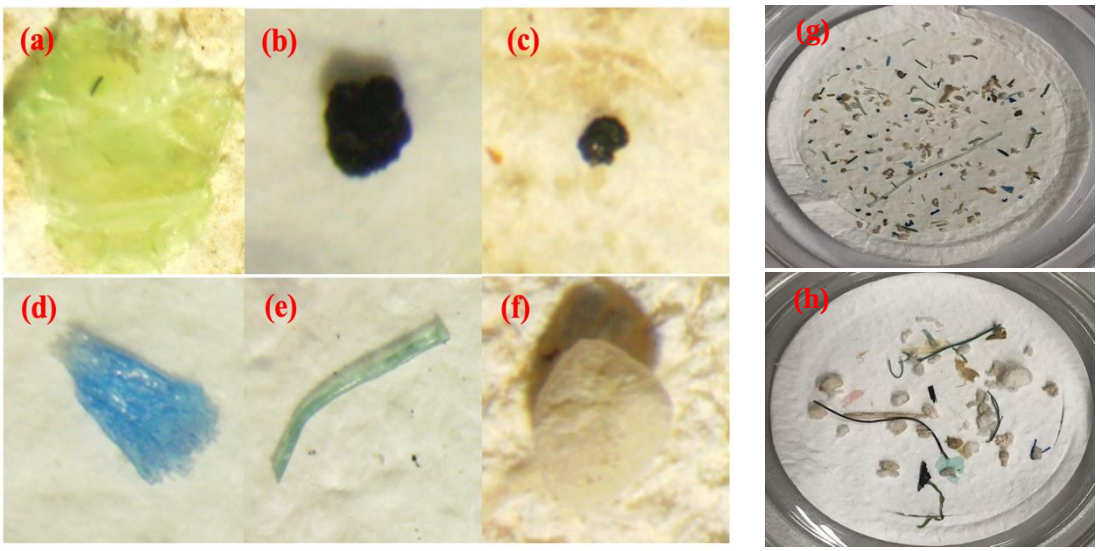


Fig. 35. Different forms of microplastics (a) Film, (b) Pellet, (c) Granule, (d) Fragment, (e) Fiber, (f) Foam, and (g) microplastics 1-5 mm (g) and (h) microplastics 0.3-1 mm in a seawater sample collected in Hai Phong, Viet Nam.

Table 3. Colors and forms of microplastics found in different sample types collected in Hai Phong, Viet Nam. The data were based on all samples of each type of environment: fish, feed, fishmeal, water, and sediment).

		Blue	Green	Red	Black	Yellow	White	Brow	Gray	Pink	Total	Average
Fish (microplastics/g)	Film					3	12				15	1.36 ± 0.67
	Pellet				2	1					3	1.50 ± 0.71
	Granule	1		7	26	10	2				46	1.48 ± 0.72
	Fragment	4	5		6	15	23	2			55	1.61 ± 0.98
	Fiber	5	2		13	1	12			1	34	1.31 ± 0.62
	Foam				1	1	8		2		10	1.43 ± 0.78
Water (microplastics/m^3)	Film	7									7	7.00 ± 4.95
	Pellet						0				0	0.00 ± 0.00
	Granule										0	0.00 ± 0.00
	Fragment	28	29		18	54	29			2	160	27.33 ± 18.04
	Fiber	3	16		3	3	25				50	8.40 ± 2.80
	Foam						26	1			27	6.75 ± 3.75
Sediment (microplastics/g)	Film	1	3	1			4				9	1.80 ± 0.83
	Pellet										0	0.00 ± 0.00
	Granule	17	28		72	2					119	10.36 ± 8.05
	Fragment	16	17	9	41		3		1		87	6.17 ± 4.30
	Fiber	2	3		9	1	11				26	2.60 ± 2.22
	Foam						5	6			11	2.75 ± 1.70
Feed (microplastics/g)	Film					1	3				4	4.00 ± 0.58
	Pellet										0	0.00 ± 0.00
	Granule										0	6 .00 ± 5.65
	Fragment	3		0	0			0		7	10	10.42 ± 10.11
	Fiber	4	1	0		1	2		1	3	12	2.25 ± 1.58
	Foam										0	0.00 ± 0.00
Fishmeal (microplastics/g)	Film	2								1	3	1.50 ± 0.71
	Pellet										0	0.00 ± 0.00
	Granule										0	0.00 ± 0.00
	Fragment	4	4	2			2			5	17	2.42 ± 0.79
	Fiber										0	0.00 ± 0.00
	Foam										0	0.00 ± 0.00

Table 4. Colors and forms of microplastics found in different sample types collected in Lampung, Indonesia (the data were based on all samples of each type of environment: fish, feed, fishmeal, water, and sediment).

		Blue	Green	Red	Black	Yellow	White	Brow	Gray	Pink	Total	Average±Std
Fish (microplastics/g)	Film					1	1				2	1.00 ± 0.00
	Pellet					1					1	1.00 ± 0.00
	Granule				18	8	8	1			35	1.52 ± 1.04
	Fragment	1			4	26	19	4			54	1.80 ± 1.21
	Fiber	2			6	4	9	7			28	1.27 ± 1.55
	Foam					2	12		1		15	2.50 ± 1.97
Water (microplastics/m^3)	Film	7	3			13	0				23	11.33 ± 2.31
	Pellet						1				1	1.00 ± 0.00
	Granule				4	0	0				4	1.33 ± 0.57
	Fragment	13	7		14	5	15		3		57	5.70 ± 5.46
	Fiber	2	5	1	8	2	2				20	2.86 ± 1.77
	Foam					3	0				3	3.00 ± 0.00
Sediment (microplastics/g)	Film	2	1		1		12				16	2.67 ± 3.61
	Pellet										0	0.00 ± 0.00
	Granule			6	88	3			1		98	10.88 ± 12.61
	Fragment	29	5	9	8	5	10	3	3		72	6.54 ± 5.78
	Fiber		1		6		11	2			20	2.22 ± 1.09
	Foam				1		11				12	3.00 ± 1.63
Feed (microplastics/g)	Film	2									2	1.00 ± 0.00
	Pellet										0	0.00 ± 0.00
	Granule										0	0.00 ± 0.00
	Fragment	1	1								2	1.00 ± 0.00
	Fiber	7	1				3			2	13	2.17 ± 0.98
	Foam										0	0.00 ± 0.00
Fishmeal (microplastics/g)	Film										0	0.00 ± 0.00
	Pellet										0	0.00 ± 0.00
	Granule										0	0.00 ± 0.00
	Fragment	4	6	1				2		5	18	2.57 ± 0.79
	Fiber	9	6	1	2					5	23	2.87 ± 1.46
	Foam										0	0.00 ± 0.00

5.2. Distribution of microplastic forms in different samples

Regarding the form of microplastics, it was found that fragment and fiber were the most abundant forms, which accounted for 11.3-85.5% (for fragment) and 11.9-77.1% (for fiber). Pellet was the least representative form of microplastics with less than 2% of all forms in all samples (Fig. 35).

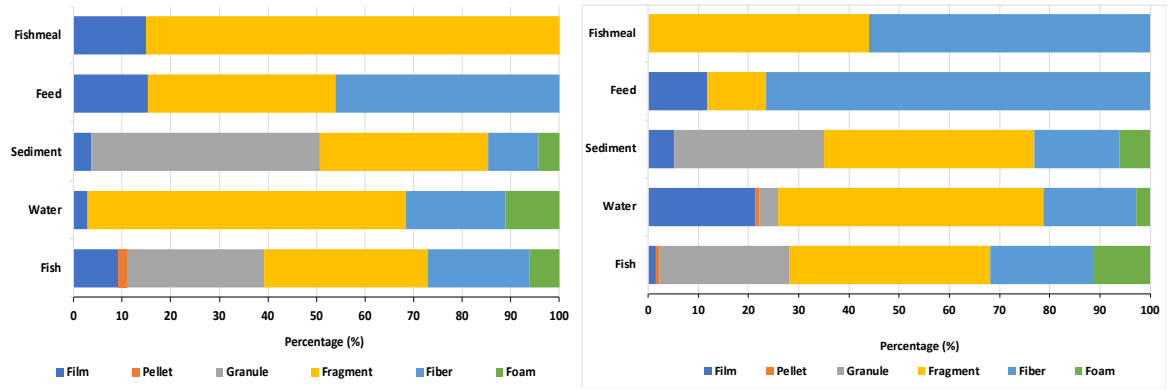


Fig. 36. Distribution of microplastic forms in different samples collected in Hai Phong, Viet Nam (left), and Lampung, Indonesia (right).

5.3. Types of microplastics found in different samples

As previously presented, names of the polymer of microplastics with sizes within the range of 2-5 mm were identified by FT-IR with reference FT-IR libraries of pure polymers which gave a match of over 75%. Fig. 37 presents an example of the spectral match between a measured microplastic fragment and PE reference spectrum, which gave a > 90% match. To identify other polymers using FT-IR (ART mode), please refer to Annexe 3.

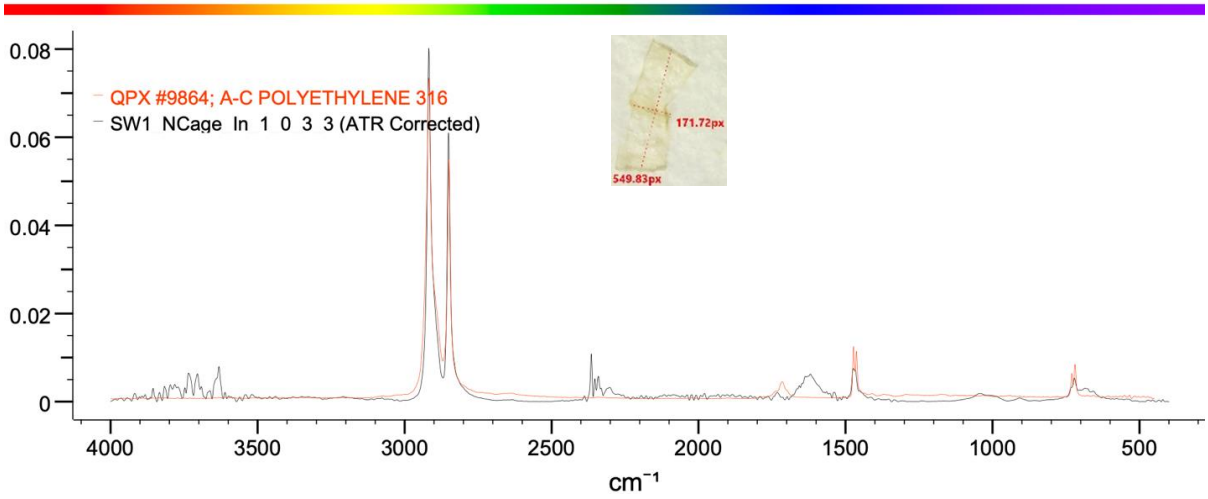


Fig. 37. Example of an FT-IR match of a microplastic (6 mm x 1.9 mm) found in a fish sample collected in Hai Phong, Viet Nam

Similar to FT-IR, micro-FT-IR was used to identify the polymer name of microplastics with sizes within the range of 0.3-2 mm with a match of measured spectra with the reference one more than 75%. Fig. 38 and 39 present the comparison of identified spectra and references as well as the proposal of polymer names. The higher match level will be normally selected; however, the analyses of used polymers in

commercial products were also deployed for the final decision. The plots with objects of different forms and colors are microplastics found in the examined samples. Annexe 4 presents the identification of other polymers.

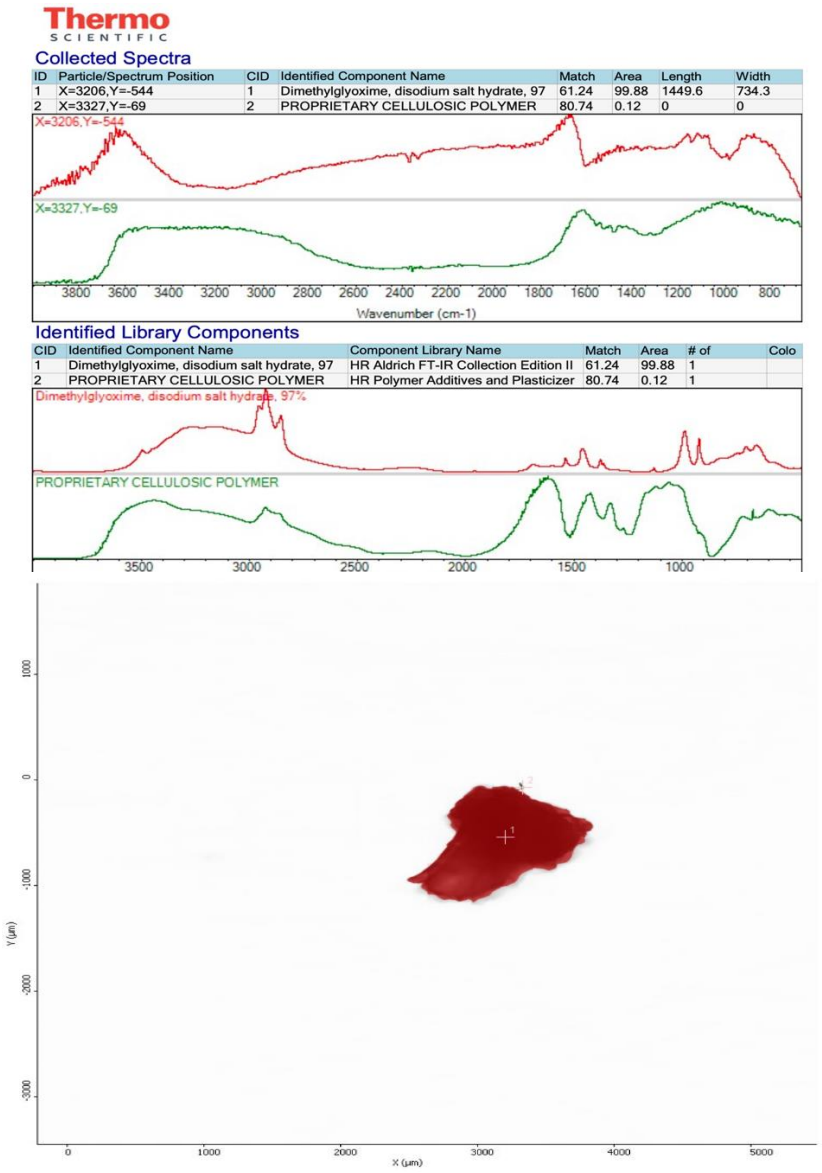
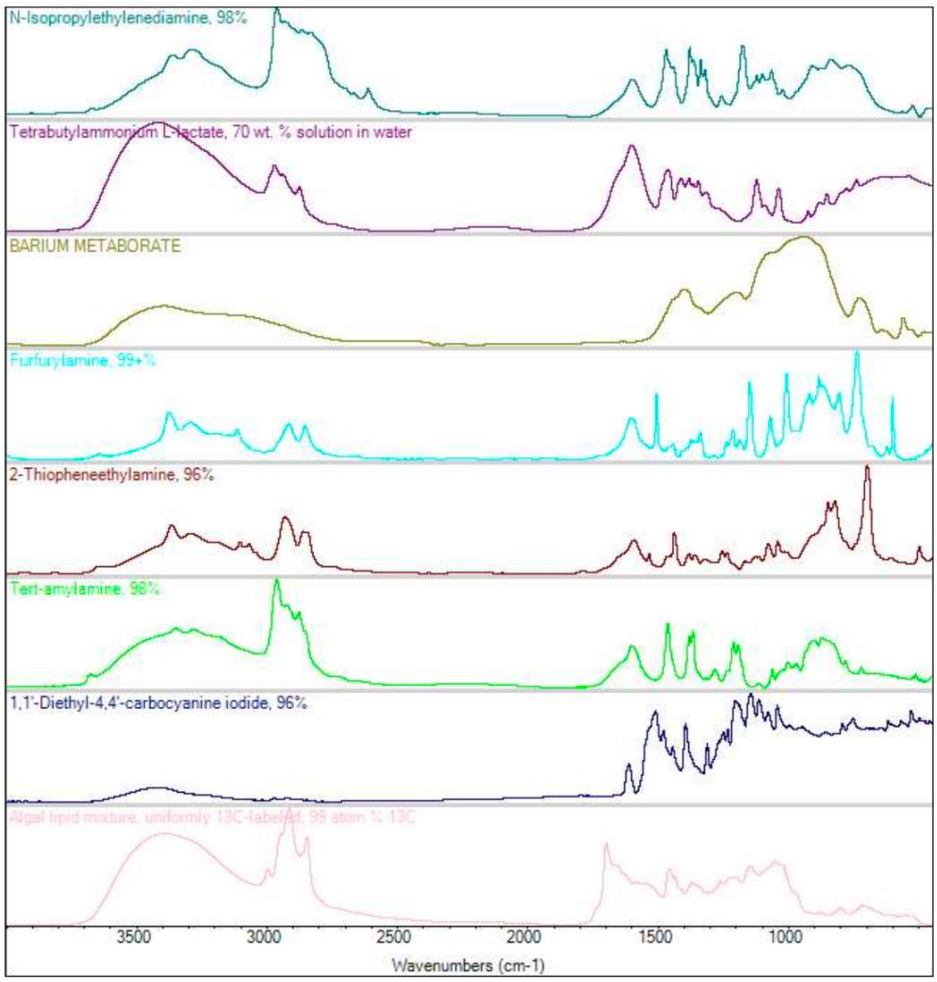


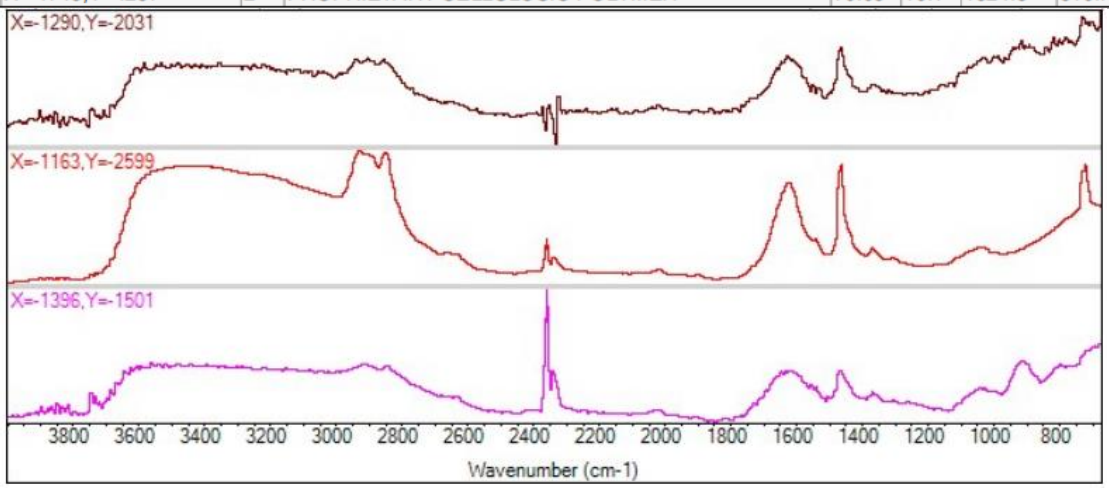
Fig. 38. Micro FT-IR match of a water sample collected in Hai Phong, Viet Nam.

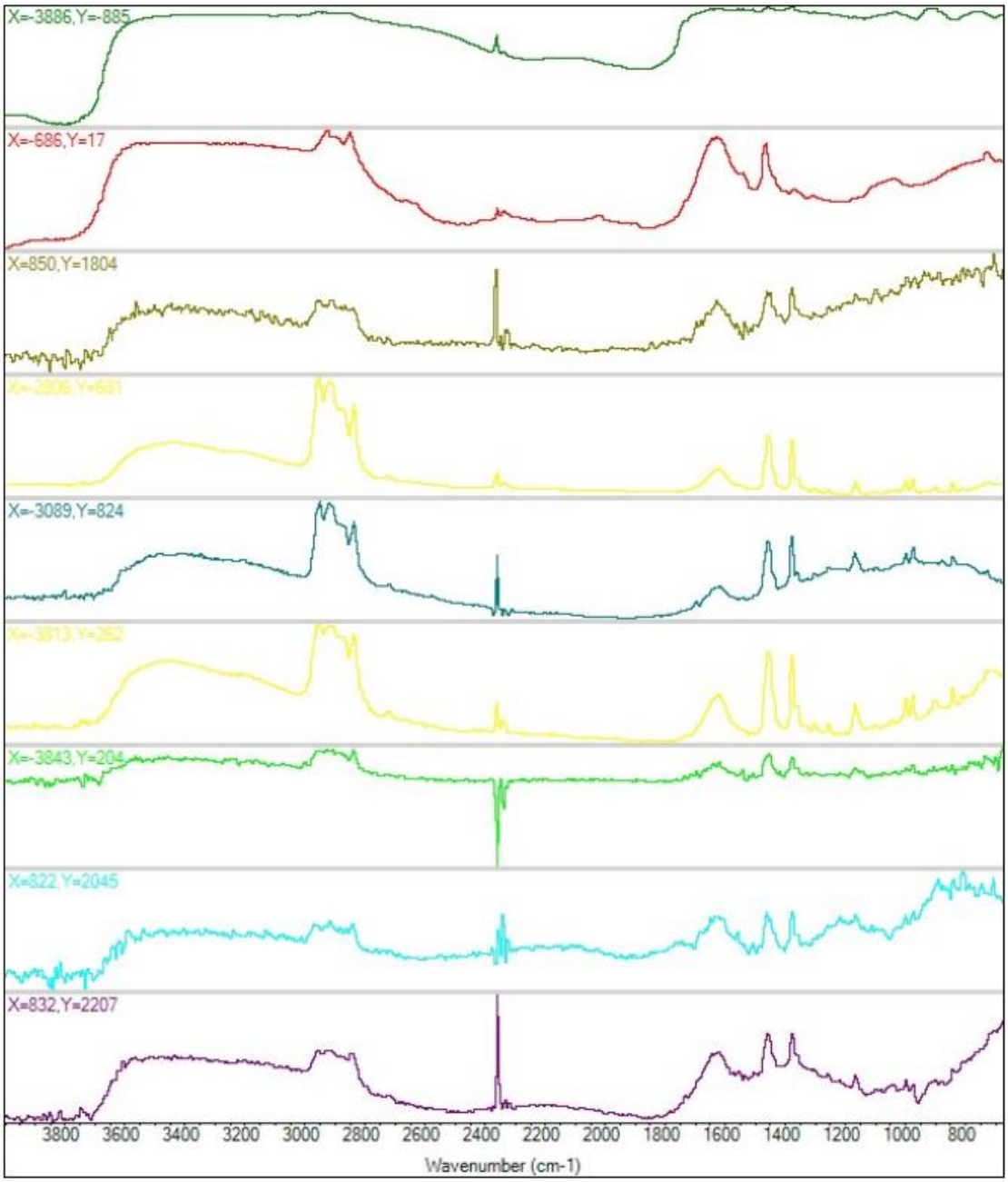


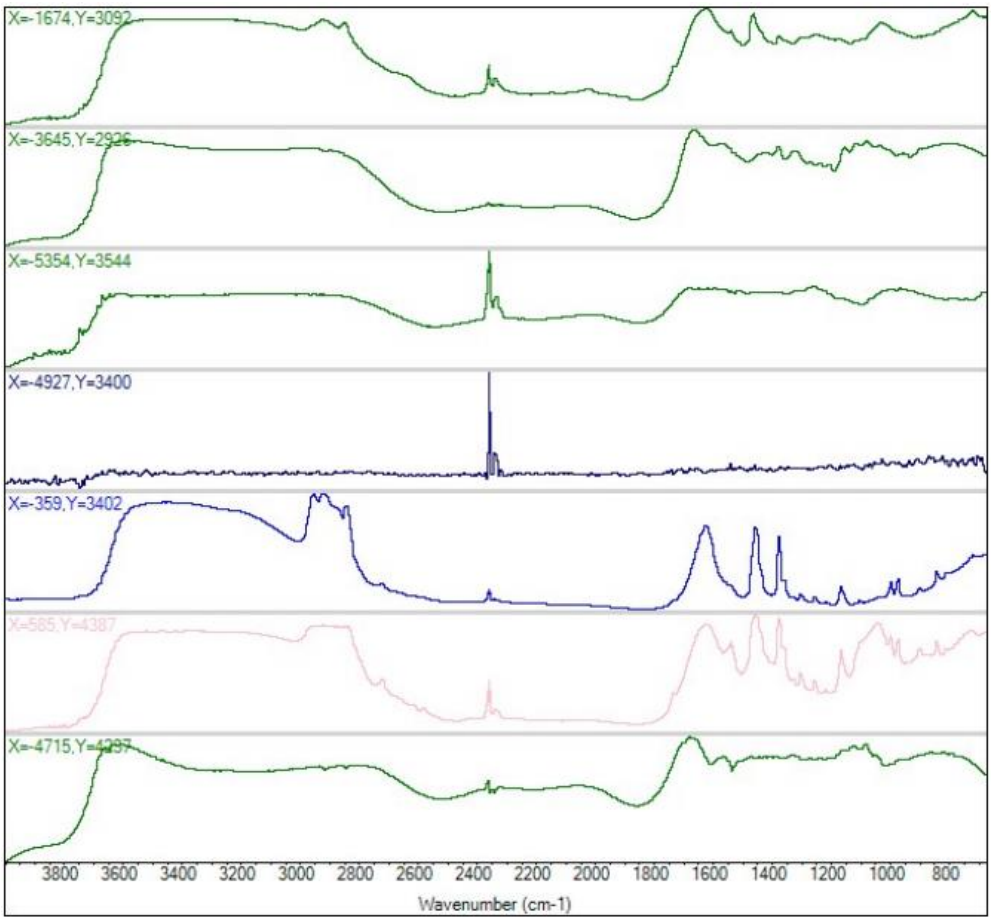
Identified Library Components

CID	Identified Component Name	Component Library Name	Match	Area	# of
1	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	HR Aldrich FT-IR Collection Ed	87.61	39.96	2
2	PROPRIETARY CELLULOSIC POLYMER	HR Polymer Additives and Pla	75.25	38.32	5
3	Piperazine hexahydrate, 98%	HR Aldrich FT-IR Collection Ed	93.23	14.45	1
4	Tetrabutylammonium fluoride hydrate, 98%	HR Aldrich FT-IR Collection Ed	90.86	4.06	2
5	Triethylmethylammonium hydroxide, 20 wt. % solution in	HR Aldrich FT-IR Collection Ed	78.83	0.32	1
6	N-Isopropylethylenediamine, 98%	HR Aldrich FT-IR Collection Ed	85.74	0.05	1
7	Tetrabutylammonium L-lactate, 70 wt. % solution in water	HR Aldrich FT-IR Collection Ed	81.18	0.04	1
8	BARIUM METABORATE	HR Polymer Additives and Pla	79.83	0.04	1
9	Furfurylamine, 99+%	HR Aldrich FT-IR Collection Ed	76.68	0.02	1
10	2-Thiopheneethylamine, 96%	HR Aldrich FT-IR Collection Ed	84.39	0.02	1
11	Tert-amylamine, 98%	HR Aldrich FT-IR Collection Ed	83.03	0.01	1
12	1,1'-Diethyl-4,4'-carbocyanine iodide, 96%	HR Aldrich FT-IR Collection Ed	62.95	0.01	1
13	Algal lipid mixture, uniformly 13C-labeled, 99 atom % 13	HR Aldrich FT-IR Collection Ed	81.79	0	1

ID	Particle/Spectrum	CID	Identified Component Name	Match	Area	Length	Width
1	X=-1290,Y=-2031	10	2-Thiopheneethylamine, 96%	84.39	0.02	47.8	19
2	X=-1163,Y=-2599	1	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	90	0.77	563.6	58.2
3	X=-1396,Y=-1501	5	Triethylmethylammonium hydroxide, 20 wt. % solution in	78.83	0.32	186.7	72.9
4	X=-3886,Y=-885	2	PROPRIETARY CELLULOSIC POLYMER	71.95	0.53	168.1	134.7
5	X=-686,Y=17	1	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	85.21	39.1	3456.6	480
6	X=850,Y=1804	8	BARIUM METABORATE	79.83	0.04	92.7	16.8
7	X=-2806,Y=681	4	Tetrabutylammonium fluoride hydrate, 98%	94.38	3.98	1718.4	97.9
8	X=-3089,Y=824	6	N-Isopropylethylenediamine, 98%	85.74	0.05	87.4	22.9
9	X=-3813,Y=262	4	Tetrabutylammonium fluoride hydrate, 98%	87.34	0.09	106.1	34.7
10	X=-3843,Y=204	11	Tert-amylamine, 98%	83.03	0.01	42.4	14.3
11	X=822,Y=2045	9	Furfurylamine, 99+%	76.68	0.02	55.8	16.7
12	X=832,Y=2207	7	Tetrabutylammonium L-lactate, 70 wt. % solution in wate	81.18	0.04	131.5	13.5
13	X=-1674,Y=3092	2	PROPRIETARY CELLULOSIC POLYMER	81.67	8.49	770.4	466.5
14	X=-3645,Y=2926	2	PROPRIETARY CELLULOSIC POLYMER	81.53	12.2	1316.9	392.3
15	X=-5354,Y=3544	2	PROPRIETARY CELLULOSIC POLYMER	71.07	0.93	936.4	41.9
16	X=-4927,Y=3400	12	1,1'-Diethyl-4,4'-carbocyanine iodide, 96%	62.95	0.01	43.1	14.1
17	X=-359,Y=3402	3	Piperazine hexahydrate, 98%	93.23	14.4	1884.7	324.6
18	X=585,Y=4387	13	Algal lipid mixture, uniformly 13C-labeled, 99 atom % 13	81.79	0	0	0
19	X=-4715,Y=4237	2	PROPRIETARY CELLULOSIC POLYMER	70.03	16.1	1324.8	516.7




X=-3886,Y=-885
X=-686,Y=17
X=850,Y=1804
X=-3089,Y=824
X=822,Y=2045
X=832,Y=2207
3800 3600 3400 3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800
Wavenumber (cm-1)



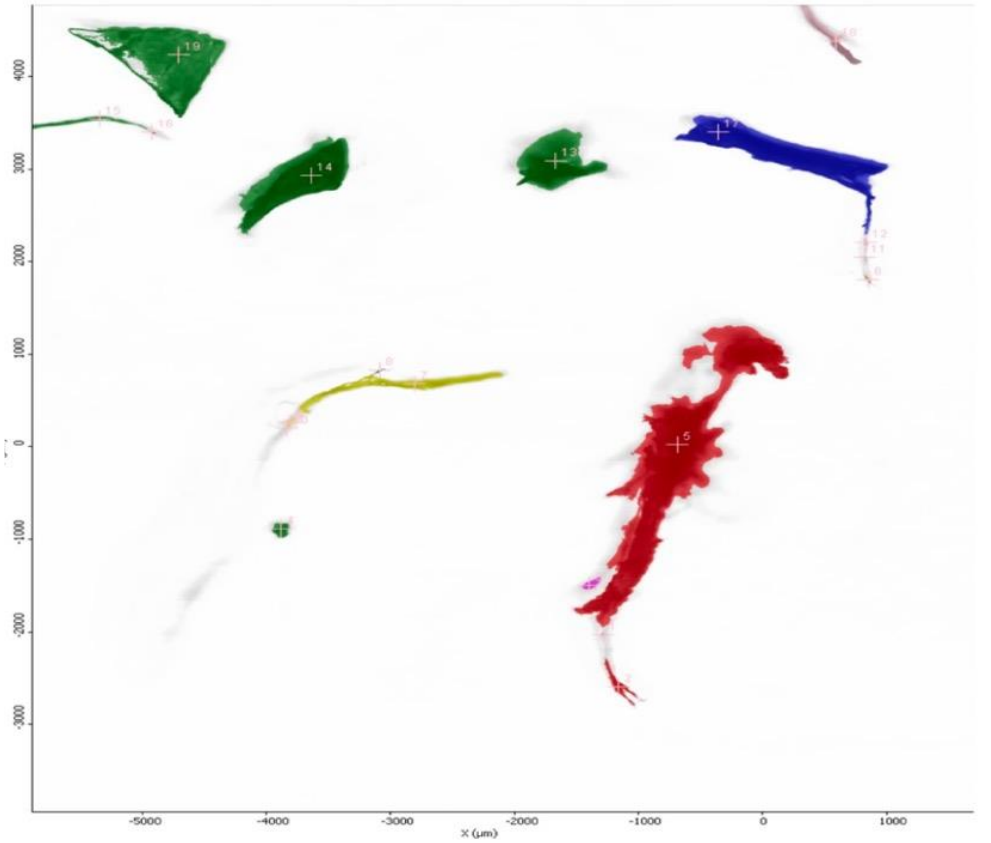


Fig. 39. FT-IR match of a sediment sample collected in Lampung, Indonesia.

The results revealed that there were a number of polymers identified in the collected samples, such as Anhydride-modified polyolefins (PLEXAR), Ethyl vinyl acetate (EV), Ethylene vinyl alcohol copolymer (EVOH), Polyethylene (PE), Polyolefin (POF), Polypropylene (PP), Cast Polypropylene (CPP), Polyphenylene Ether (PPE), Polyethylene terephthalate (PET), High Density Polyethylene (HDPE), Linear Low Density Polyethylene (LLDPE), Polyester (PES), Polystyrene (PS), Polyethylenimine (PEI), Polyamide (Nylon 66)- (PA), Poly(ethylene-vinyl acetate) (PEVA), Polyurethane (PU), Polyureformaldehyde (URF), Melamine-urea-formaldehyde (MUF), Polyvinyl alcohol (PVA), Polyvinylchloride (PVC), Polyvinylidene fluoride (PVDF), Cellophane (CP), Cellulose derivatives (CL), EVOH (Ethylene vinyl alcohol), Polyacrylamide (PAM), Polyphthalamide (PPA), Polyacrylates (PAK), Norbornene or Polynorbornene (PNB), Polyfluoroalkyl substances (PFAS) (Fig. 37-42). It is noted that Fig. 37 presents the FT-IR spectra of some commercial polymers widely applied which were collected in the 2-5 mm fraction while Fig. 38 and 39 present FT-IR spectra of all polymers identified which were collected in the 0.3-1 mm fraction.

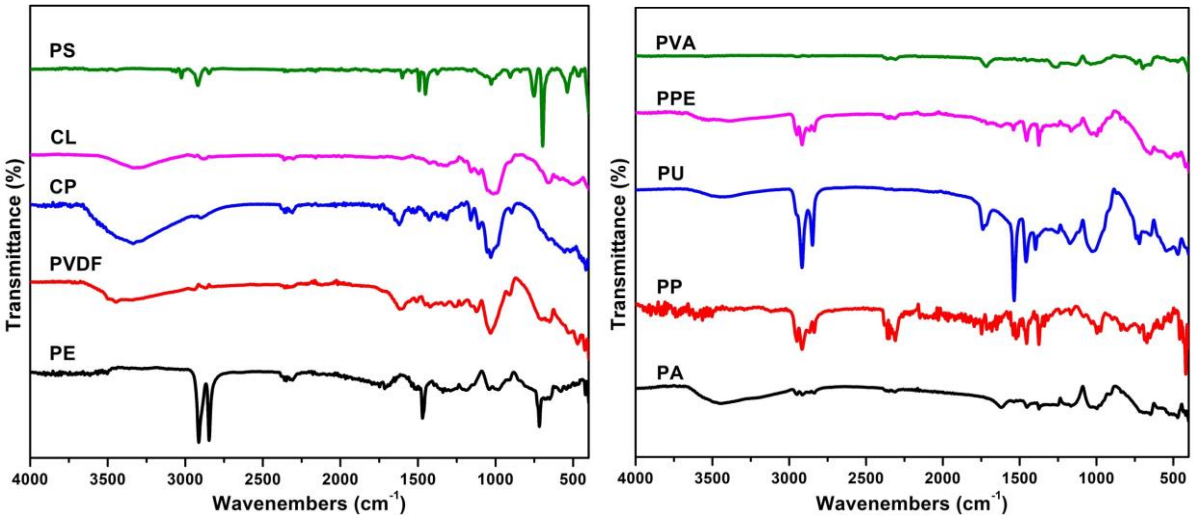


Fig. 40. Commercial polymers found in water and sediment samples

5.4. Distribution of forms of microplastics found in different samples

Once the names of the polymers were identified, the data treatment and analyses were conducted to determine the distribution of different polymers in collected samples. Fig. 41 and 42 revealed that there were a small number of microplastics in feed, fish, and fishmeal samples; most of them were cellophane, PE, PA and cellulose derivatives

which accounted for 10.5% to 36.6% of all polymers identified in the samples collected in Lampung, Indonesia. In contrast, these figures for samples collected in Hai Phong, Viet Nam ranged from 9.80 % to 50.40%. Water and sediment samples contained significantly more microplastics, mainly PET, PA, and Rayon. PET accounted for 50.26% of all polymers in sediment samples collected in Lampung, Indonesia, while this value was 20.59% for Hai Phong, Viet Nam. In water samples, PET represented 44.02% (for Lampung) and 22.06% (for Hai Phong). PET took the lead of 84.85% and 35.90% for sediment samples collected in Lampung and Hai Phong, respectively. The number of PA in fish and shrimp samples was even higher than PET (38.10% vs 33.33% for samples collected in Lampung and 50% vs 16.76% for samples collected in Hai Phong). It is noted that the data presented in Fig. 41 and 42 are the averages of all the samples for each type of environment (fish, feed, fishmeal, water, sediment).

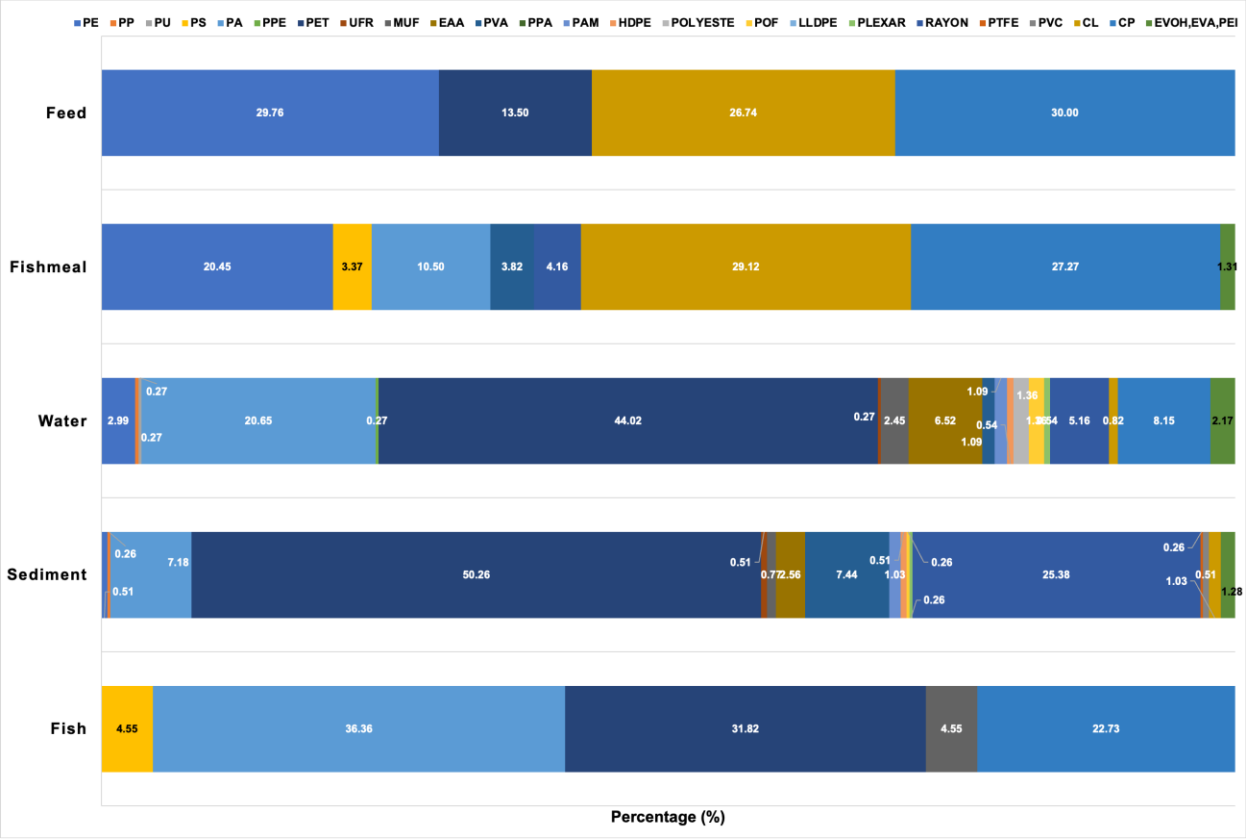


Fig. 41. Distribution of polymers corresponding to microplastics found in water, sediment, fish and shrimp, feed, and fishmeal samples collected in Lampung, Indonesia (the data are based on the number of microplastics of all samples for each type of environments: water, sediment, fish, feed, fishmeal).

There were several other polymers found in water, sediment, fish, fishmeal, feed, and shrimp samples such as Anhydride-modified polyolefins (PLEXAR), Ethyl vinyl acetate (EV), Ethylene vinyl alcohol copolymer (EVOH), Polyolefin (POF), Polypropylene (PP), Cast Polypropylene (CPP), Polyphenylene Ether (PPE), High-Density Polyethylene (HDPE), Linear Low-Density Polyethylene (LLDPE), Polyester (PES), Polystyrene (PS), Polyethylenimine (PEI), Poly(ethylene-vinyl acetate) (PEVA), Polyurethane (PU), Polyureformaldehyde (URF), Melamine-urea-formaldehyde (MUF), Polyvinyl alcohol (PVA), Polyvinylchloride (PVC), Polyvinylidene fluoride (PVDF), Polyphthalamide (PPA), Polyacrylates (PAK), Norbornene or Polynorbornene (PNB), Polyfluoroalkyl substances (PFAS).

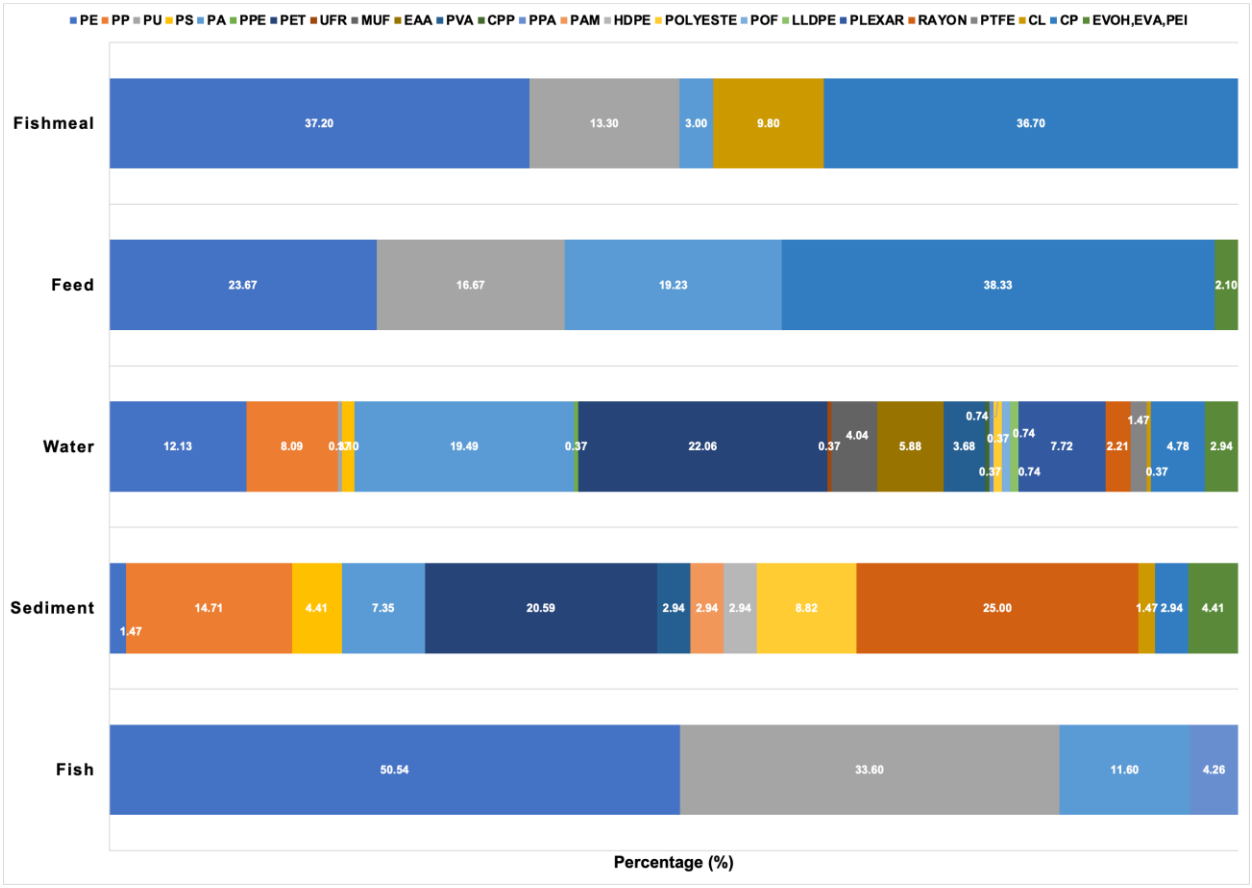


Fig. 42. Distribution of polymers corresponding to microplastics found in water, sediment, fish and shrimp, feed, and meal samples collected in Hai Phong, Viet Nam (the data are based on the number of microplastics of all samples for each type of environments: water, sediment, fish, feed, fishmeal).

The distribution of microplastics in two fractions (0.3-1 mm and 1-5 mm of the collected samples is presented in Fig. 43. It is found that, most of the microplastics were

found in 1-5 mm fraction for almost all the samples except for fishmeal samples collected in Lampung. For instance, microplastics were present in 1-5 mm fraction accounted for 57.14% to 71.79% of all samples collected in Hai Phong while these figures for fish and shrimp, sediment, water, and feed samples collected in Lampung were within the range of 49.35-83.33%. Regarding fishmeal samples collected in Lampung, microplastics in 0.3-1 mm fraction accounted for about 73%.

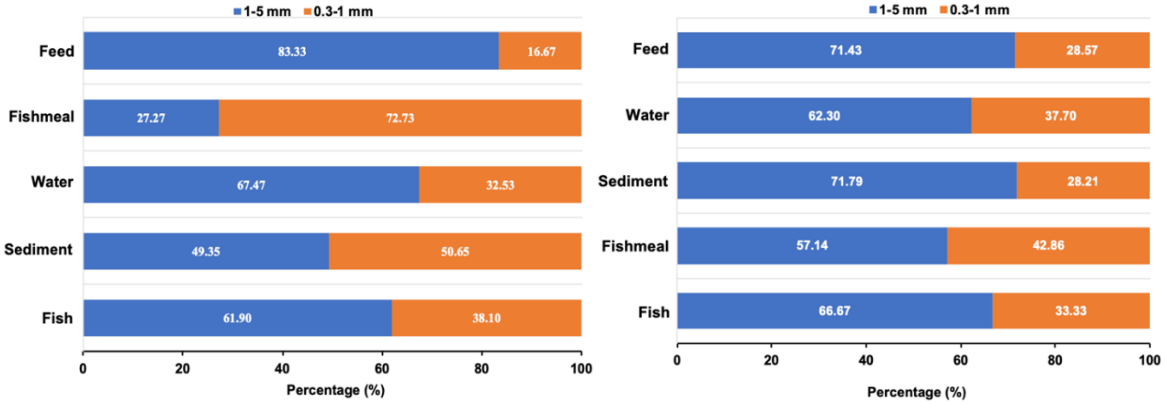


Fig. 43. Distribution of microplastics in 0.3-1 mm and 1-5 mm fractions collected in Lampung, Indonesia (left) and Hai Phong, Viet Nam (right) (the data are based on the number of microplastics of all samples for each type of environments: water, sediment, fish, feed, fishmeal

Regarding the statistics of the number of microplastics in water samples, most of microplastics were found in 0.3-1 mm fraction for water samples collected in Hai Phong, Viet Nam while their presence in 0.3-1 mm and 1-5 mm fractions were relatively comparable for the samples collected in Lampung (Fig. 44). In general, water samples contained less than 1 microplastic/m^3, with a typical value of 0.40-0.45 particles/m^3. There were very high levels of microplastics in the 0.3-1 mm fraction sampled in Hai Phong, which surpassed 1 particle/m^3. There was also a very large fluctuation in the number of microplastics found in the 0.3-1 mm fraction in water samples collected in Hai Phong. Similarly, the number of microplastics found in 1.0-5.0 mm fraction collected in Lampung, Indonesia, witnessed a relatively large variation but with a smaller margin compared to 0.3-1 mm fraction in water samples collected in Hai Phong.

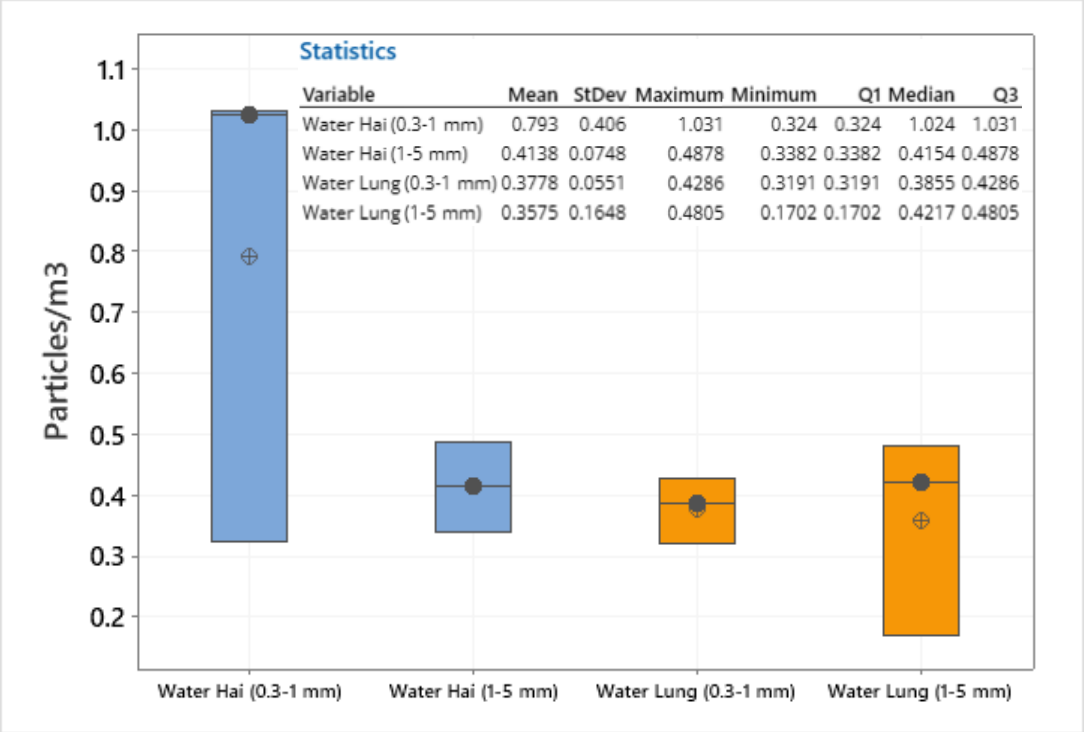


Fig. 44. Summary of microplastics in water samples collected in Hai Phong, Viet Nam and Lampung, Indonesia

As for fish and shrimp samples, the number of microplastics found was comparable for samples collected in Hai Phong and Lampung (Fig. 45), with about 0.01 particles/g of fish and shrimp. However, there was a significant variation in the number of microplastics in different types of fish. This issue is analyzed in more detail in the following section. Regarding the distribution of microplastics according to their size, it is revealed that the percentage of microplastics in 0.3-1 mm was comparable with that in 1-5 mm fraction (~ 50%) for all samples collected in Hai Phong and Lampung. It is noted that the data on microplastics in fish and shrimp samples were calculated based on the weight of each fish and shrimp.

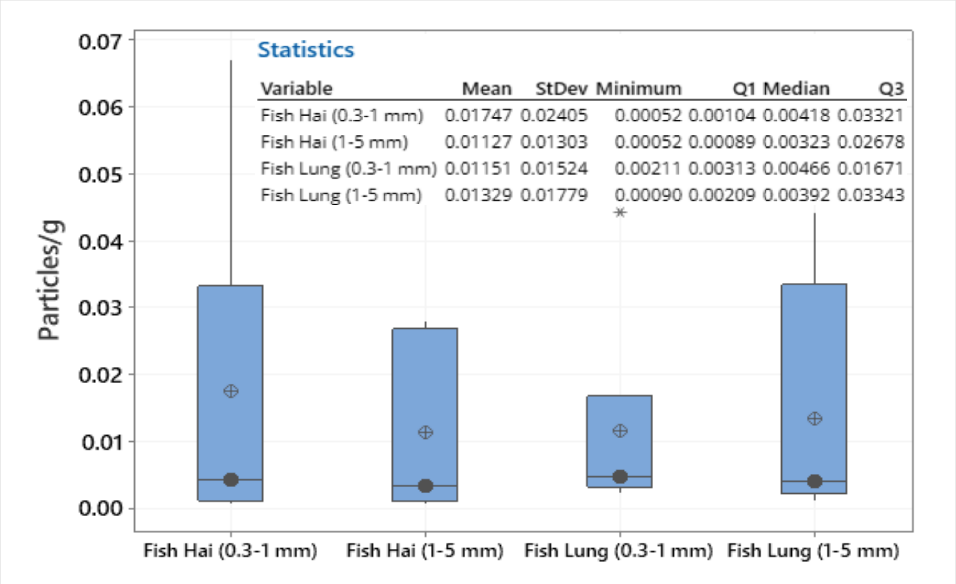


Fig. 45. Summary of microplastics in fish and shrimp samples collected in Hai Phong, Viet Nam and Lampung, Indonesia

Sediment samples presented much higher microplastics than fish and shrimp samples. The average number of microplastics was about 0.2 particles/g (dry sample), ranging from 0 particles/g to 1.5 particles/g. Microplastics in sediment samples collected in Hai Phong were comparable with those in Lampung. It is found that microplastics presented more in smaller fraction (0.3-1 mm) than in larger one (1-5 mm) for all samples collected in Hai Phong and Lampung (Fig. 46). This might cause more negative impacts on the environment and aquaculture in the studied areas.

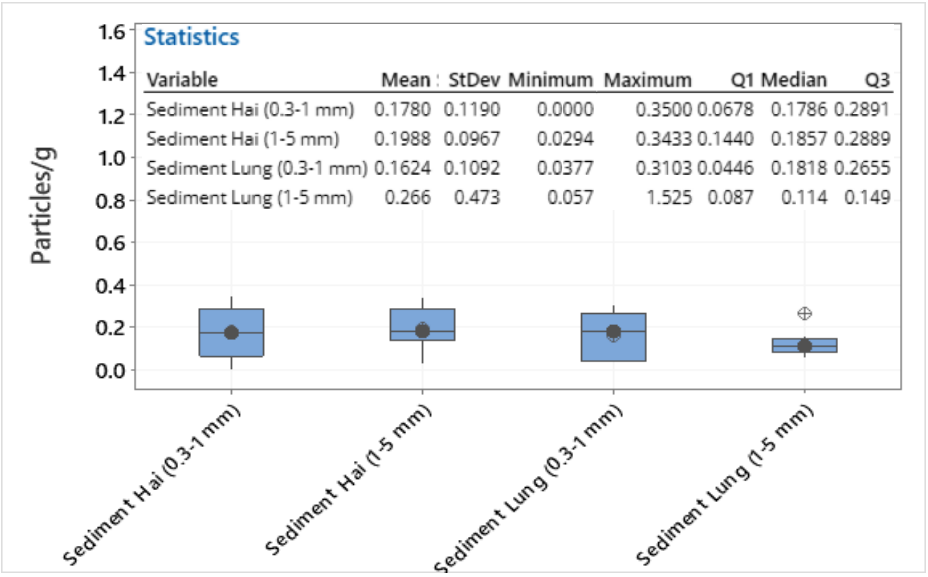


Fig. 46. Summary of microplastics in sediment samples collected in Hai Phong, Viet Nam and Lampung, Indonesia

It is interesting to note that commercial feed samples bought in Hai Phong and Lampung contained comparable numbers of microplastics, with average values of about 0.1 particles/g, which were much higher than fish and shrimp samples (0.01 particles/g), and relatively lower than sediment samples (about 0.2 particles/g). The distribution of microplastics was also comparable for the two fractions (0.3-1 mm and 1-5 mm), and there are relatively large variations in plastic number in different types of feeds (Fig. 47). Regarding fishmeal samples, the results revealed that the average number of microplastics in this type of samples were comparable to much higher than in fish feeds, varying from 0.22±0.0447 particles/g to 0.520±0.295 partiles/g. Those values were event higher than those for sediment samples, which were in the range of 0.1624±0.1092-0.266±0.473 particles/g. Microplastics seemed to accumulate more in smaller fraction (0.3-1 mm) for all samples collected in Lampung and Hai Phong (Fig. 48).

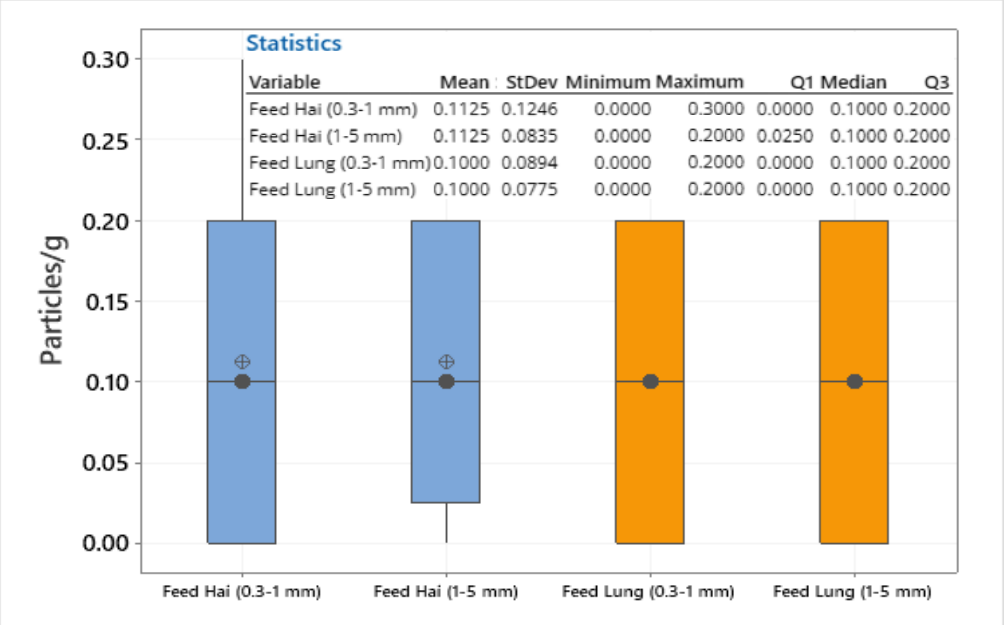


Fig. 47. Summary of microplastics in feed samples collected in Hai Phong, Viet Nam and Lampung, Indonesia

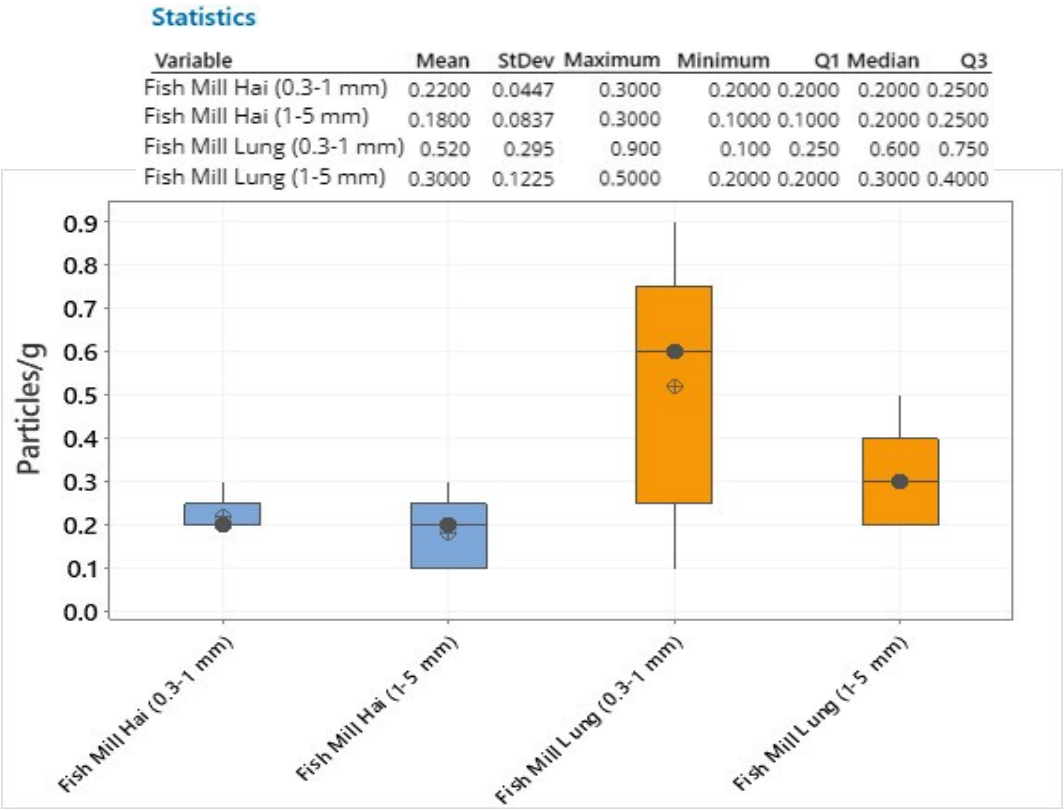


Fig. 48. Summary of microplastics in fishmeal samples collected in Hai Phong, Viet Nam and Lampung, Indonesia

As previously presented, the number of microplastics varied from fish and shrimp samples to samples. An analysis in more detail of the data on the presence of microplastics in different types of fish was performed. Regarding fish collected in Lampung, Rabbitfish and Yellow tail contained the most microplastics, with average numbers of 0.037 particles/g of fish and 0.051 particles/g of fish, respectively, while the average values for others were 0.014 particles/g (Giant Trevally) and lower for other types of fish (Fig. 49). It is noted that Rabbitfish is a wild fish and Yellow tail is trash fish. The behavior of fish in consuming food and their interaction with the environment should also be taken into consideration to have a better conclusion about microplastics found in fish and shrimps raised in ponds, net cages, and natural environments. The results also revealed that Rabbitfish and Yellow tail also presented the most variation in the number of microplastics, which was in the range of 0.0085-0.0704 particles/g (Rabbitfish) and of 0.02597-0.07353 particles/g (Yellow tail).

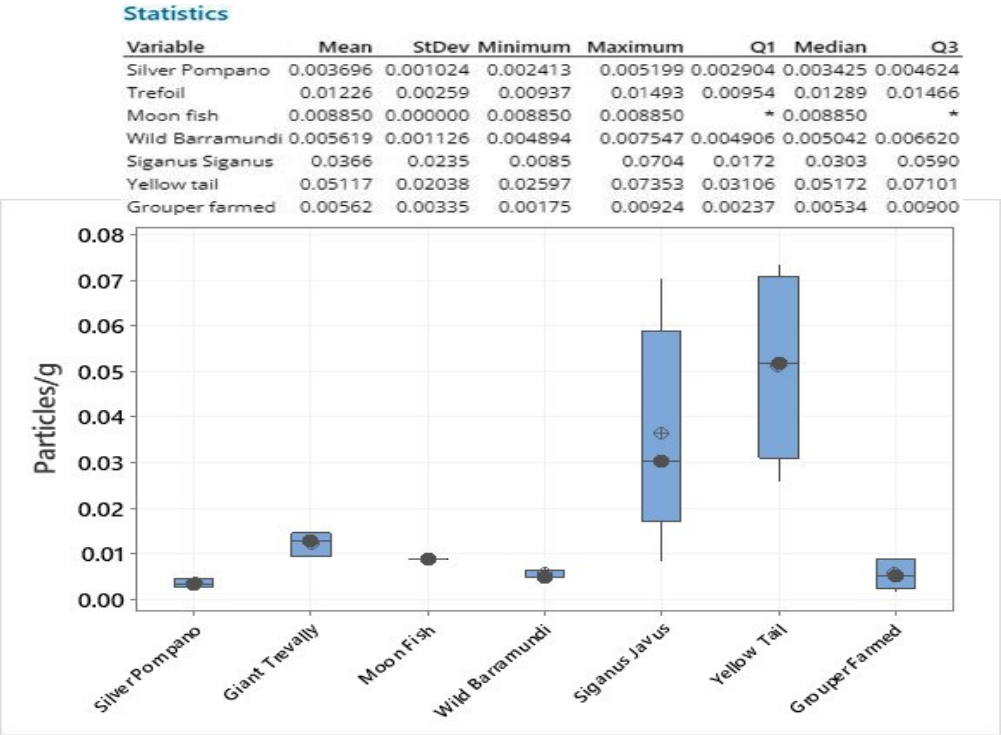


Fig. 49. Summary of microplastics in different types of fish collected in Lampung, Indonesia

As for the fish and shrimp samples collected in Hai Phong, the number of microplastics was classed into three main groups i) Diamond Trevallies, Barramudi, Groupers, and Bronze Croakers presented with the lowest plastic fragments, with average values in the range of 0.001-0.004 particles/g of fish; ii) the second group consist of Star Snappers, Golden, and Scatophagus, which presented average numbers of microplastics ranging from 0.01-0.05 particles/g. This group contained much more microplastics than the first group (about 10 times); and iii) the third group presenting the highest number of microplastics is Halfbeak fish with an average number of 0.1489 particles/g (Fig. 50). The average weight of this type of fish was 15 g, implying more than two microplastics per a fish. It is noted that halfbeak is also a trash fish. The behavior of this type of fish with food and the environment should be considered to better interpret the obtained results in this research.

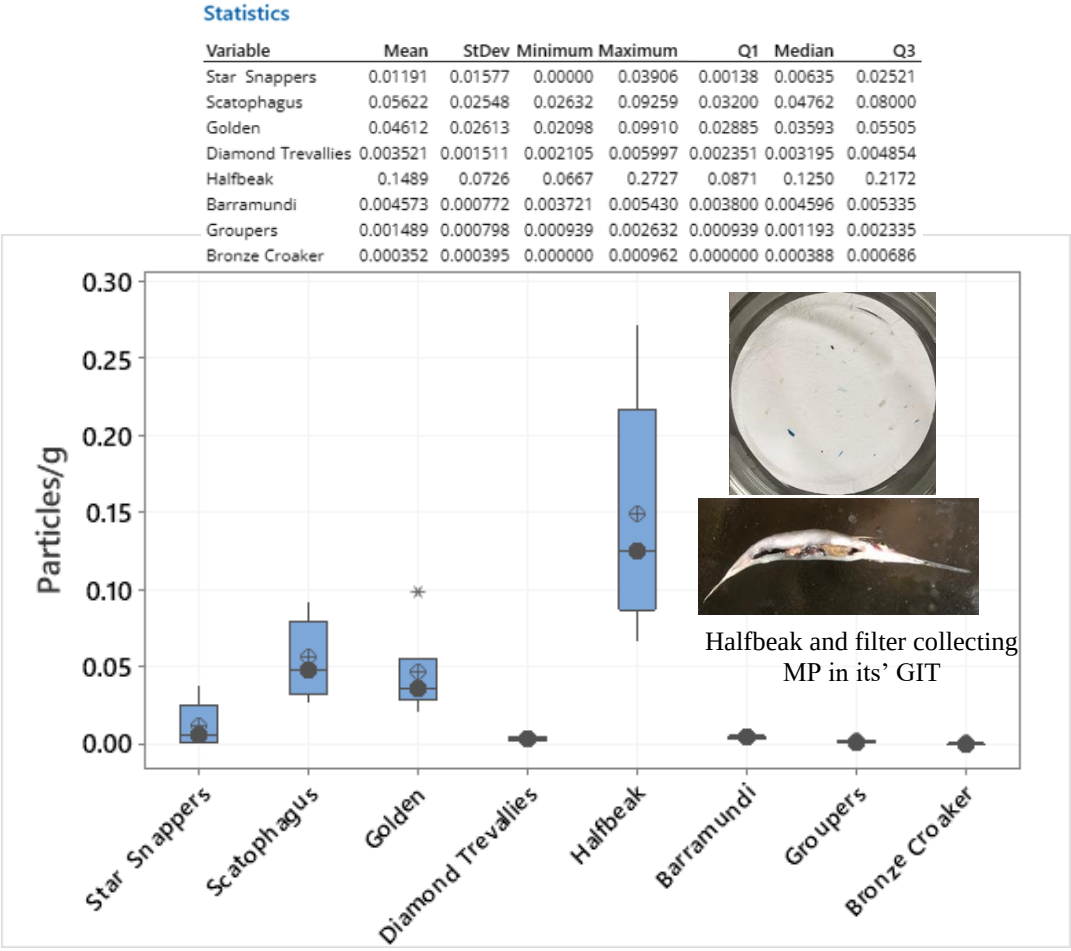


Fig. 50. Summary of microplastics in different types of fish collected in Hai Phong, Viet Nam

5.5. Chemical composition of microplastics found in different samples

Some results of the chemical composition analyses of microplastics are presented in Fig. 51 and 52. The results confirmed that a PE found in sediment samples in Hai Phong contained only carbon, with 100% (weight) of the polymer (Fig .51 a). It is noted that EXD method could not allow for quantifying the weight of hydrogen in the sample. Still, it is clear that hydrogen is 12 times lighter than carbon and that carbon atoms could not have bonds with other carbons in a polymer, so the results from EDX analyses are supported. Other elements in the identified polymers can be quantified by their weight in the sample. For instance, Fig. 52 (a) revealed that a fish sample collected in Lampung contained cellulose derivatives, in which carbon- and oxygen-based compounds make up most of the total sample weight. The weight of carbon compound was 63.01%, while the percentage for oxygen compound was 36.99% indicated by the well-mixed of the two chemical compositions in the samples (Fig. 52). The EXD analytical tool is

therefore a complementary method to confirm the presence of microplastics in the collected samples [24, 25].

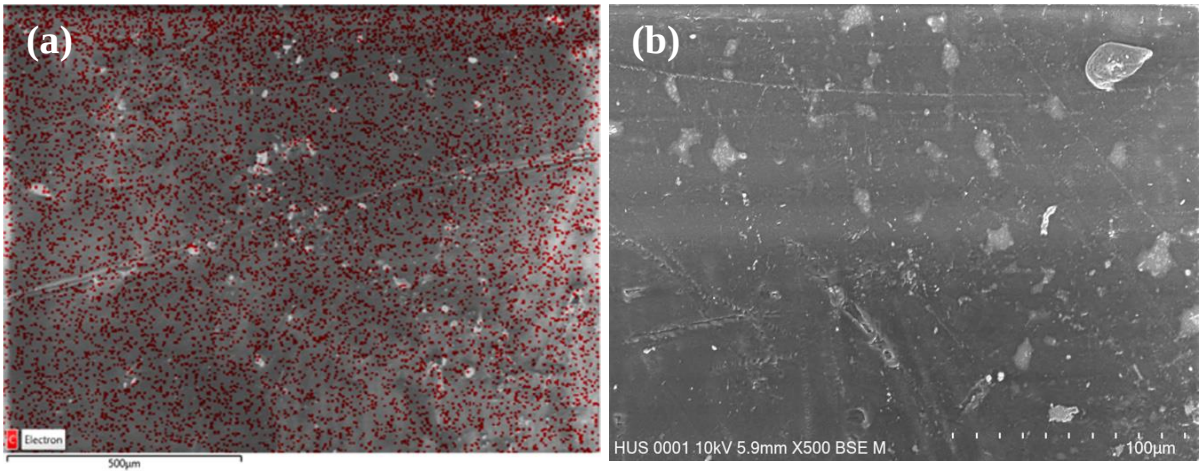


Fig. 51. Chemical composition (a) and morphology (b) of a microplastic in sediment sample collected in Hai Phong, Viet Nam.

Regarding the surface morphology of microplastics in Fig. 51 (b) and 52 (b), it was quite smooth with certain scratches on the surface, suggesting that these microplastics already underwent different abrasion processes, making a more porous structure for adsorption of micropollutants and/or chemicals on the surface of microplastics. These pollutants can eventually cause negative impacts on the environment and human health via the food chain.

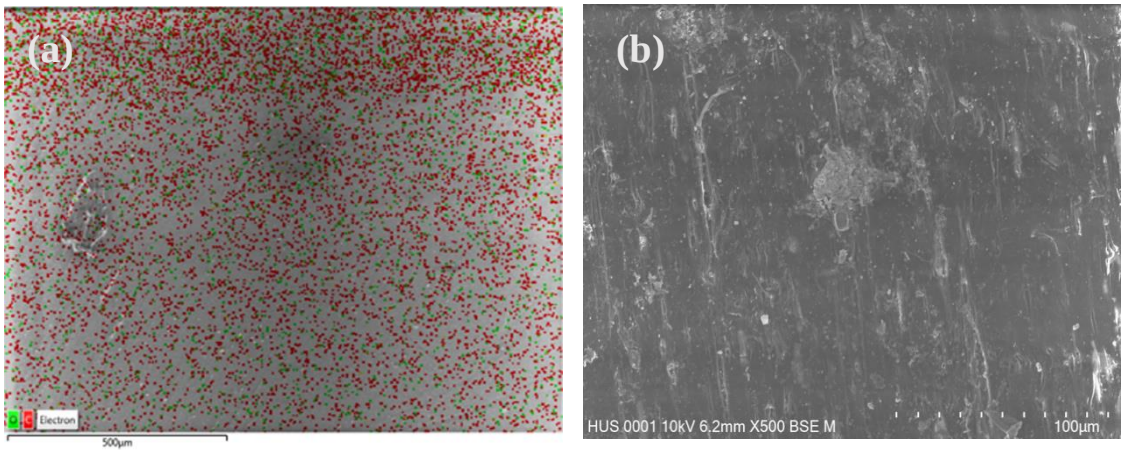


Fig. 52. Chemical composition (a) and morphology (b) of a microplastic in fish sample collected in Lampung, Indonesia.

6. Conclusions and recommendations

6.1. Conclusions

Two large sampling campaigns in Indonesia and Viet Nam were successfully accomplished for collecting surface water, sediment, farmed/wild/trash fish, shrimps, fish fed feeds, shrimp fed feeds, and fishmeal. In total, 6 surface water samples were collected around the net cages. Of 18 sediment samples, 6 were collected at the net cages, 6 were collected halfway between net cages and beaches, and the last 6 samples were sampled on beaches. At the shrimp ponds, 6 surface water samples were collected in the middle and sides (at least 2 m from the banks) of the surveyed ponds. The 18 sediment samples were collected in the middle and sides (at least 3 m from the banks) of the surveyed ponds. All the types of samples agreed to in the contract were successfully and accordingly taken.

Different approved sample preparation and treatment procedures were applied to different types of samples such as water, sediment, GIT of fish and shrimp, commercial feed and fishmeal. The analyses of microplastics were performed using a stereo microscope, FT-IR, micro-FT-RT, SEM, and EDX mapping. All the sample preparation/treatment and analyses were conducted within the VNU laboratories.

The obtained results showed that blue, green, black, yellow and white are among the most abundant colors of microplastics collected in water, sediment, fish, shrimp, feed and meal samples in Hai Phong, Viet Nam and Lampung, Indonesia. Fragment and fiber were the most abundant forms, which accounted for 11.3-85.5% (for fragment) and 11.9-77.1% (for fiber), while pellet was the least representative form of microplastics with less than 2% of all forms in all samples.

Water, feed and fishmeal contained significantly more microplastics than fish/shrimp samples, mainly PET and PA. In water samples, PET represented 44.02±20.61% (for Lampung) and 20.06±7.89% (for Hai Phong). These figures were 50.26±19.43% and 20.59±9.36% for sediment samples collected in Lampung and Hai Phong, respectively. In fish and shrimp samples, the numbers of PA were even higher than PET (36.36±11.13% vs 31.82±12.78% for samples collected in Lampung, and 11.60±4.21% vs ~0.0 % for samples collected in Hai Phong).

Microplastics were presented in two fractions (0.3-1 mm and 1-5 mm) and were relatively comparable for most of the samples in terms of number of microplastic particles. In general, water samples contained the most microplastics, with a typical value of 0.45 particles/m^3, varying from 0.1702 particles/m^3 to 1.031 particles/m^3. Regarding solid samples, the number of microplastics in fishmeal was highest, with average values varying from 0.22±0.0447 particles/g to 0.520±0.295 partiles/g. Sediment samples were ranked second in terms of microplastics, with average values in the range of 0.1624±0.1092-0.266±0.473 particles/g, which were about 20 times more microplastics than fish and shrimp samples (~ 0.2 particles/g of dried sediment vs about 0.01 particles/g of fish). Commercial feed samples bought in Hai Phong and Lampung contained comparable concentration of microplastics, with average values of about 0.1±0.085 particles/g of fish, which were about 10 times higher than fish and shrimp samples. Finally, trash and wild fish contained more microplastics than fed fish.

6.2. Recommendations

With respect to the results of this research conducted in two APEC economies, and due to the interconnection, similar farming technologies and input products, the context of this research in the selected sites could be similar in other APEC economies. Firstly, the interconnected marine environments allow the distribution of microplastics in waterways of APEC economies where coastal aquaculture takes place. Secondly, most APEC economies practice similar farming technologies and use similar or the same input products that are contaminated by microplastics. However, the specific nature of microplastics and the level of contamination may differ from one place to another due to factors such as different levels of marine plastic pollution management and physical geography. Therefore, larger sampling campaigns in different areas of APEC member economies should be taken into consideration to support the management of microplastic issues in the aquaculture activities of all the member economies. In addition, more research on the behavior of fish and shrimp towards food and environments should be examined in more detail to better understand and minimize the uptake of microplastics by fish and shrimps. Toxicology research should also be carried out to better understand the toxic mechanisms and sources of microplastic that negatively impact the environment and human health.

Better management of microplastics in Coastal Aquaculture Input Systems and an effective Mitigation Plan towards Seafood Safety among APEC member economies. Additionally, more research on sources of microplastics in environments (water, sediments, wide fish associated with aquaculture systems), and fishmeal and alternative/replacement ingredients should be conducted. Technology development for monitoring of microplastics should also be considered. Some other approaches that could be actioned by APEC are the development of guidelines for safe levels of microplastics in fish feed and microplastic-free feed production protocols with certification. The practice of Reduce, Reuse and Recycle (3Rs) is also a significant approach for reducing microplastic loading in marine environments apart from using biodegradable plastics and microplastics.

Safe production of fishmeal concerning microplastics and product certification should be considered a practical tool to minimize microplastics. Finally, the engagement of the industry, especially the key actors in the domains associated with aquaculture, should be encouraged and assured for any practical applications in the management of microplastics.

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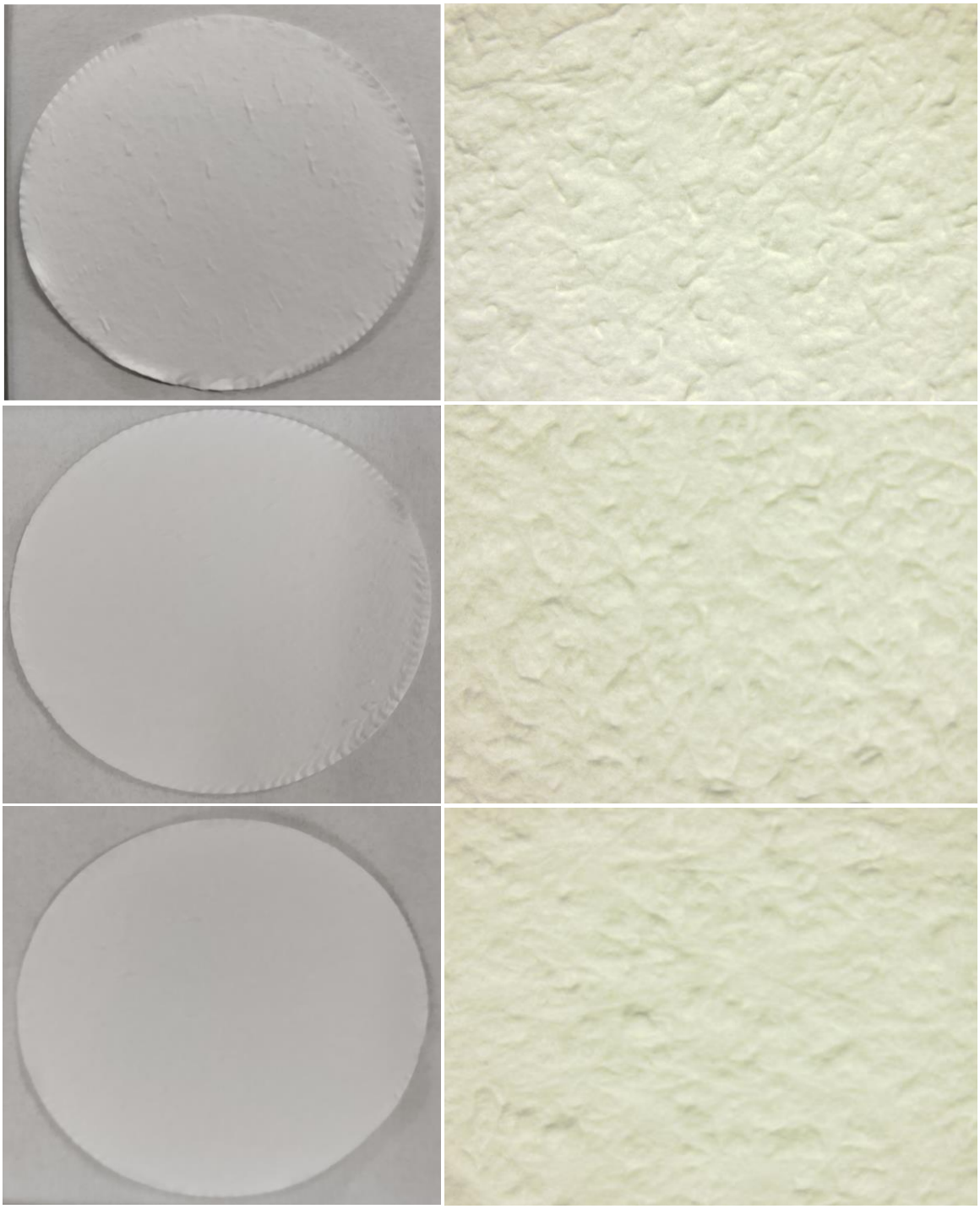
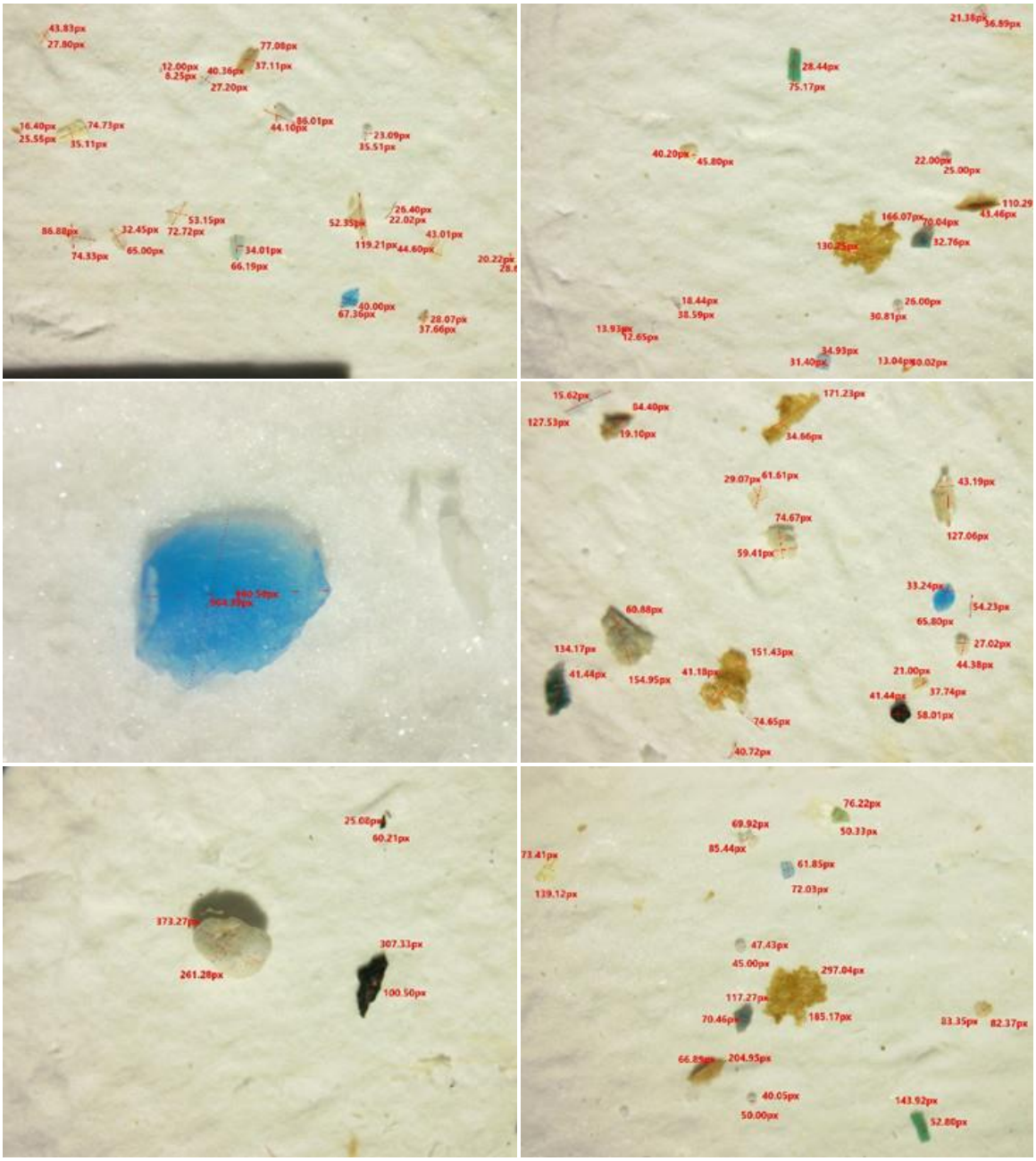
Annexes

Annexe 1. Representatives of blank filters observed by a Stereo Microscope Carl Zeiss, Stemi 508



Annexe 2. Examples of Microplastics' sizes, colors, and morphology observed by a Stereo Microscope Carl Zeiss, Stemi 508




147.05px
71.06px
81.57px
442.33px
56.84px
295.62px
75.00px
103.48px
192.02px
206.82px
122.61px
122.55px
33.53px
90.38px
259.06px
118.44px
81.57px
49.95px
247.13px
107.70px
67.78px
37.74px
77.83px
65.00px
120.78px
287.70px
48.09px
203.12px
79.43px
72.07px
53.60px
55.66px
44.20px
224.08px
159.40px
80.06px
92.91px
29.73px
167.71px
84.08px
47.42px
76.84px
96.18px
102.96px
354.58px
74.33px
111.97px
50.09px
50.99px
45.28px
143.45px
101.98px
72.35px
75.19px
79.08px
196.35px
78.00px
58.00px
43.05px
68.01px
69.63px

Annexe 3. Examples of FT-IR (ATR) spectra of microplastic samples

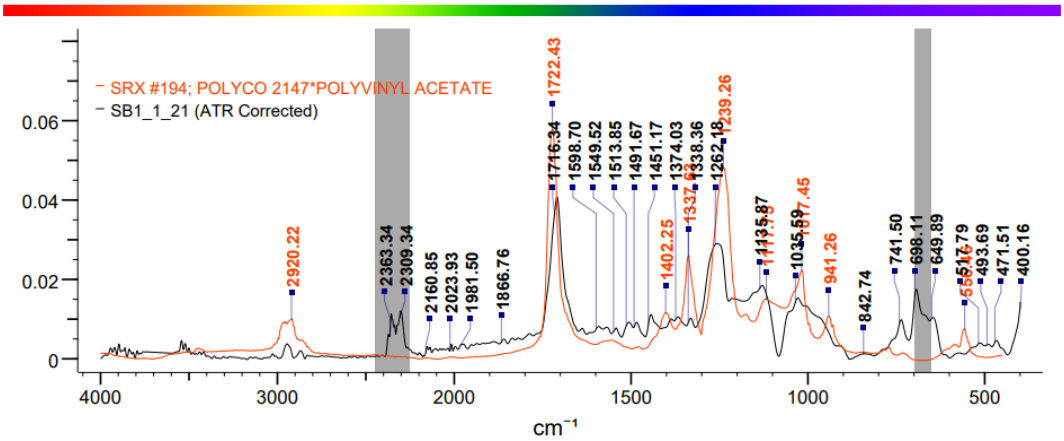


Fig. A3.1. FT-IR (ATR) of a microplastic in a sediment sample collected in Hai Phong, Viet Nam

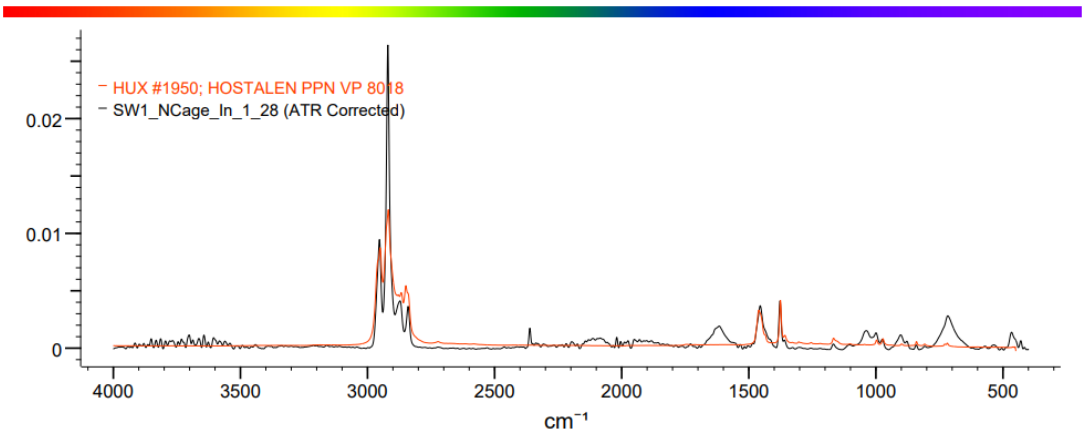


Fig. A3.2. FT-IR (ATR) of a microplastic in a fish sample collected in Hai Phong, Viet Nam

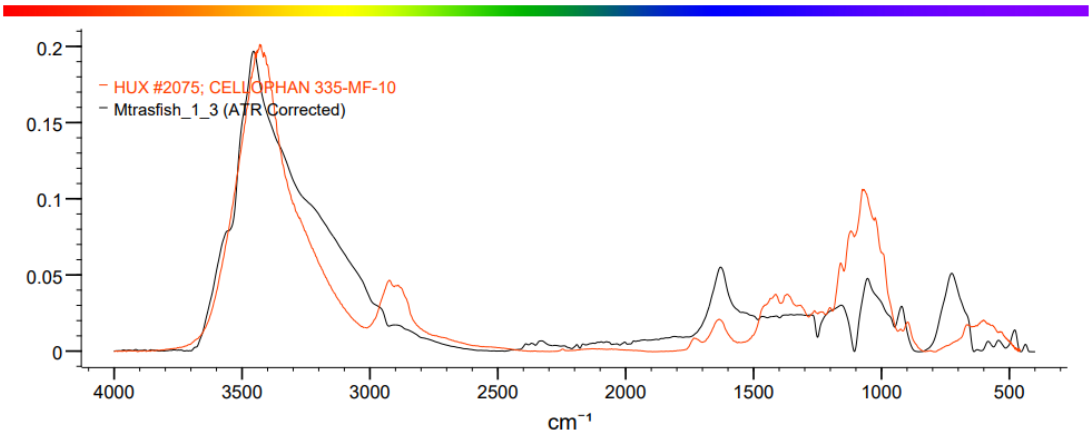


Fig. A3.3. FT-IR (ATR) of a microplastic in a feed meal sample collected in Hai Phong, Viet Nam

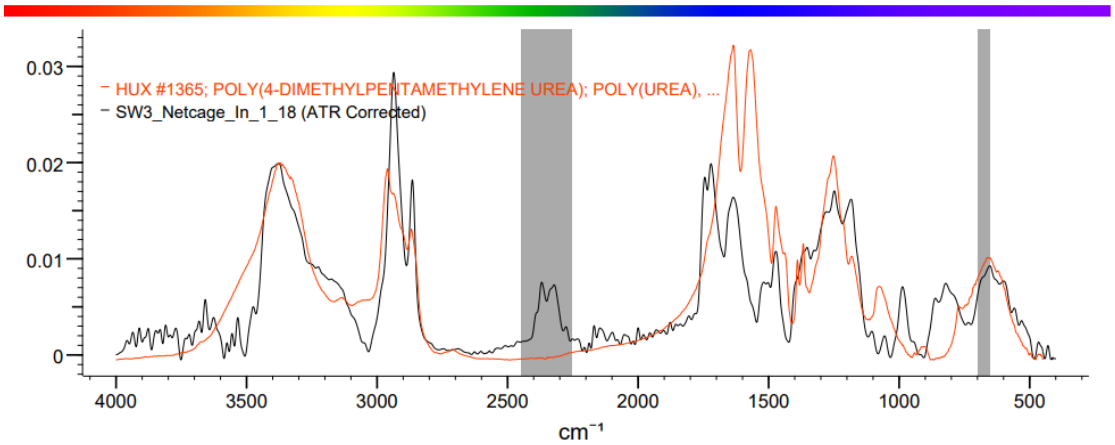


Fig. A3.4. FT-IR (ATR) of a microplastic in a water sample collected in Lampung, Indonesia

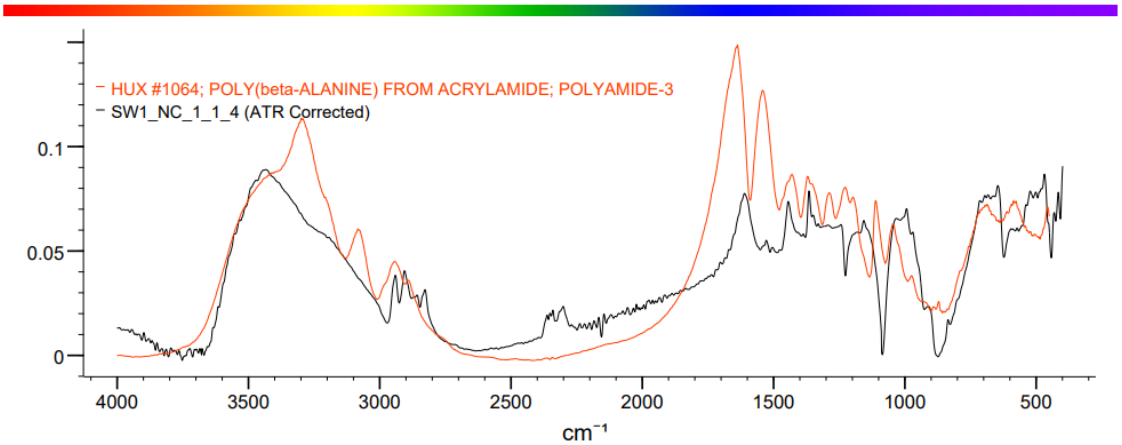


Fig. A3.5. FT-IR (ATR) of a microplastic in a fishmeal sample collected in Lampung, Indonesia

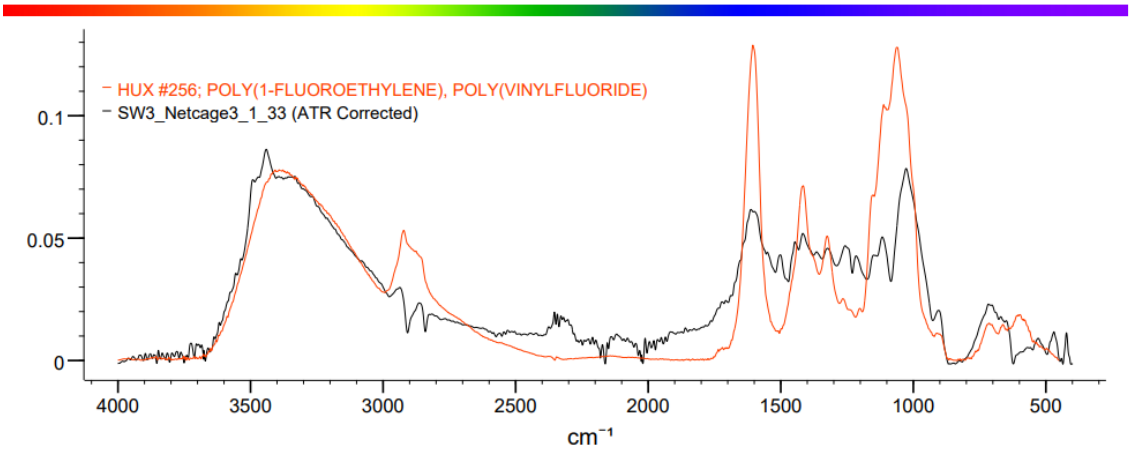


Fig. A3.6. FT-IR (ATR) of a microplastic in a water sample collected in in Lampung, Indonesia.

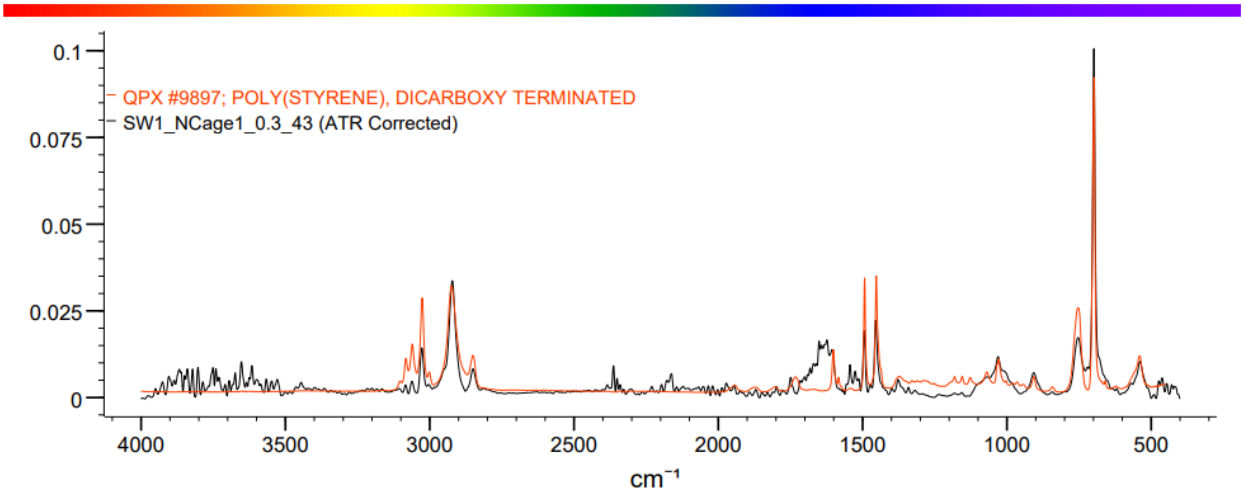


Fig. A3.7. FT-IR (ATR) of a microplastic in a sediment sample collected in in Lampung, Indonesia

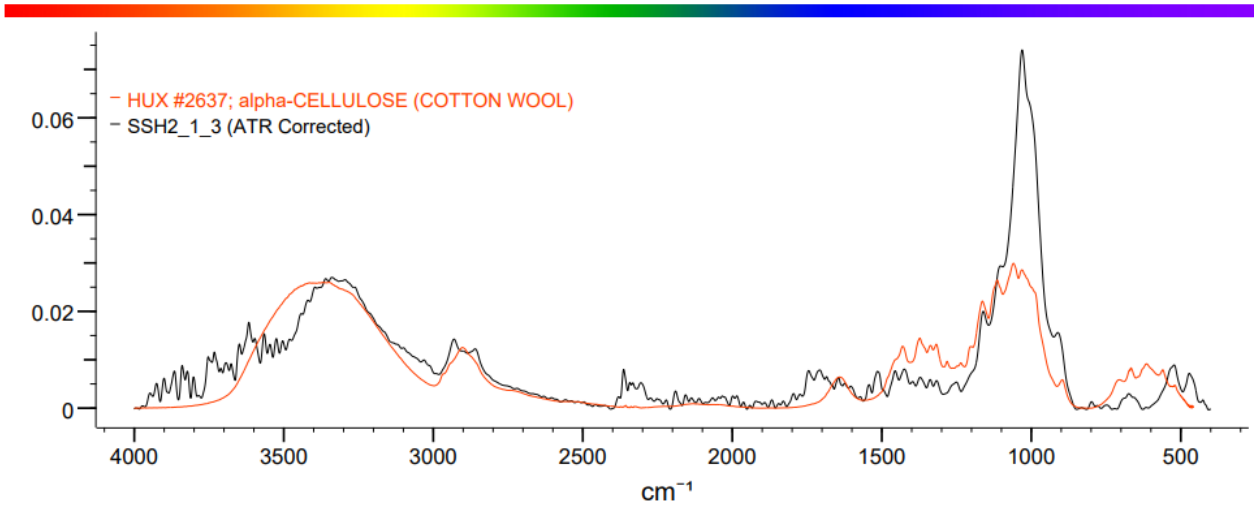
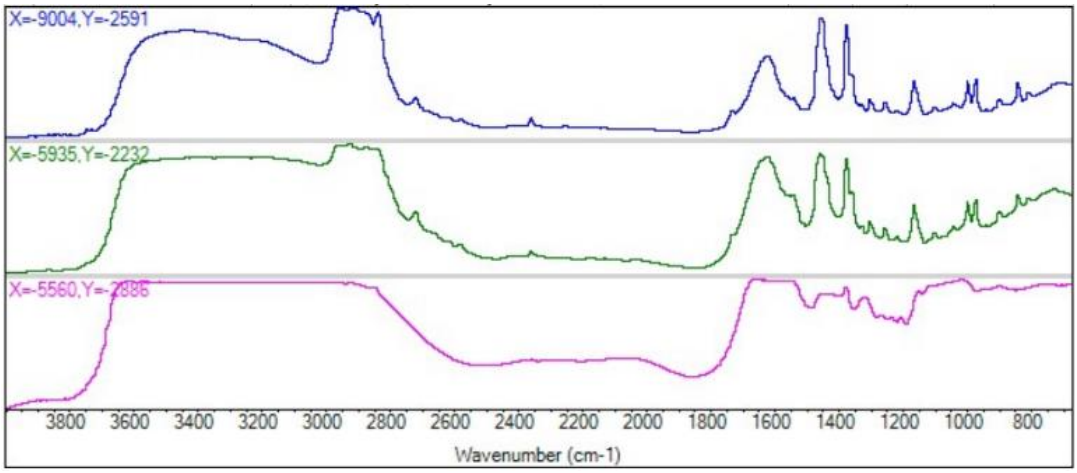
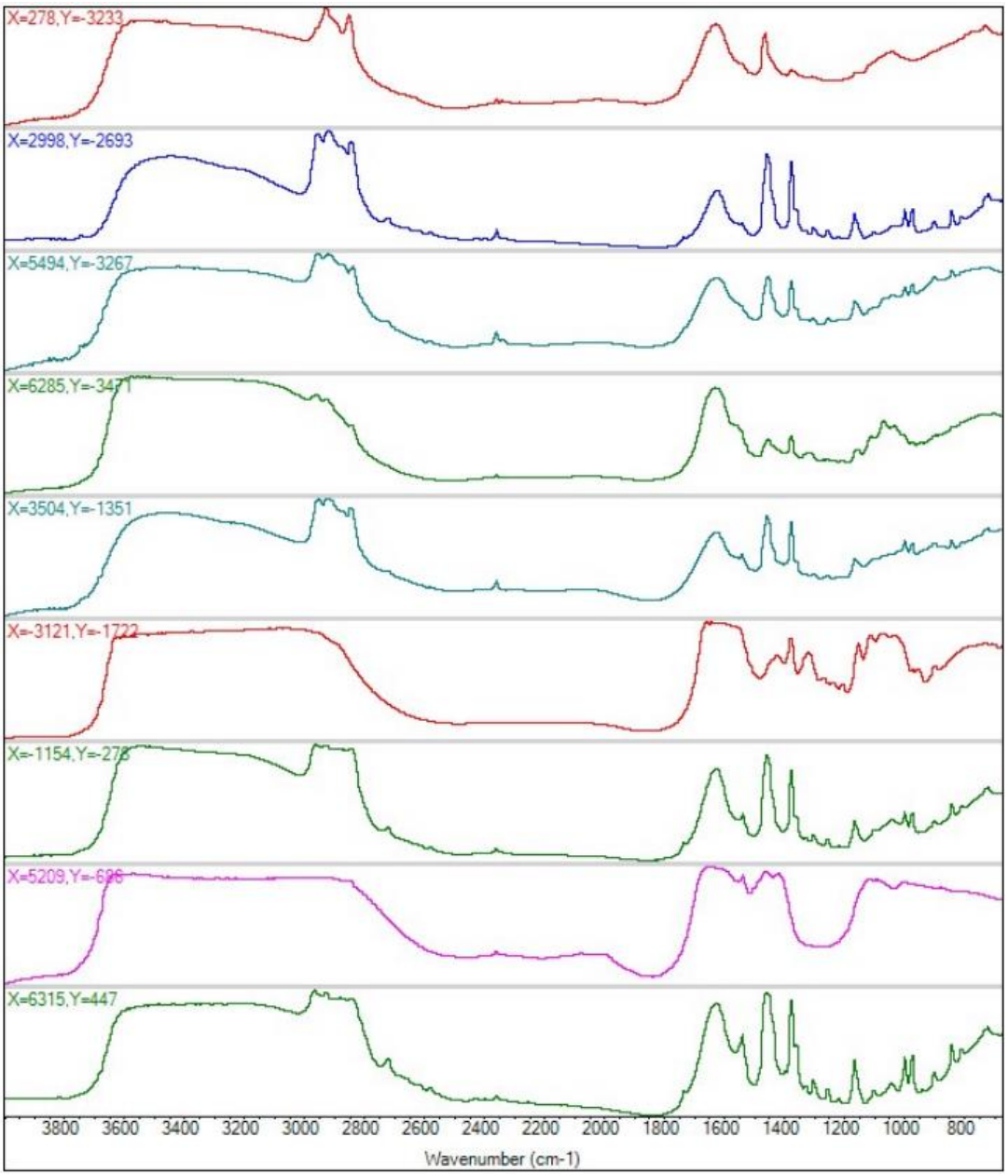


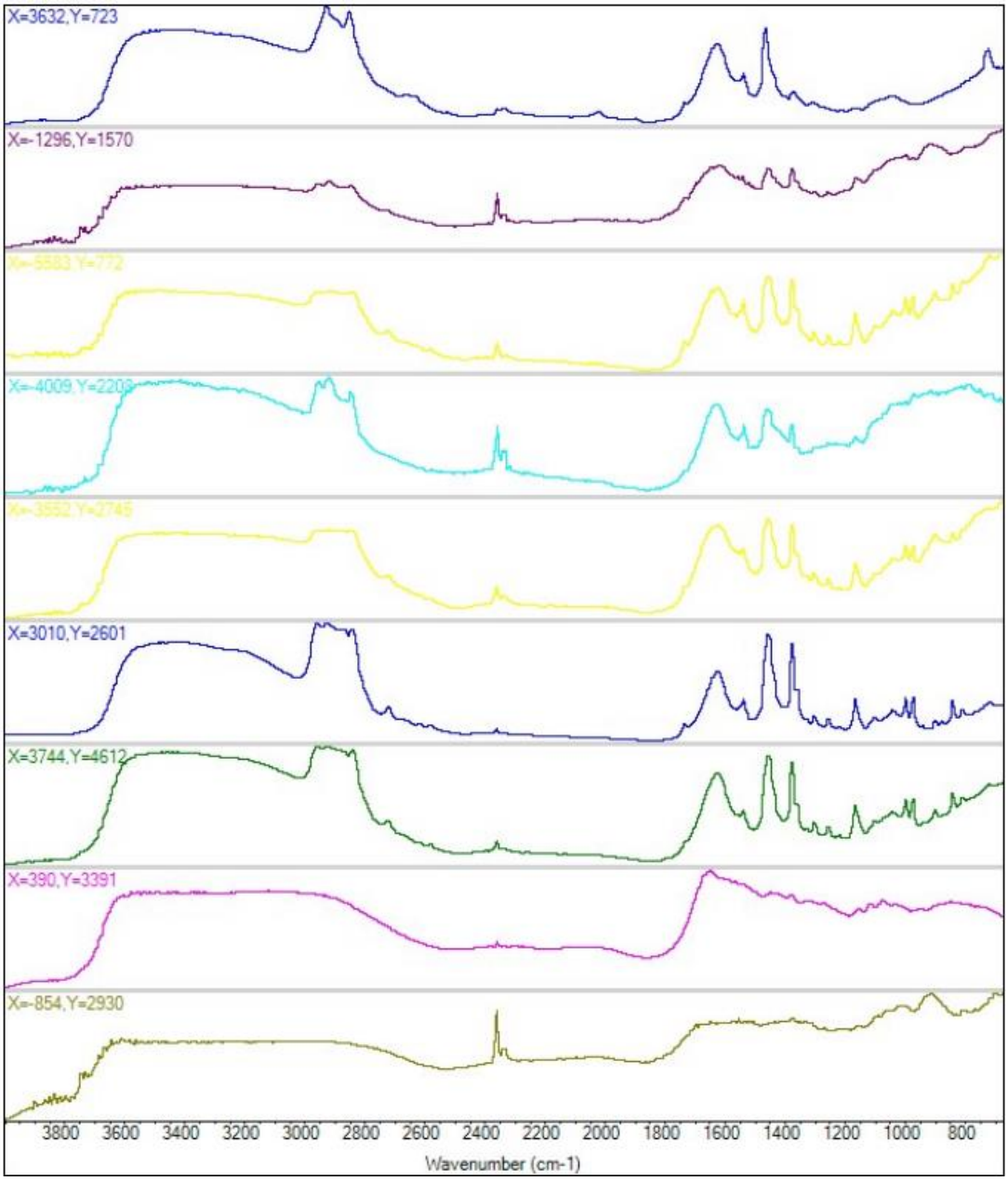
Fig. A3.8. FT-IR (ATR) of a microplastic in a fish sample collected in in Lampung, Indonesia

Annexe 4. Micro- FT-IR spectra

ID	Particle/Spectrum	CID	Identified Component Name	Match	Area	Length	Width
1	X=-9004,Y=-2591	3	DIMETHYLOLEYLAMINE OXIDE	90.53	1.79	1257.7	136.8
2	X=-5935,Y=-2232	2	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	86.96	6.58	1240.1	510.4
3	X=-5560,Y=-2886	5	PROPRIETARY CELLULOSIC POLYMER	81.05	0.61	401.7	146.9
4	X=278,Y=-3233	1	Tetrabutylammonium L-lactate, 70 wt. % solution in wate	85.96	11.0	1526.8	696.4
5	X=2998,Y=-2693	3	DIMETHYLOLEYLAMINE OXIDE	92.79	0.49	439.2	106.5
6	X=5494,Y=-3267	6	Tert-amylamine, 98%	83.29	0.48	465.9	98.7
7	X=6285,Y=-3471	2	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	92.4	0.45	307.6	139.9
8	X=3504,Y=-1351	6	Tert-amylamine, 98%	85.96	4.07	1590.5	246.1
9	X=-3121,Y=-1722	1	Tetrabutylammonium L-lactate, 70 wt. % solution in wate	84.53	17.0	2337.2	701.1
10	X=-1154,Y=-278	2	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	91.03	8.01	3005.3	256.5
11	X=5209,Y=-686	5	PROPRIETARY CELLULOSIC POLYMER	79.1	0.85	394.9	207
12	X=6315,Y=447	2	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	88.26	6.68	1320.4	486.7
13	X=3632,Y=723	3	DIMETHYLOLEYLAMINE OXIDE	90.49	3.76	857.3	421.8
14	X=-1296,Y=1570	7	2-Thiopheneethylamine, 96%	77.33	0.12	151.8	76.3
15	X=-5583,Y=772	4	2-Thiophenemethylamine, 96%	82.52	5	1352.5	356.1
16	X=-4009,Y=2208	9	Hydrazine monohydrate, 98%	83.17	0.02	74.9	21
17	X=-3552,Y=2745	4	2-Thiophenemethylamine, 96%	81.84	7.71	2942.4	252.3
18	X=3010,Y=2601	3	DIMETHYLOLEYLAMINE OXIDE	92.49	9.22	3024.5	293.6
19	X=3744,Y=4612	2	Titanium(IV) bis(ammonium lactato)dihydroxide, 50 wt. %	88.95	6.28	3993.1	151.4
20	X=390,Y=3391	5	PROPRIETARY CELLULOSIC POLYMER	82.05	7.96	2031.5	377.3
21	X=-854,Y=2930	8	1,1'-Diethyl-4,4'-carbocyanine iodide, 96%	70.9	0.04	0	0




X=278,Y=-3233
X=2998,Y=-2693
X=5494,Y=-3267
X=6285,Y=-3471
X=3504,Y=-1351
X=-3121,Y=-1722
X=-1154,Y=-278
X=5209,Y=-696
X=6315,Y=447
3800 3600 3400 3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800
Wavenumber (cm-1)


X=3632,Y=723
X=-1296,Y=1570
X=-4009,Y=2208
X=3010,Y=2601
X=3744,Y=4612
X=390,Y=3391
X=-854,Y=2930
3800 3600 3400 3200 3000 2800 2600 2400 2200 2000 1800 1600 1400 1200 1000 800
Wavenumber (cm-1)

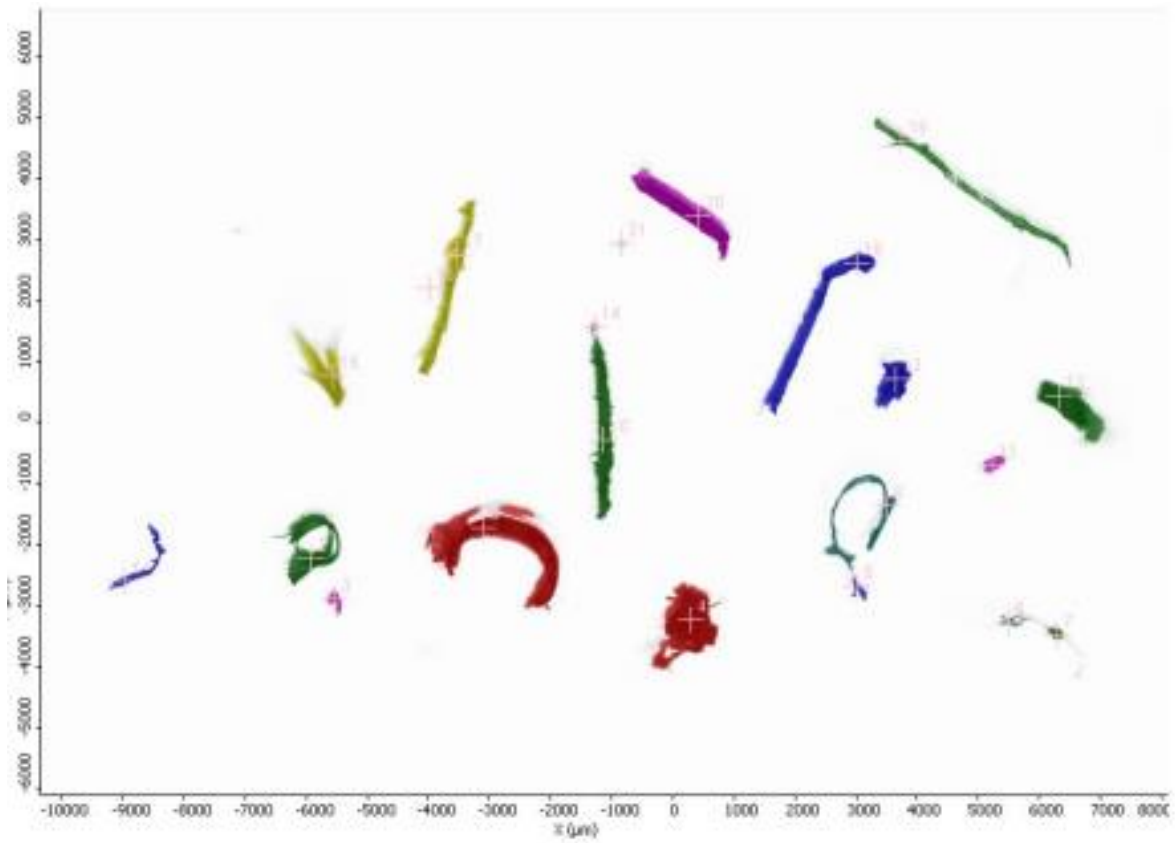
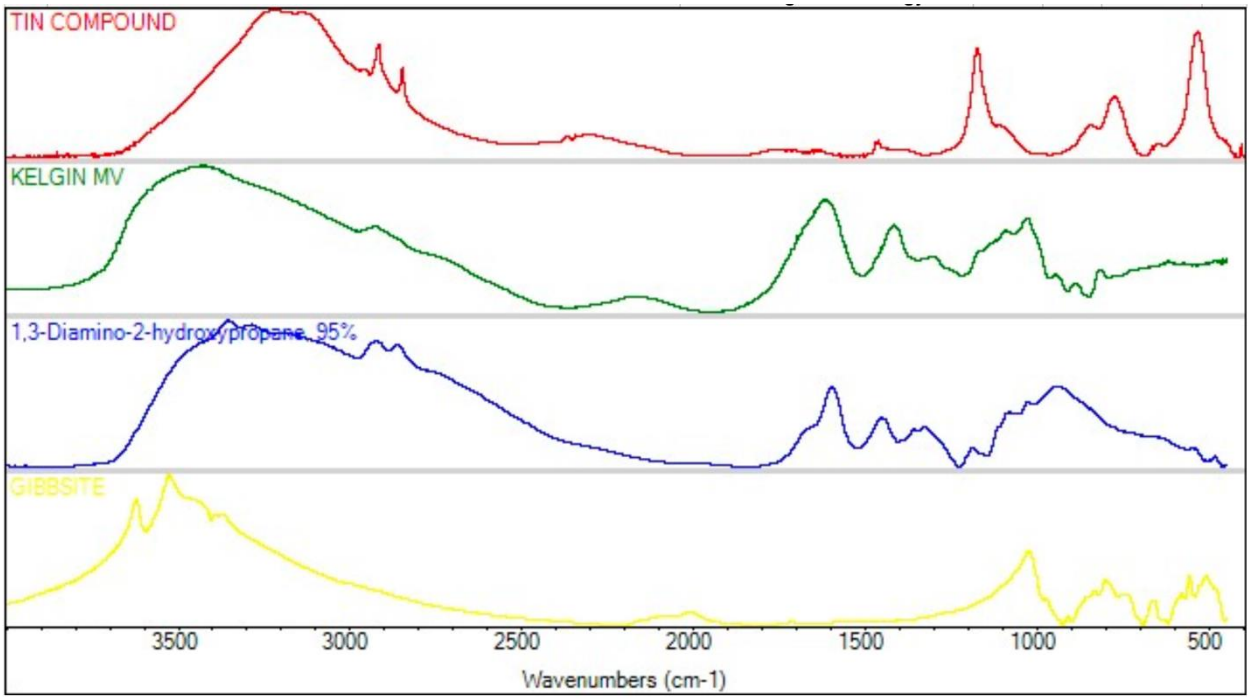


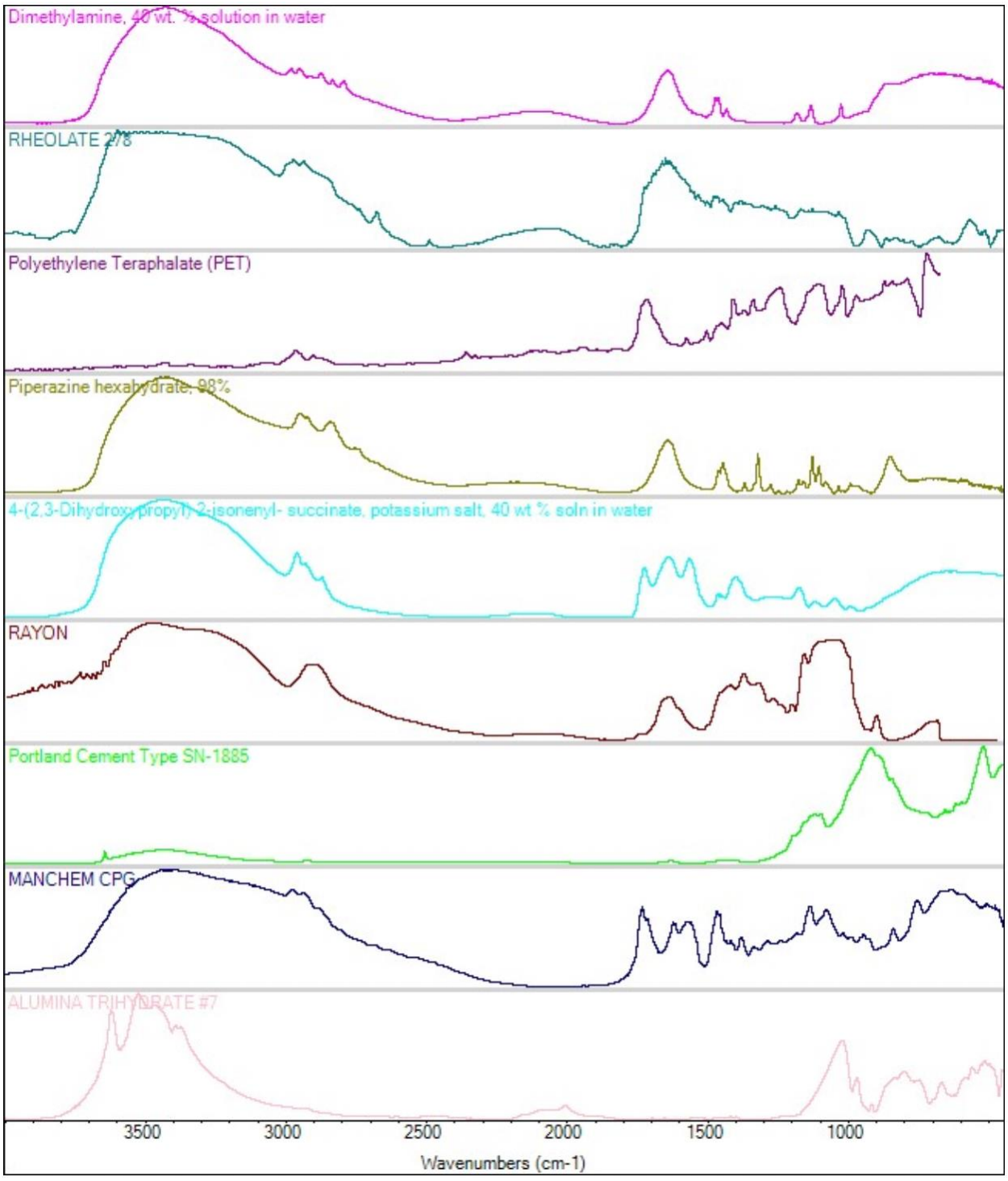
Fig. A4.1. Fishmeal sample 1

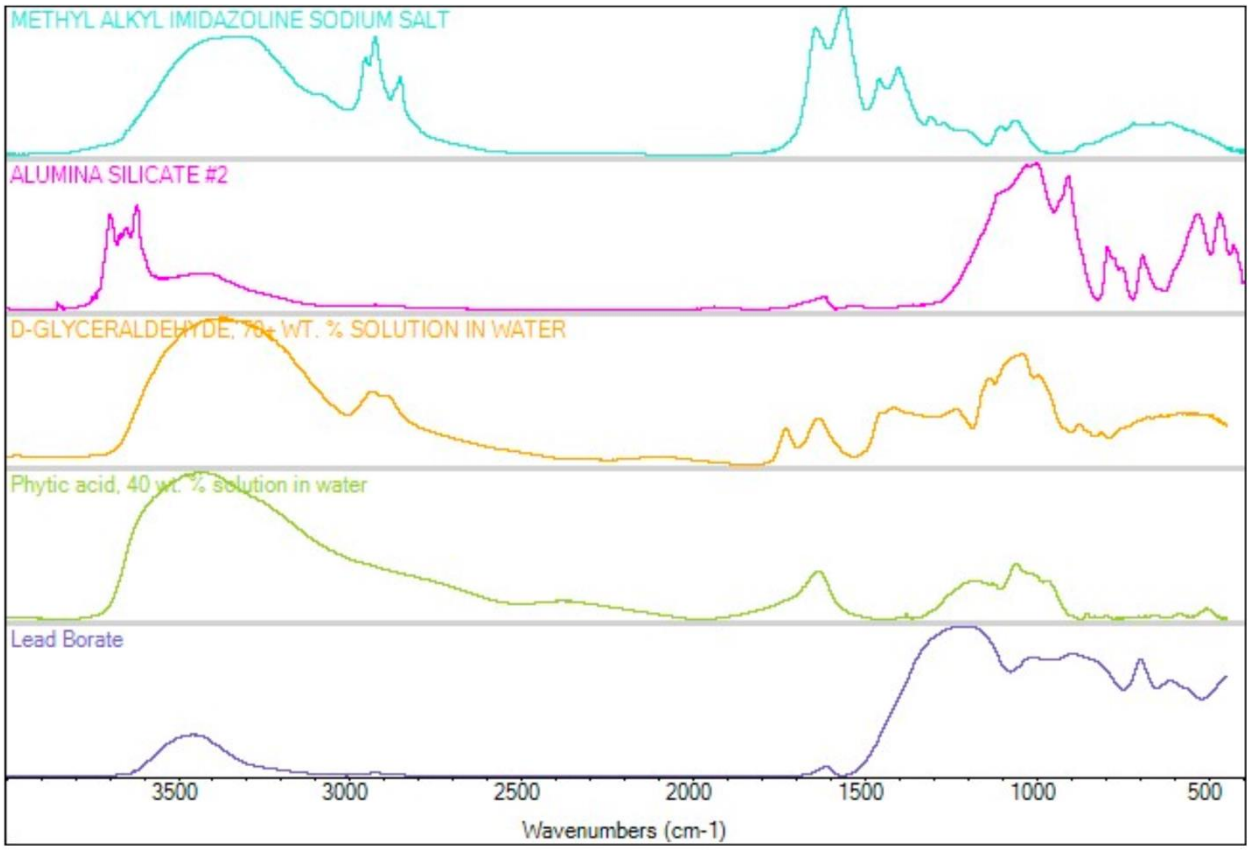
Thermo SCIENTIFIC

Identified Library Components

CI	Identified Component Name	Component Library Name	Match	Area	# of	Col
2	KELGIN MV	HR Industrial Coatings	87.99	34.4	13	
3	1,3-Diamino-2-hydroxypropane, 95%	HR Aldrich FT-IR Collection	90.92	8.3	1	
4	GIBBSITE	HR Industrial Coatings	84.69	4.6	13	
5	Dimethylamine, 40 wt. % solution in water	HR Aldrich FT-IR Collection	90.97	4.34	1	
6	RHEOLATE 278	HR Industrial Coatings	91.97	3.05	2	
7	Polyethylene Teraphalate (PET)	Cross Sections Wizard	86.89	2.08	4	
8	Piperazine hexahydrate, 98%	HR Aldrich FT-IR Collection	90.58	1.37	2	
9	4-(2,3-Dihydroxypropyl) 2-isonenyl- succinate, potassium salt,	HR Aldrich FT-IR Collection	90.86	1.08	1	
10	RAYON	Synthetic Fibers by Microsc	83.62	0.98	4	
11	Portland Cement Type SN-1885	HR Coatings Technology	84.03	0.97	1	
12	MANCHEM CPG	HR Industrial Coatings	84.91	0.77	2	
13	ALUMINA TRIHYDRATE #7	HR Polymer Additives and P	68.85	0.35	1	
14	METHYL ALKYL IMIDAZOLINE SODIUM SALT	HR Polymer Additives and P	93.63	0.29	1	
15	ALUMINA SILICATE #2	HR Polymer Additives and P	70.15	0.18	2	
16	D-GLYCERALDEHYDE, 70+ WT. % SOLUTION IN WATER	HR Aldrich Aldehydes and K	92.39	0.16	1	
17	Phytic acid, 40 wt. % solution in water	HR Aldrich FT-IR Collection	85.34	0.14	1	
18	Lead Borate	HR Coatings Technology	86.99	0.09	1	


TIN COMPOUND
KELGIN MV
1,3-Diamino-2-hydroxypropane, 95%
GIBBSITE
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)


Dimethylamine, 40 wt. % solution in water
RHEOLATE 278
Polyethylene Teraphalate (PET)
Piperazine hexahydrate, 98%
4-(2,3-Dihydroxypropyl)-2-isononyl- succinate, potassium salt, 40 wt % soln in water
RAYON
Portland Cement Type SN-1885
MANCHEM CPG
ALUMINA TRIHYDRATE #7
3500
3000
2500
2000
1500
1000
Wavenumbers (cm-1)


METHYL ALKYL IMIDAZOLINE SODIUM SALT
ALUMINA SILICATE #2
D-GLYCERALDEHYDE, 70+ WT. % SOLUTION IN WATER
Phytic acid, 40 wt. % solution in water
Lead Borate
3500
3000
2500
2000
1500
1000
500
Wavenumbers (cm-1)

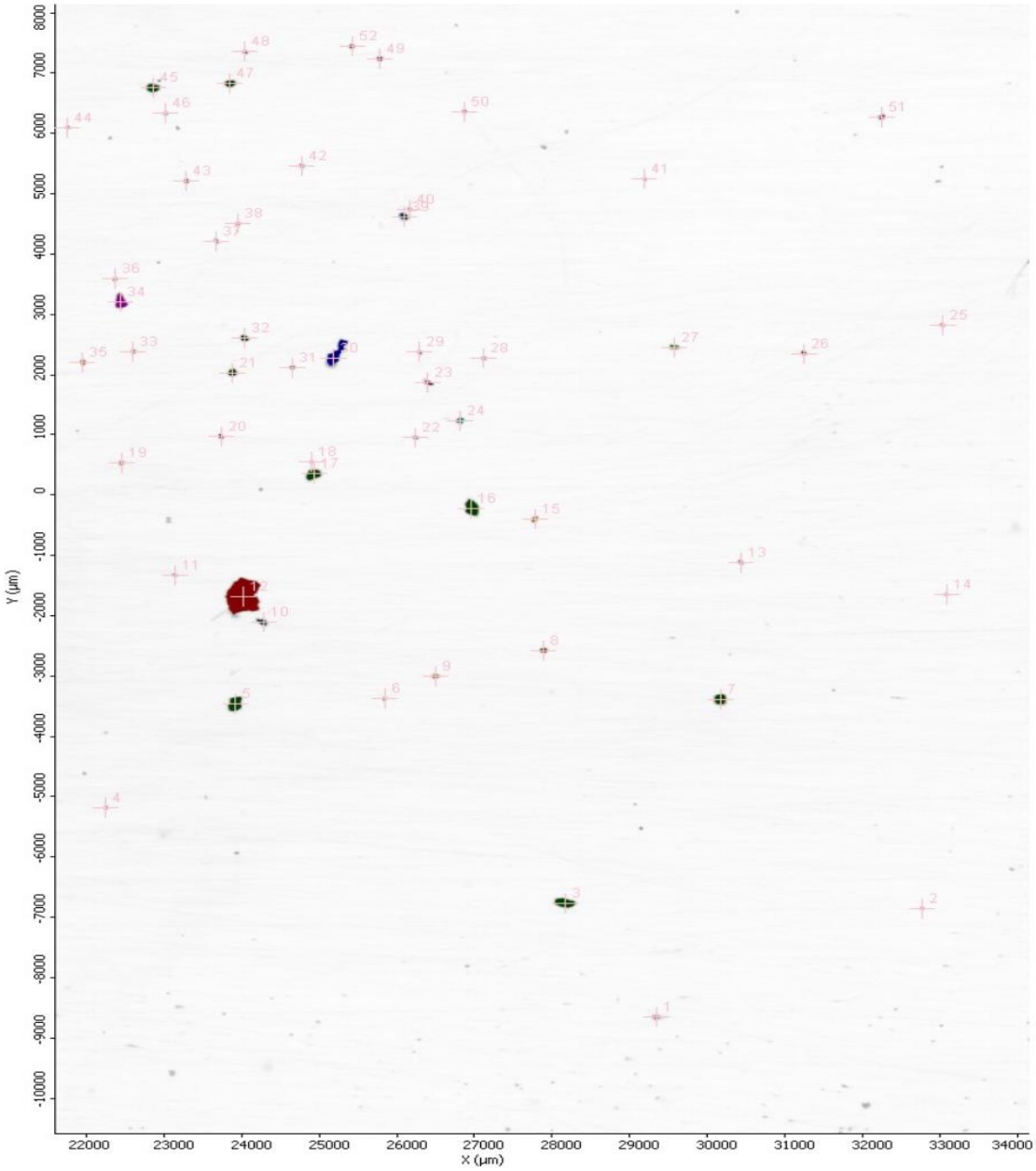


Fig. A4.2. Micro-FT-IR of a water samples collected in Lampung, Indonesia

Thermo SCIENTIFIC

Collected Spectra

ID	Particle/Spectrum Position	CID	Identified Component Name	Match	Area	Length	Width
1	X=-454,Y=-8698	21	SODIUM BISULFATE IN KBR	76.44	0.06	67.1	34.8
2	X=-253,Y=-8332	18	POLYESTER	85.22	0.14	89.5	64.9
3	X=1021,Y=-7541	12	POLYESTER	93.29	0.2	282	28.6
4	X=1604,Y=-5370	12	POLYESTER	87.65	0.35	716.2	20.1
5	X=906,Y=-5494	30	1,1'-Diethyl-4,4'-carbocyanine iodide, 96%	87.74	0.03	53.8	22.4
6	X=-1260,Y=-5855	17	1,2-Dimethylhydrazine dihydrochloride, 99+%	70.72	0.16	89.5	72
7	X=-1327,Y=-6538	6	XANTHAN GUM	80.41	1.09	238.7	188.2
8	X=-7027,Y=-6430	5	KELGIN MV	94.16	1.06	268.6	162.8
9	X=-7573,Y=-3953	1	Borax	83.87	46.94	1988.3	971.9
10	X=-473,Y=-3722	11	Polyethylene Teraphalate (PET)	78.02	0.01	22.4	22.2
11	X=3001,Y=-3636	8	ZINC OXIDE	76.38	0.69	181.7	156
12	X=3763,Y=-4065	19	ALUMINA SILICATE #2	69.52	0.07	59.7	51.1
13	X=4384,Y=-3886	28	RAYON	91.93	0.04	44.8	38
14	X=4815,Y=-3737	13	GIBBSITE	89.5	0.17	89.5	79.2
15	X=4432,Y=-2681	11	Polyethylene Teraphalate (PET)	76.93	0.18	104.4	71.2
16	X=3979,Y=-1775	26	2-Ethyl-1,3-cyclopentanedione, 99%	62.82	0.06	67.1	33.8
17	X=3975,Y=-2931	9	MANCHEM CPG	87.28	0.64	192.5	135.8
18	X=3782,Y=-2237	15	Triethylmethylammonium hydroxide, 20 wt. % solutio	88.74	0.13	89.5	60.2
19	X=3563,Y=-1775	24	EVOH EVAL film	83.75	0.04	93.5	16.7
20	X=3299,Y=-2010	4	AMA 120	85.39	1.49	865.4	71
21	X=2860,Y=-2584	19	ALUMINA SILICATE #2	66.41	0.06	53.8	43.5
22	X=2741,Y=-2077	24	EVOH EVAL film	66.67	0.02	42.2	21.8
23	X=2113,Y=-1935	3	D-Glyceraldehyde, 70+ wt. % solution in water	96.95	2.78	496.3	230.3
24	X=-2434,Y=-2342	35	MANCHEM APG-X	72.49	0.01	29.8	19
25	X=-2839,Y=-2487	27	Barium nitrate	85.79	0.02	29.8	23.7
26	X=-2981,Y=-2435	33	K-CURE 129-B	71.84	0.02	29.8	23.7
27	X=-5949,Y=-1271	9	MANCHEM CPG	78.06	0.02	22.4	22.4
28	X=-5095,Y=-913	5	KELGIN MV	90.89	0.25	111.9	90.6
29	X=-4340,Y=-1260	5	KELGIN MV	89.67	0.06	59.7	42.7
30	X=371,Y=-1599	21	SODIUM BISULFATE IN KBR	73.29	0.01	22.4	22.4
31	X=4075,Y=-1424	7	TAPIOCA FLOUR	86.9	0.93	786.5	48.7
32	X=4830,Y=-1625	10	Piperazine hexahydrate, 98%	94.59	0.59	231.3	104.2
33	X=2868,Y=-133	23	Poly(vinyl alcohol), 100% hydrolyzed, average M.W.	81.12	0.1	74.6	55.1
34	X=2470,Y=878	14	RAYON	73.09	0.14	97	59.2
35	X=2296,Y=795	14	RAYON	75.5	0.01	29.8	19
36	X=-2022,Y=467	37	Poly(terephthaloyl oxamidrazone)+SrCO3	46.54	0.01	22.4	22.2
37	X=-3475,Y=1098	14	RAYON	82.45	0.08	59.7	53.4
38	X=-6700,Y=904	27	Barium nitrate	75.86	0.01	22.4	22.2
39	X=-8454,Y=-33	13	GIBBSITE	62.36	0.05	44.8	44.8
40	X=-2490,Y=2396	20	HYDRAZINE MONOHYDRATE, 98%	86.97	0.11	74.6	61.7
41	X=-2442,Y=1594	13	GIBBSITE	86.5	0.2	93.5	87.9
42	X=2645,Y=1750	2	OLEFIN	82.01	39.92	2491.7	659.6
43	X=3094,Y=1195	22	Trimethylboroxine, 99%	66.84	0.1	76.8	56.3
44	X=3923,Y=1937	36	Lignin sulfate	91.54	0.01	22.4	22.4
45	X=267,Y=2769	34	ALUMINA TRIHYDRATE #1	74.14	0.02	29.8	21.4
46	X=-3805,Y=3082	14	RAYON	79.53	0.04	37.3	37.3
47	X=-7651,Y=3033	31	TRIACETYLMETHANE, 97%	75.59	0.02	37.3	24.7
48	X=-4601,Y=4279	13	GIBBSITE	85.83	0.04	44.8	41.2
49	X=1757,Y=4477	11	Polyethylene Teraphalate (PET)	93.27	0.35	217.2	65.9
50	X=3061,Y=5622	32	RHEOLATE 278	77.54	0.02	29.8	23.7
51	X=1363,Y=5798	29	POLYGALACTURONIC ACID SODIUM	89.77	0.03	37.3	34.2
52	X=984,Y=5764	16	Methylamine - 40 wt.% solution in water	77.85	0.17	111.9	63.3
53	X=-2780,Y=6670	11	Polyethylene Teraphalate (PET)	88.24	0.03	37.3	37.3
54	X=133,Y=6875	27	Barium nitrate	81.83	0.01	22.4	22.4
55	X=2593,Y=7088	25	OPIUM POWDER IN KBR	92.42	0.06	58.3	41.3

Thermo SCIENTIFIC

Collected Spectra

ID	Particle/Spectrum Position	CID	Identified Component Name	Match	Area	Length	Width
56	X=4231,Y=6816	15	Triethylmethylammonium hydroxide, 20 wt. % solutio	88.68	0.08	74.6	43.7
57	X=-2538,Y=8200	21	SODIUM BISULFATE IN KBR	78.69	0.04	0	0

Identified Library Components

CI	Identified Component Name	Component Library Name	Matc	Are	# of	Co
1	Borax	HR Nicolet Sampler Library	83.8	46.9	1	
2	OLEFIN	Synthetic Fibers by Microscope	82.0	39.9	1	
3	D-Glyceraldehyde, 70+ wt. % solution in	HR Aldrich FT-IR Collection Edition II	96.9	2.78	1	
4	AMA 120	HR Industrial Coatings	85.3	1.49	1	
5	KELGIN MV	HR Industrial Coatings	91.5	1.37	3	
6	XANTHAN GUM	HR Industrial Coatings	80.4	1.09	1	
7	TAPIOCA FLOUR	HR Industrial Coatings	86.9	0.93	1	
8	ZINC OXIDE	HR Polymer Additives and Plasticizers	76.3	0.69	1	
9	MANCHEM CPG	HR Industrial Coatings	82.6	0.65	2	
10	Piperazine hexahydrate, 98%	HR Aldrich FT-IR Collection Edition II	94.5	0.59	1	
11	Polyethylene Teraphalate (PET)	Cross Sections Wizard	84.1	0.57	4	
12	POLYESTER	Synthetic Fibers by Microscope	90.4	0.55	2	
13	GIBBSITE	HR Industrial Coatings	81.0	0.47	4	
14	RAYON	Synthetic Fibers by Microscope	77.6	0.27	4	
15	Triethylmethylammonium hydroxide, 20	HR Aldrich FT-IR Collection Edition II	88.7	0.21	2	
16	Methylamine - 40 wt.% solution in water	HR Nicolet Sampler Library	77.8	0.17	1	
17	1,2-Dimethylhydrazine dihydrochloride,	HR Aldrich FT-IR Collection Edition II	70.7	0.16	1	
18	POLYESTER	Synthetic Fibers by Microscope	85.2	0.14	1	
19	ALUMINA SILICATE #2	HR Polymer Additives and Plasticizers	67.9	0.13	2	
20	HYDRAZINE MONOHYDRATE, 98%	HR Aldrich Organometallic, Inorganic, Silanes, Borane	86.9	0.11	1	
21	SODIUM BISULFATE IN KBR	Georgia State Crime Lab Sample Library	76.1	0.11	3	
22	Trimethylboroxine, 99%	HR Aldrich FT-IR Collection Edition II	66.8	0.1	1	
23	Poly(vinyl alcohol), 100% hydrolyzed, av	HR Aldrich FT-IR Collection Edition II	81.1	0.1	1	
24	EVOH EVAL film	Polymer Laminate Films	75.2	0.06	2	
25	OPIUM POWDER IN KBR	Georgia State Crime Lab Sample Library	92.4	0.06	1	
26	2-Ethyl-1,3-cyclopentanedione, 99%	HR Aldrich FT-IR Collection Edition II	62.8	0.06	1	
27	Barium nitrate	HR Hummel Polymer and Additives	81.1	0.04	3	
28	RAYON	Synthetic Fibers by Microscope	91.9	0.04	1	
29	POLYGALACTURONIC ACID SODIUM	Sigma Biological Sample Library	89.7	0.03	1	
30	1,1'-Diethyl-4,4'-carbocyanine iodide, 96	HR Aldrich FT-IR Collection Edition II	87.7	0.03	1	
31	TRIACETYLMETHANE, 97%	HR Aldrich Aldehydes and Ketones	75.5	0.02	1	
32	RHEOLATE 278	HR Industrial Coatings	77.5	0.02	1	
33	K-CURE 129-B	HR Industrial Coatings	71.8	0.02	1	
34	ALUMINA TRIHYDRATE #1	HR Polymer Additives and Plasticizers	74.1	0.02	1	
35	MANCHEM APG-X	HR Industrial Coatings	72.4	0.01	1	
36	Lignin sulfate	HR Hummel Polymer and Additives	91.5	0.01	1	
37	Poly(terephthaloyl oxamidrazone)+SrC	HR Hummel Polymer and Additives	46.5	0.01	1	

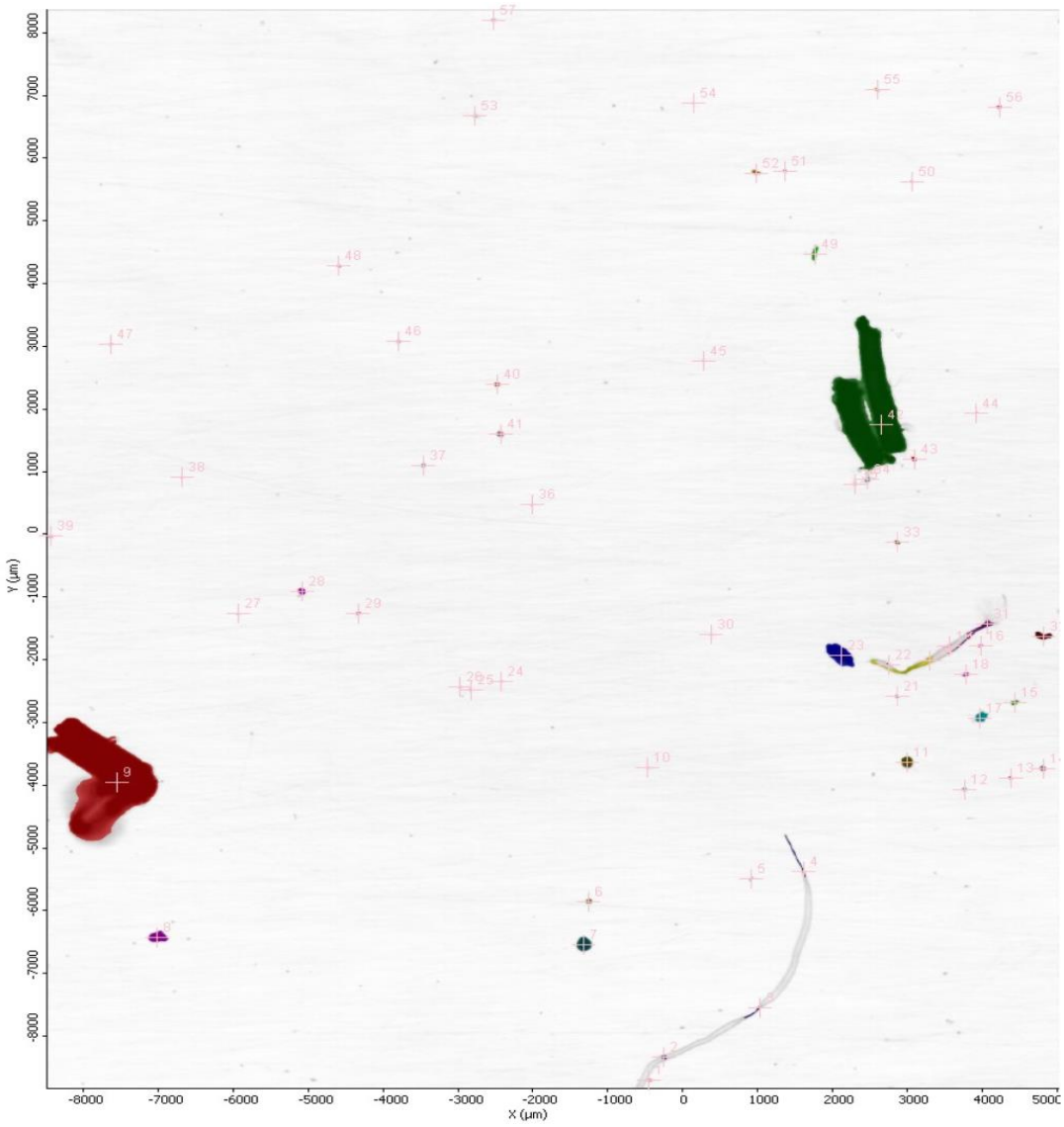


Fig. A4.3. Micro-FT-IR of a sediment samples collected in Hai Phong, Viet Nam