Identification and characterization of microplastics in freshwater fishponds and marine cages in Baler, Aurora, Philippines

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Abstract. The Philippines is renowned for its emerging aquaculture industry in both freshwater and marine environments, as well as its significant research on microplastics (MPs). However, there is a lack of information and sources on MPs in different regions. This study investigated the presence of MPs in aquaculture systems (fishponds and marine cages) in Baler, Aurora. The microplastics isolated were characterized in terms of type, shape, color and polymer type. Samples of water, sediments, and fish all contained microplastics. A higher concentration of MPs was observed in marine cages compared to freshwater fishponds, with a total average concentration of 69.5 items mL^{-1} (water), 51.67 items g^{-1} (sediments), and 168 items pc^{-1} (fish). Using a stereomicroscope, MPs were characterized based on the types, shapes, and colors found in the water, sediments, and fish samples. The study revealed different types of MP at varying frequencies, with fibers and fragments being the most common. In marine cages, the concentration of fibers was significantly higher, with a frequency of 63.22 items pc^{-1} in marine fish (milkfish) and 12.2 items mL^{-1} in water. In freshwater fishponds, the concentration of fragments was higher, with a frequency of 35.44 items pc^{-1} in fish (tilapia) and 7.6 items mL^{-1} in water. The highest frequency of MPs in sediments was found in fragments, with 9.28 items g^{-1} observed in freshwater fishponds. The most common shape of MPs was irregular, with white and black colors in both systems, especially in fish. Fourier transform infrared spectrometer analysis identified polymers such as rayon, polyethylene, and polypropylene in freshwater ponds and polypropylene and nylon in marine cages. Despite variations in MP types and shapes, independent t-tests indicate no significant difference in MP concentrations between the two aquaculture environments. This study emphasizes the widespread nature of MP pollution and suggests the need for effective mitigation strategies for responsible aquaculture practices.

Key Words: aquaculture, fiber, microplastics, plastic pollution, polypropylene, stereomicroscope.

Introduction. The Philippines, a country renowned for its rich marine biodiversity and thriving aquaculture industry, faces growing concerns over the presence and impact of microplastics (MPs) in its freshwater and marine ecosystems. MPs are small plastic particles < 5 mm, and have become a significant global environmental issue affecting aquatic habitats (UNEP 2019). MPs include beads, fragments, pellets, film, foam, and fibers. MPs can be classified into two distinct categories: primary MP and secondary MP. The primary MP encompasses micropellets or microbeads, which produce larger plastic items or are used as personal care product additives. However, secondary MP is derived from a variety of materials (meso- and macro-plastics, > 5 mm such as bottles, purses, and toys (NOAA 2021). In the Philippines, where aquaculture plays a vital role in food security and economic development (FAO 2018), it is crucial to understand the extent and characteristics of MP contamination in fish farms (Ma et al 2020) to ensure the sustainability of this industry and the preservation of the country's valuable aquatic resources.

The Philippines is known for its diverse aquaculture practices, including farming freshwater species like Nile tilapia (*Oreochromis niloticus*), freshwater giant prawn (*Macrobrachium rosenbergii*), catfish (*Clarias* spp.), and marine species like milkfish

(*Chanos chanos*) and grouper (*Epinephelus* spp.) (Tahiluddin & Terzi 2021). The production of plastics makes MP pollution ubiquitous in distribution, which will have a lasting impact on the global environment, especially on the aquaculture system. However, the potential presence of MP in fish farms poses risks to farmed fish and the broader ecosystem (Vázquez-Rowe et al 2021). MPs can enter aquaculture fish farms through various pathways, including contaminated water sources, pipe-borne water, dilapidated aquaculture facilities, fish gears (Iheanacho et al 2023), feed or fishmeal (Wang et al 2022), or plastic debris in the surrounding environment (Chen et al 2021; Wu et al 2023). As MPs have the potential to accumulate in fish tissues and transfer to human consumers, their presence raises concern about food safety and human health implications (Chen et al 2021).

According to Coyle et al (2020), MPs make up 92% of the plastic pollution in the ocean's surface waters. Food and Agriculture Organization (FAO) assessment reports that MPs occurrences in mariculture structures are buoyed by expanded polystyrene (EPS) or plastic buoys and anchored with non-buoyant plastic lines and ropes (FAO 2018). On the other hand, the development of freshwater fish culture systems, fisheries, and aquaculture have relied heavily on plastic use and are likely to continue doing so in the foreseeable future. Plastic is widely used in aquaculture for seafood packaging, transportation, ropes, floats, fish crates and boxes, fish cages, pond lining, fish feeders, and fish tanks (FAO 2018). Based on research conducted by the FAO regarding MPs in aquatic ecosystems, it has been discovered that urban lakes or rivers located in regions with dense human populations tend to have the most significant concentrations of MPs worldwide. Nevertheless, the study discovered in Los Baños, Laguna, that the Molawin River’s downstream station contains the highest concentration of MPs (Limbago et al 2021).

Despite the global recognition of MP pollution, there is a need to have a greater understanding of the specific characteristics and sources of MPs in fish farms within the Philippine context. Therefore, conducting a comprehensive study on the characterization and identification of MPs in freshwater fish farms in the Philippines is crucial. Such research can provide essential insights into the types, distribution, abundance, and potential sources of MPs in fish farms, enabling evidence-based management strategies to mitigate the risks and promote sustainable aquaculture practices in the country. In the present study, the MPs were isolated and extracted in water, sediment, and fish samples collected from fishponds and marine cages, and characterized the types, shapes, and colors using a microscopic technique. The results of this study provided valuable insights into fish farms in freshwater and marine aquaculture system, with a focus on Baler, Aurora province. Moreover, it helped in understanding the types, shapes, colors, and frequency of MPs in fish farms.

Material and Method

Site selection. The study took place in April 2024 at six large-scale (1000-5000 m^2) fish farms (Moses 2023) located in Baler, Aurora, Philippines (15°45’30”N, 121°33’45”E), three freshwater fishponds in Brgy. Reserva, and three marine cages in Brgy. Zabali (Figure 1). These sites were chosen based on the Municipal Agriculturist’s Office (MAO) Baler's recommendation.

Collection of samples. A three-day field collection was organized to collect water, sediment, and fish samples, each with three (3) replications in both freshwater fishponds (Figure 2) and marine cages (Figure 3), respectively. The water samples were collected using the standard protocol, utilizing a bucket method (Barrows et al 2017; Prata et al 2019). A bucket container was used to collect water from fishponds. The samples were then transferred and stored in a 1-L glass bottle for water analysis. For the collection of sediment samples, a grab collector method (Bordós et al 2019; Razeghi et al 2021) was followed. The sampling tool was lowered to a desired depth to retrieve 400 g of sediment, which was then placed in an aluminum foil container. The fish samples were Nile tilapia (*Oreochromis niloticus*) from freshwater fishponds and milkfish (*Chanos*

chanos) from marine cages, a total of 9 pieces (3 pcs per farm/cage) were randomly caught from each freshwater and marine environment using a cast net. After the fish were hauled from the water, pithing was used as the method for killing them. A pithing needle was inserted into the head to reach the brain, rendering the fish unconscious and ensuring a humane death, then were wrapped in aluminum foil and placed in Ziploc bags. Composite sampling was applied to water and sediment samples. All the samples were placed in chiller containers with ice, sealed, and stored at low temperatures to avoid contamination during transport to the CLSU-Institute of Climate Change and Environmental Management (ICCEM) laboratory for further analysis.

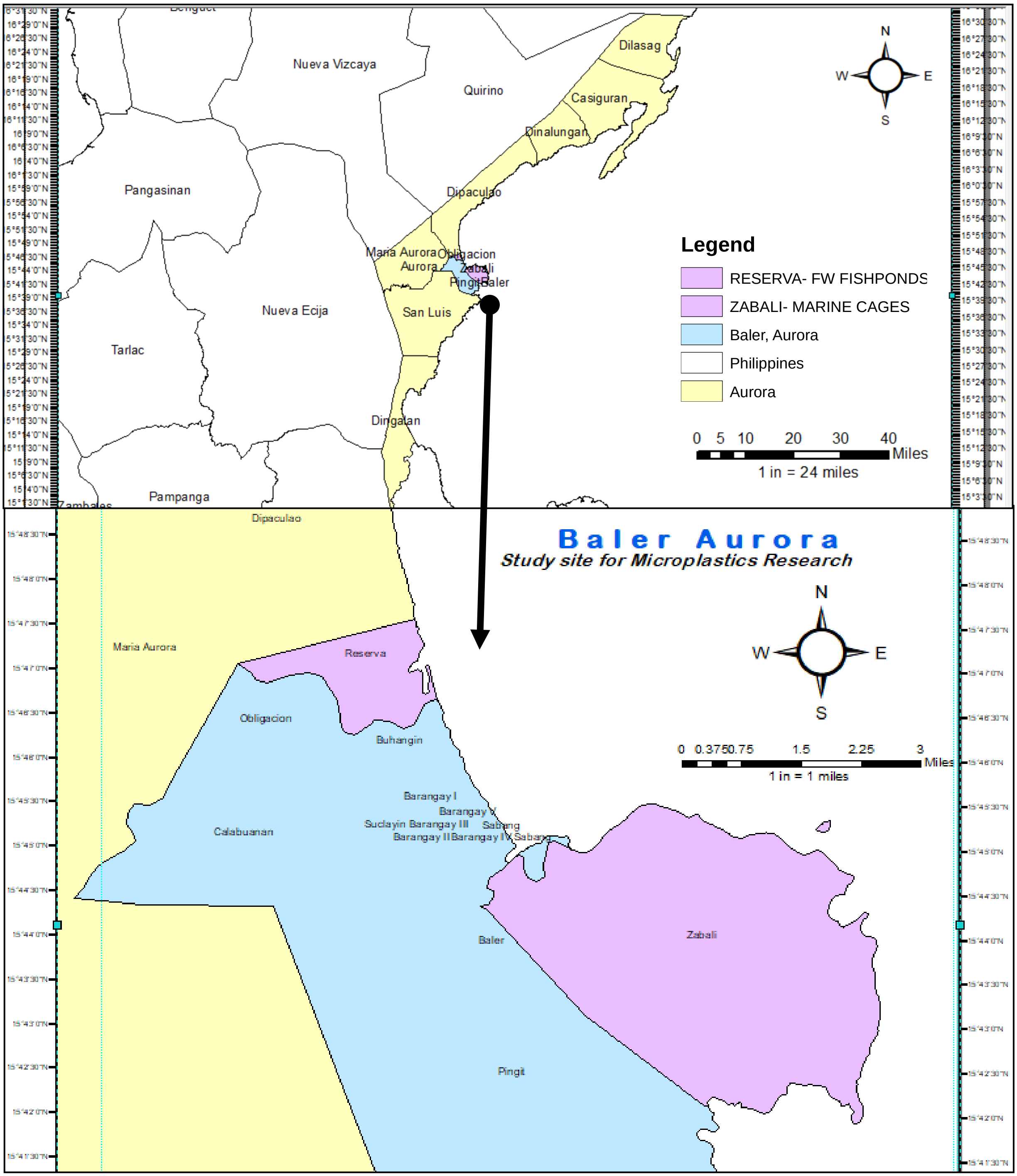

Figure 1. Map of the study site, (Brgy. Reserva – freshwater fishponds and Brgy. Zabali – marine cages).

Figure 2. Sampling collection in freshwater fishponds.

Figure 3. Sampling collection in marine cages.

Isolation of microplastics in water samples. The water samples were subjected to wet peroxide oxidation (WPO) according to the procedure by NOAA (Masura et al 2015; Saipolbahri et al 2020). The WPO underwent density separation of plastic debris through flotation in sodium chloride (NaCl). The mixture was put in a magnetic hotplate stirrer at a temperature of 75°C and was covered with aluminum foil. Next, 6 g of NaCl was added to the sample as a density separation solution, and the mixture was stirred on a magnetic hotplate for 15 minutes. Following this, the solution was filtered using a vacuum pump with glass fiber filter (GF/C) paper (47 mm). Once the solution was placed into the filtration funnel, the top was covered with aluminum foil. After all the liquid was transferred from the glass beaker, the walls of the filtration device were washed and rinsed with distilled water to ensure that all particles were recovered on the filter. The filter was then inserted into a labeled Petri dish and left to dry within a sealed glass desiccator. Once thoroughly dried, the isolated particles were observed under a stereomicroscope. Subsequently, Fourier transform infrared spectroscopy - attenuated total reflectance (FTIR-ATR) was used to identify the isolated particles chemically.

Isolation of microplastics in sediment samples. The collected sediment samples were stored in an aluminum tray (Frias et al 2018) and were treated by oven drying for

8-10 hours until completely dried at 90^{o}C. Afterward, the sediment samples were sieved and divided into quarter parts to be measured at 20 g and were transferred to an individually labeled 1-L glass beaker, which had been thoroughly sterilized. Then, the sediment samples were subjected to WPO as stated in the above (Masura et al 2015; Saipolbahri et al 2020) studies. The WPO underwent density separation of plastic debris through flotation in NaCl. Following this, the solution was filtered using a vacuum pump with glass fiber (GF/C) filters. The filter paper was inserted into a labeled Petri dish for drying. Finally, the isolated particles were examined visually using a stereomicroscope and FTIR-ATR spectroscopy.

***Fish sample extraction and isolation**.* The collected 18 fish samples, 9 pieces of *O. niloticus* from freshwater fishponds, and 9 pieces of *C. chanos* from marine cages were washed, dissected and extracted in the laboratory. The gut was collected, placed in glass jars, and stored at low temperatures for subsequent MP analysis. A wet digestion procedure was carried out in the fish gut by introducing 100 mL of 1M sodium hydroxide (NaOH) in a 1-L beaker (Catarino et al 2017), then it was put in a laboratory oven at 60°C for 8 hours (Bilugan et al 2021). This was followed by incubation for 24 hours at room temperature. In the process of density separation, 200 mL of a saturated NaCl solution (30 g per 100 mL) was added. The samples were thoroughly mixed and stirred using a stirring hotplate, and left undisturbed overnight to facilitate the separation of tissue from denser plastic debris. Following an overnight density separation, the samples were subjected to vacuum filtration using a 47 mm GF/C filter. After filtration, the filter papers were stored in clean Petri dishes, which were securely covered with lids. Subsequently, the samples underwent visual examination through a stereomicroscope, and FTIR-ATR spectroscopy was employed for comprehensive characterization and identification purposes.

***Characterization of microplastics**.* MPs were characterized based on the description of Hidalgo-Ruz et al (2012) and Espiritu et al (2019) as presented in Table 1. The MPs were photographed and analyzed using a 40x magnification stereomicroscope (Hitachi, Japan) at the Analytical and Biotechnology Center of CLSU. High-resolution images were acquired from the water, sediment, and fish gut samples collected at the two aquaculture environments. Then, the samples were transferred to a sample carrier for FTIR analysis using Perkin-Elmer Spectrum II FTIR. FTIR spectroscopy was used to identify functional groups associated with polymer chemical properties. Samples were analyzed using Attenuated Total Reflectance (ATR) and scanned per analysis (Saipolbahri et al 2020). FTIR-ATR spectroscopy is commonly used to identify MP polymers (Arcadio et al 2023); the identification of polymer types in isolated MPs was done at the DOST-Advanced Device and Materials Testing Laboratory (ADMATEL).

Table 1

Characterization of the microplastics following the procedure of Hidalgo-Ruz et al (2012) and Espiritu et al (2019)

Characterization	*Description*
Type	Plastic fragments, pellets, filaments, plastic films, foamed plastic, granules, and Styrofoam.
Shape	For pellets: cylindrical, disks, flat, ovoid, spheruloids; For fragments: rounded, subrounded, subangular, angular; General: irregular, elongated, degraded, rough, and broken edges.
Color	Transparent, crystalline, white, clear-white-cream, red, orange, blue, opaque, black, gray, brown, green, pink, tan, yellow, and pigmentation.

***Quality control procedure**.* Contamination of samples was a common problem during collection and processing, often caused by factors such as atmospheric fallout, unsterilized equipment, or contaminated glassware or cloths. To obtain accurate results, it was crucial to take preventive measures against contamination (Tirkey & Upadhyay

2021). During the sampling period, all samples were carefully placed in containers that were sealed properly, labeled accurately, and then kept on ice to maintain their quality. To minimize the risk of sample contamination, all tools and materials used for the dissection, digestion, and processing of samples were made exclusively of stainless steel, glass, or ceramic (Cabansag et al 2021). To minimize contamination in the workplace, alcohol was used to clean work surfaces, and lab coats, cotton clothing, and gloves were worn. Hands and forearms were scrubbed, and laboratory materials were washed thoroughly, rinsed multiple times with distilled water, and finally air-dried in an inverted position. When not in use, they were kept inverted (Lusher et al 2016). During microscopy, all the dried samples to be analyzed were kept covered in glass Petri dishes (Arcadio et al 2023). As for the transport of MP samples for analysis, the GF/C filter was kept in a covered glass Petri dish and placed in a sealed specimen container.

Data analysis. The frequency of MPs in water was calculated by dividing the number of MPs collected by the volume of the sample (no. items mL^{-1}). Likewise, the frequency of MPs in sediment and fish was expressed as no. items g^{-1} and no. items pc^{-1}, respectively. The data collected involved a descriptive analysis of MPs based on types, shapes, and colors, by calculating frequencies and percentages. The significant differences in the MPs present in water, sediment, and fish samples collected among the two aquaculture fish farms were analyzed by the Independent Sample T-test. Significant differences were recorded at $p \leq 0.05$. The statistical tool used was STAR 2.0.1.

Results. The results in Figure 4 illustrate the average concentrations of microplastics (MPs) in water, sediments, and fish in both freshwater fishponds and marine cages. The mean concentrations, along with standard errors (SE), highlight notable differences between the two environments. Marine cages have slightly higher MP concentrations in water (69.5±43.17 items mL^{-1}) compared to freshwater fishponds (58.67±22.01 items mL^{-1}). Sediment MP concentrations are similar between the two systems: 51.92±27.87 items g^{-1} in freshwater fishponds and 51.67±23.77 items g^{-1} in marine cages. The most significant difference is in fish, with marine cages showing a much higher MP concentration (168±94.00 items pc^{-1}) than freshwater fishponds (108.17±44.23 items pc^{-1}).

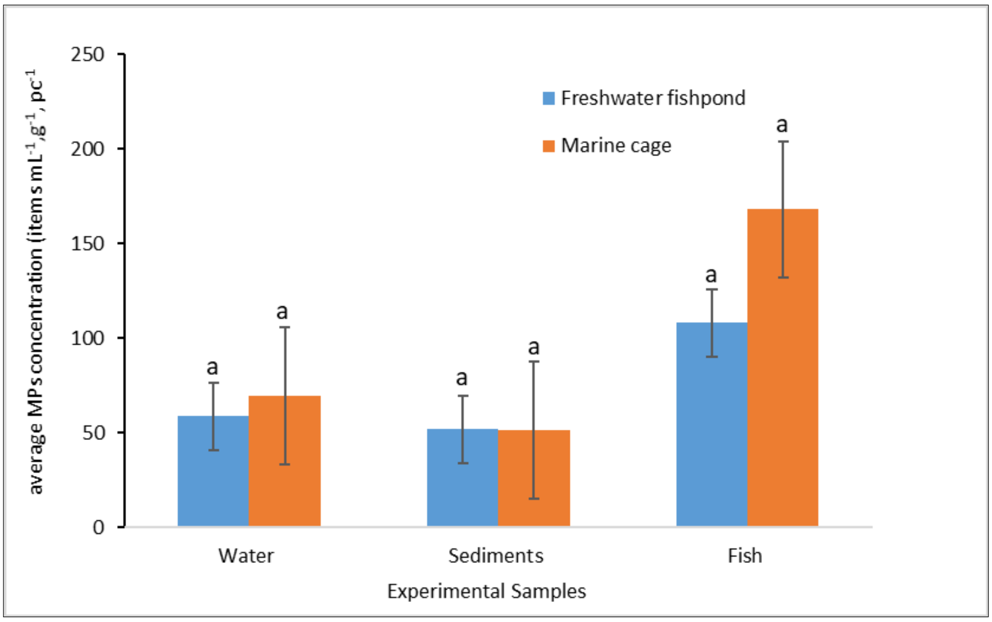

Figure 4. The average (mean±SE) concentration of MPs in water, sediments, and fish under the two aquaculture systems.

Types of microplastics in freshwater fishponds and marine cages. The results in Figure 5 presented the frequency of different types of MPs in marine cages and freshwater fishponds across three samples: water, sediments, and fish. In both environments, fragments and fibers dominate, with marine cages exhibiting a higher overall frequency, particularly in fish samples. Fibers were notably more prevalent in marine cages, particularly in fish samples (63.22 items pc^{-1}), compared to freshwater fishponds (12.78 items pc^{-1}). In freshwater fishponds, fragments were the most prevalent type of MPs found in water, sediments, and fish samples, with frequencies of 7.6 items mL^{-1}, 9.28 items g^{-1}, and 35.44 items pc^{-1}, respectively. This pattern was also observed in marine cages, where fragments were also abundant, but with slightly higher frequencies in fish samples (36 items pc^{-1}). Filaments, pellets, and plastic foam were generally found in lower frequencies across both environments.

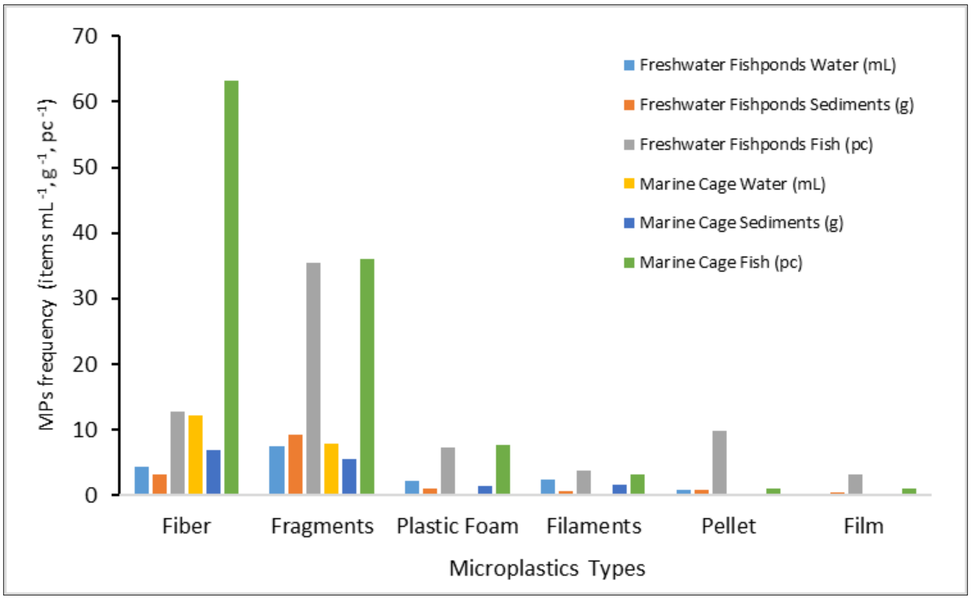

Figure 5. MPs frequency based on type in water, sediments and fish at two aquaculture systems.

MPs shape in the freshwater fishponds and marine cages. The results in Figure 6 illustrate the frequency of different shapes of MPs in water, sediment, and fish samples from both freshwater fishponds and marine cages revealing significant differences.

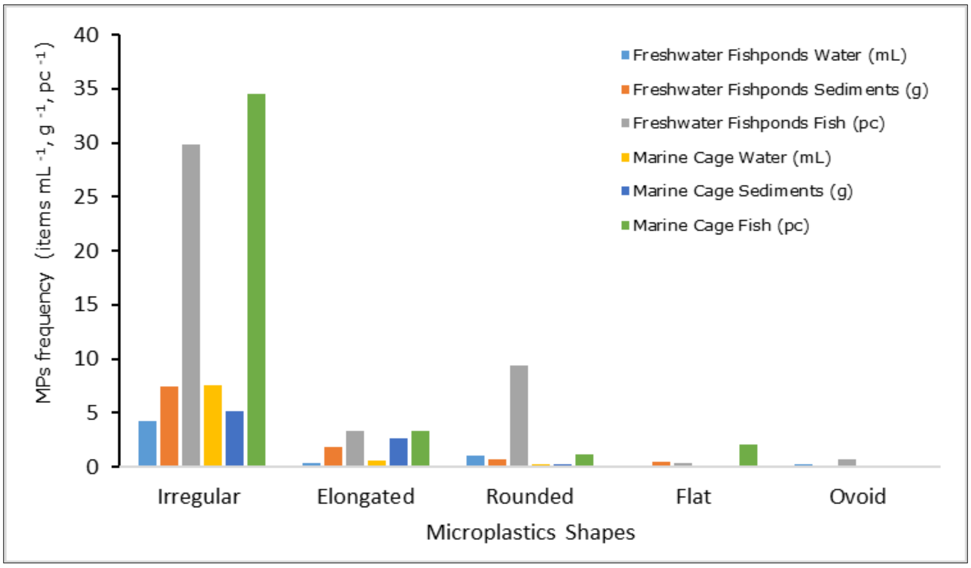

Figure 6. MPs frequency based on shapes in water, sediments and fish at two aquaculture systems.

In freshwater fishponds, irregular-shaped MPs dominate across all sample types, particularly in sediment (7.40 items g^{-1}) and fish (29.78 items pc^{-1}). In marine cages, irregular MPs are most dominant, particularly in fish samples (34.56 items pc^{-1}). Elongated and rounded MPs are found in lower frequencies in both environments, with the highest concentration of elongated MPs in marine cage sediments (2.7 items g^{-1}) and highest rounded MPs in freshwater fish (9.33 items pc^{-1}). Flat and ovoid MPs are the least common across both systems.

Colors of MPs in freshwater fishponds and marine cages. The results in Figure 7 illustrate the frequency of MPs by color in water, sediment, and fish samples from freshwater fishponds and marine cages revealing distinct differences in their distribution. In freshwater fishponds, black MPs are predominant in fish samples (18.78 items pc^{-1}) and water (4.7 items mL^{-1}), while white are also significant in sediment samples (7.93 items g^{-1}). In marine cages, white MPs are the most prevalent across all sample types, particularly in fish (47.78 items pc^{-1}), water (9.2 items mL^{-1}) and sediments (8.55 items g^{-1}), respectively. The presence of other colors, such as blue, red, orange, and more other colors like gray, white cream, brown, green, yellow and pink is notable but in lower frequencies compared to black and white MPs.

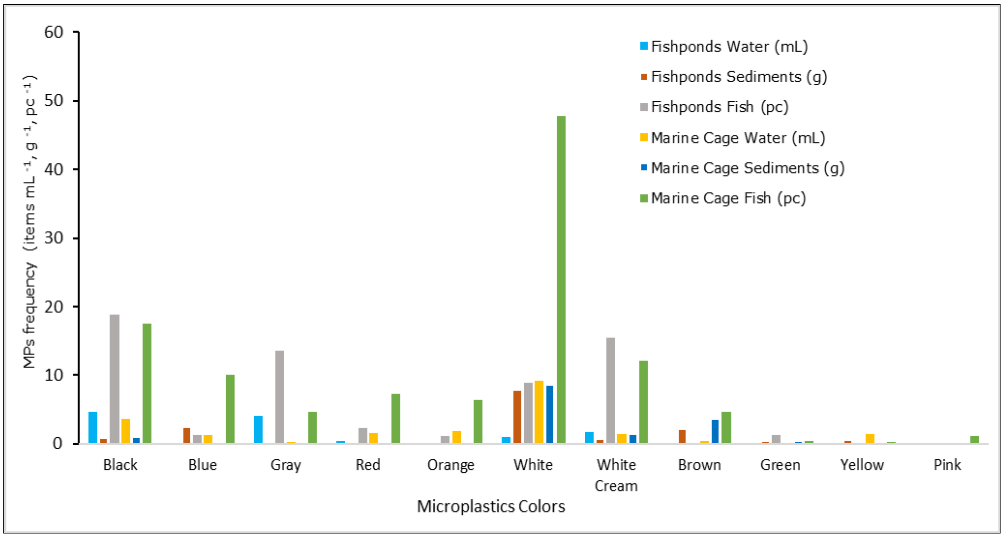

Figure 7. MPs frequency based on colors in water, sediments, and fish at two aquaculture systems.

Polymer identification of microplastics. Polymers were identified by FTIR analysis, and the selected suspected MPs are rayon (RY), polyethylene (PE), and polypropylene (PP) in freshwater ponds (Figures 8, 9, and 10). Polypropylene (PP) and nylon (Figures 11 and 12) were identified in marine cages in the water, sediments, and fish, respectively.

Comparison of the two aquaculture systems. The independent t-test results in Table 2 show no significant difference in the mean concentrations of MPs between freshwater and marine environments for water ($p = 0.7107$), sediments ($p = 0.9862$), and fish ($p = 0.3270$) in the 0.05 level of significance. This suggests that MP pollution levels are comparable in both environments, despite slight variations in mean frequency concentrations. These findings highlight the pervasive nature of MP pollution across different aquatic environments and the need for targeted mitigation efforts.

Table 2

Results of independent t-tests comparing MP concentrations

Samples	*Mean±SE*		*p-value (0.05)*
	Freshwater	*Marine*	*Independent t-test*
Water	0.98±0.24	1.16±0.42	0.7107
Sediment	0.87±0.3	0.86±0.23	0.9862
Fish	12.02±3.2	18.67±5.84	0.3270

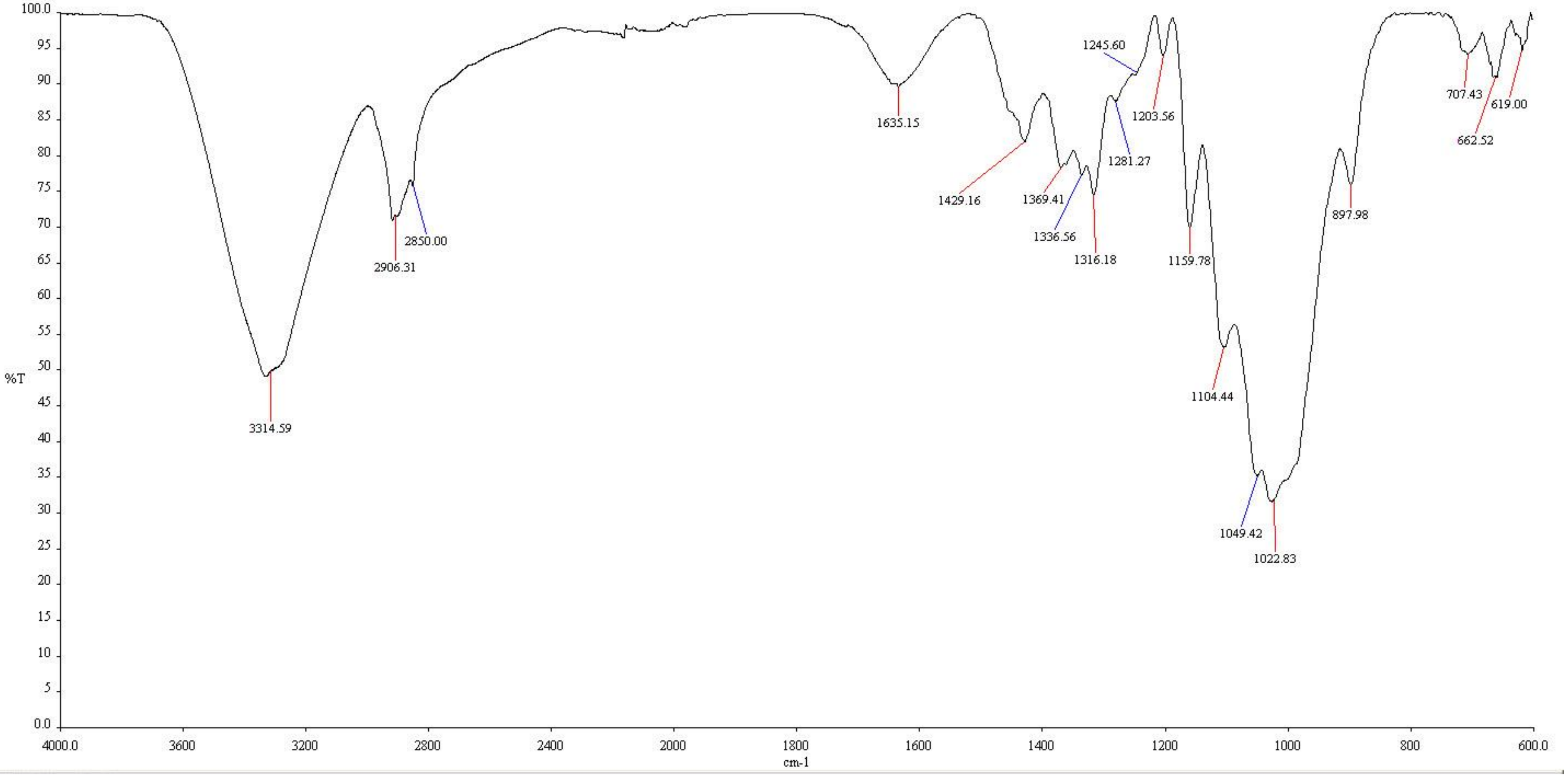

Figure 8. FTIR spectrum of rayon polymer identified from suspected MPs in freshwater fishponds.

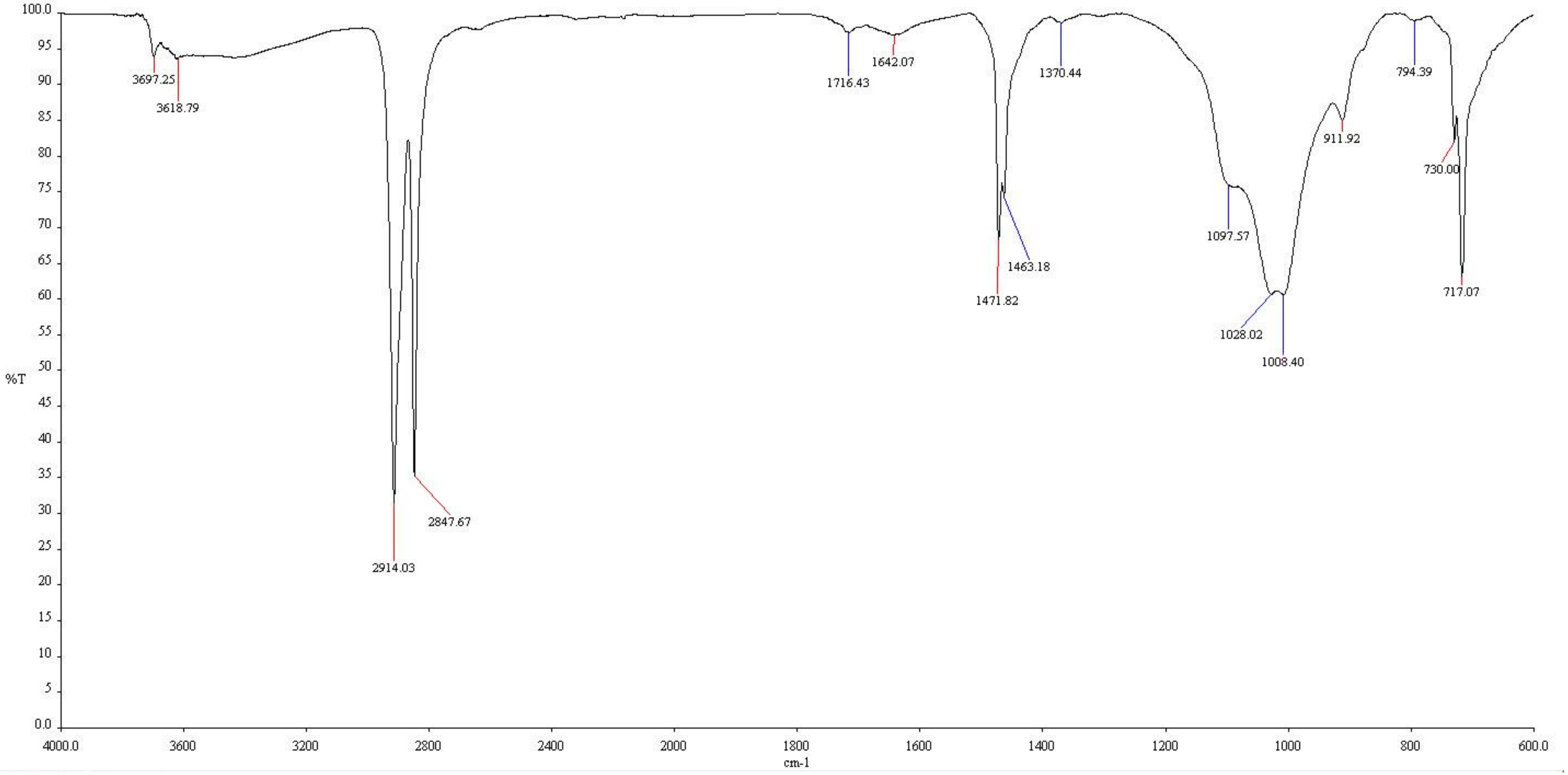

Figure 9. FTIR spectrum of polyethylene identified from suspected MPs in freshwater fishponds.

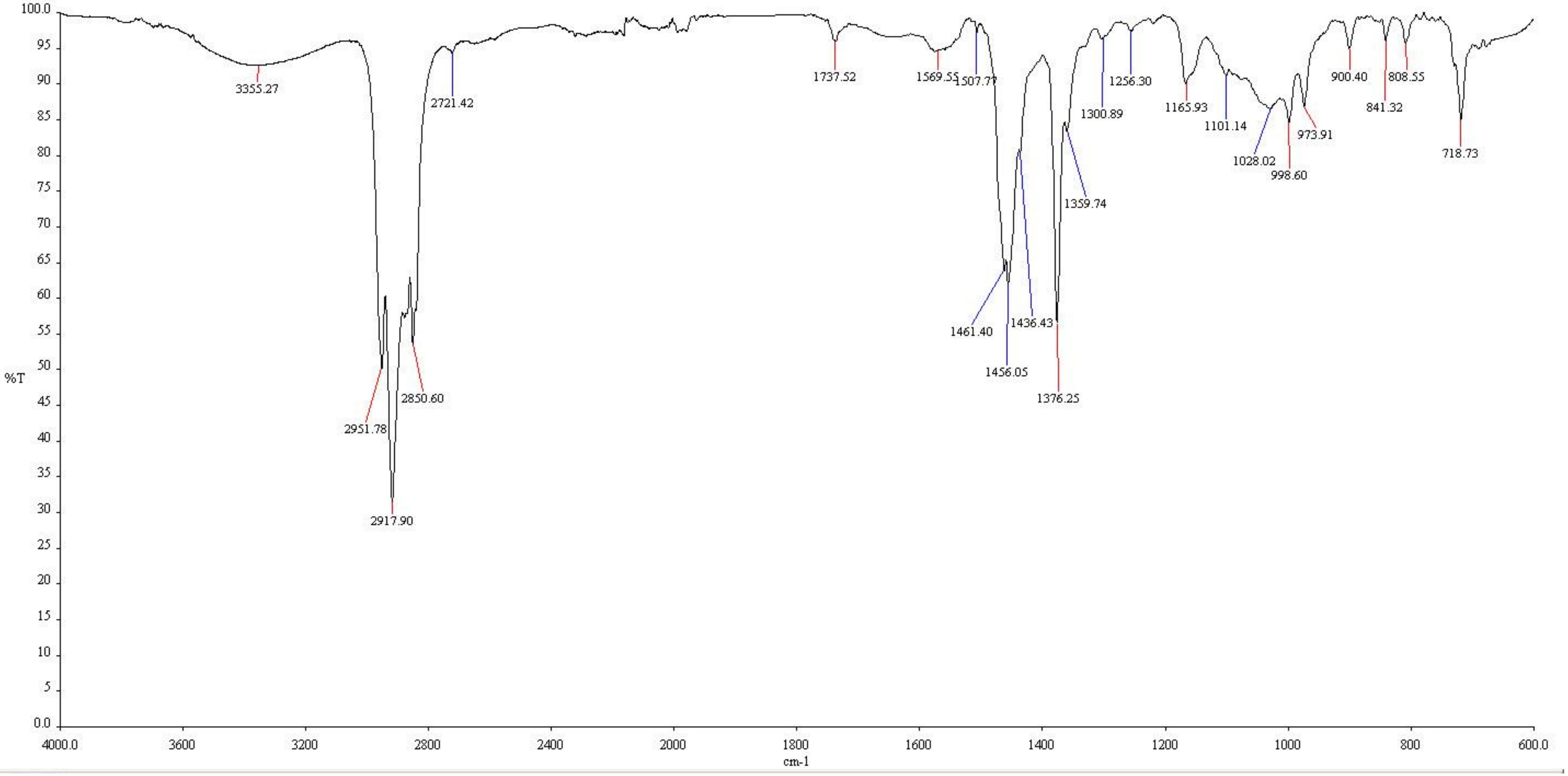

Figure 10. FTIR spectrum of polypropylene identified from suspected MPs in freshwater fishponds.

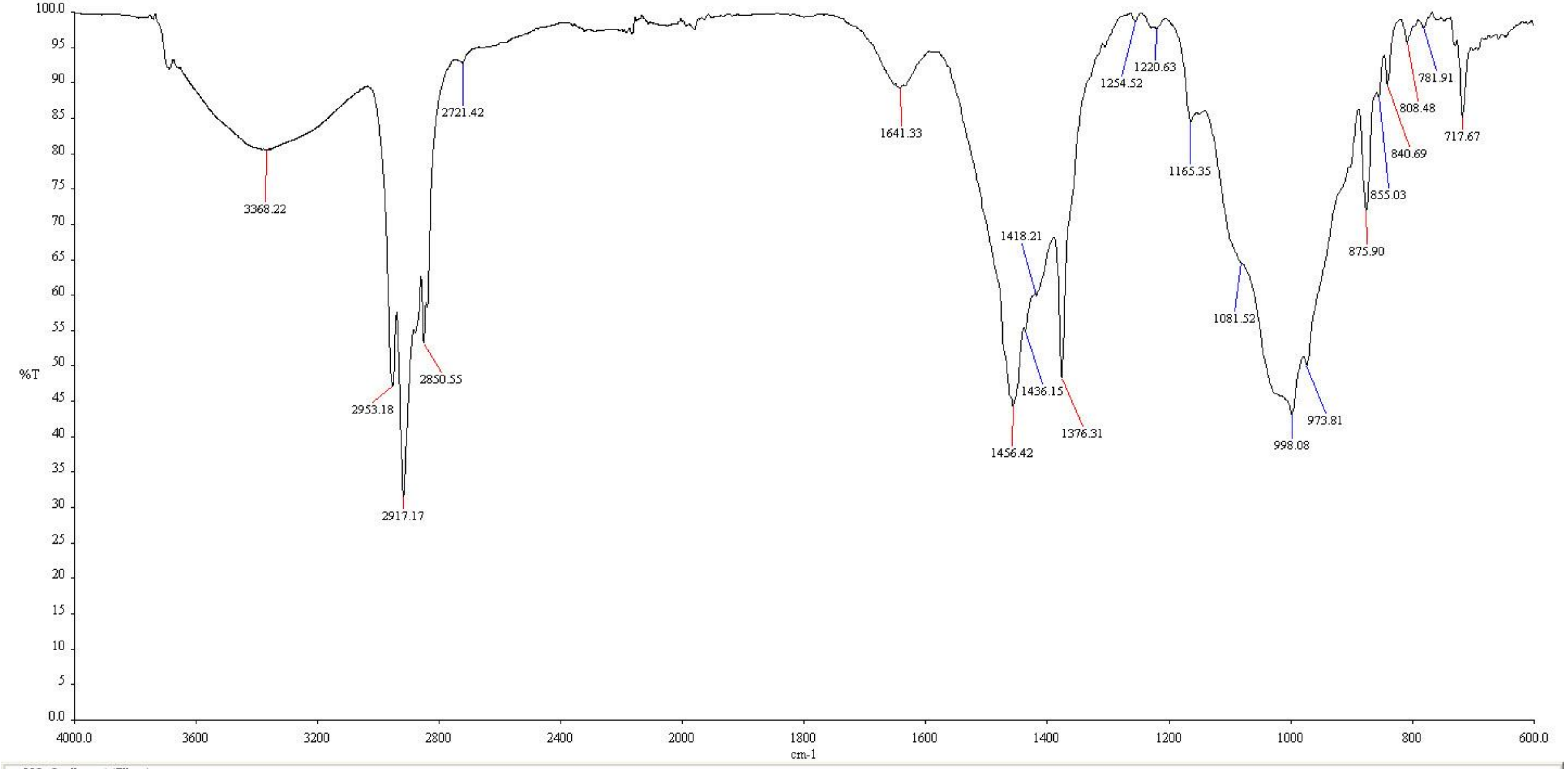

Figure 11. FTIR spectrum of polypropylene polymer identified from suspected MPs in marine cages.

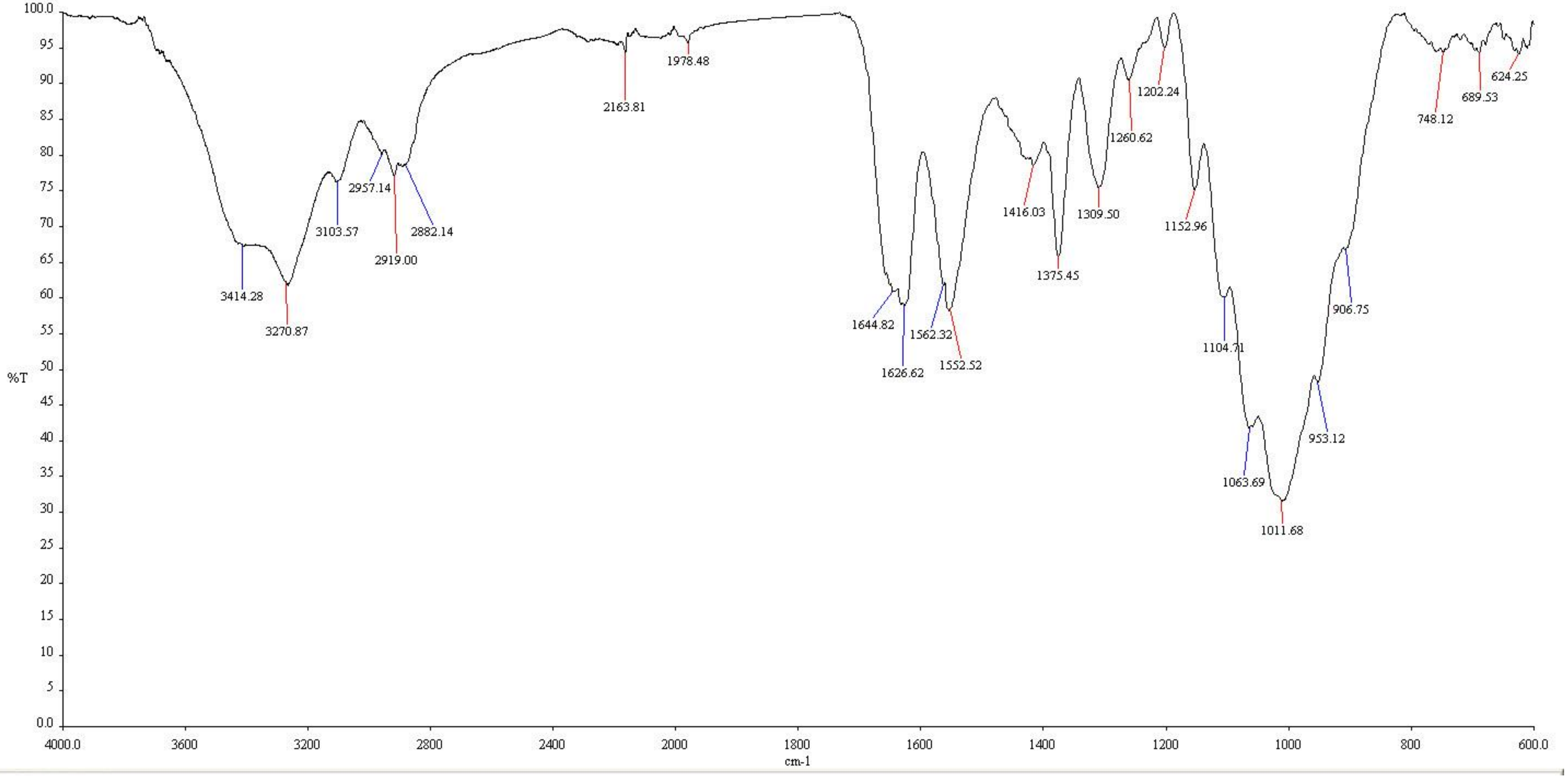

Figure 12. FTIR spectrum of nylon polymer identified from suspected MPs in marine cages.

Discussion. Plastic pollution is a significant global concern that affects aquatic environments and species. The Philippines is one of the top sources of plastic waste, contributing 8.8% to global marine pollution (Meijer et al 2021). Microplastics (MPs) found in water and sediment can pose a threat to organisms, particularly fish that consume them, due to their different types, shapes, and colors. Furthermore, these small plastic particles, less than 5 mm in size, may enter the human food chain and have harmful effects on human health (Chen et al 2021).

The analysis of MP concentrations in freshwater and marine aquaculture systems highlights similar levels in both water and sediments, suggesting common sources such as runoff from agricultural activities, commercial, tourist, and household areas, and atmospheric deposition (Li et al 2018; Pothiraj et al 2023). Additionally, according to Bordós et al (2019) sediments indicated that freshwater fish ponds may act as a deposition area for MPs. The higher concentration of MPs in milkfish from marine cages indicates potential for accumulation in marine environments compared to freshwater fishponds. This is supported by previous studies by Wang et al (2020), suggesting that marine organisms are more vulnerable to ingesting MPs due to their diverse feeding habits and the pervasive presence of MPs in marine water. Similarly, studies by Avio et al (2017) and Fareza & Sembiring (2020) found high concentrations of MPs in milkfish from marine cages in coastal regions, emphasizing the significant impact of marine plastic pollution. On the other hand, a study by Martinez-Tavera et al (2021) observed notable levels of MPs in Nile tilapia in freshwater fishponds, although the concentrations were lower than those in marine environments. Additionally, it is important to note that single-use plastic waste can accumulate in cultured fishponds (Li et al 2020) due to the facilities being located near household areas. These studies collectively highlight the widespread issue of MP pollution in aquaculture and its potential impacts on aquatic life and human health (Chen et al 2021; Similatan et al 2023).

The MP types found in the water, sediments, and fish varied from fragments, filaments, plastic foam, and fiber (a, b, c, d respectively) shown in Figure 10 are the common dominants in both aquaculture systems (freshwater fishponds and marine cages). This study found fibers were notably more common in marine cages, particularly in fish samples, indicating the accumulation of plastic debris transported by ocean currents was highlighted as a significant contributor to the higher exposure to synthetic textiles in marine environments. The study emphasized the impact of various marine activities, such as fishing and shipping, as well as waste disposal and the conversion of coastal areas into private resorts and restaurants. These findings are consistent with previous research by Barrows et al (2018), which identified clothing and fishing gear as common sources of MPs in marine ecosystems. Additionally, high levels of fibers were also detected in freshwater fish (Nile tilapia), similar to the results of Martinez-Tavera et al (2021), where identified potential pathways for microplastics (MPs) infiltrating aquaculture facilities encompass wastewater, pipe-borne water, fishing gear, and aquafeed (fishmeal) (Iheanacho et al 2023). In both freshwater fishponds and marine cages, there is a significant presence of plastic fragments. Recent studies have indicated that these fragments are the predominant form of microplastics in aquatic environments. This is attributed to the breakdown of larger plastic items and can be linked to diverse potential sources (Espiritu et al 2019). Probably due to the existing tourism activities, some of the plastics were also degraded from plastics used by fishermen to capture fish or sell their goods (Saipolbahri et al 2020). The difference in pollution and water management practices may explain the lower presence of filaments and plastic foam in marine cage water samples compared to freshwater fishponds. The high frequency of pellets in fish samples from freshwater fishponds is likely due to the proximity of the fishponds to residential areas. Pellets or microbeads originate from various personal care products such as toothpaste, shower gels, or exfoliates. These small items could have settled into the sediments over time (Cabansag et al 2021).

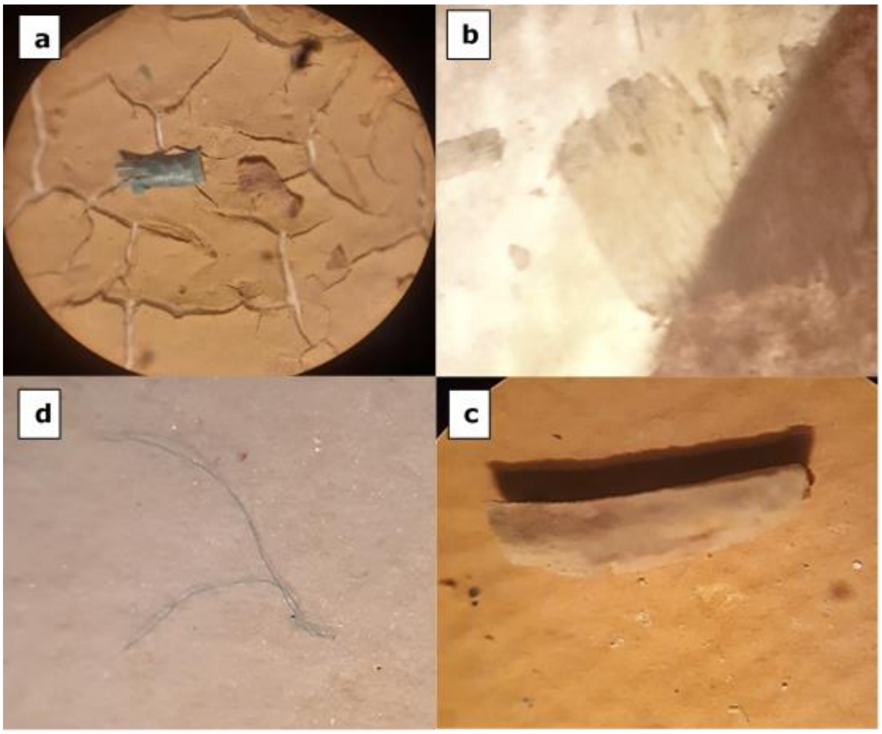

Figure 10. MPs type – fragments (a), filament (b), plastic foam(c), and fiber(d) found in the water, sediments, and fish samples under the 40x magnification stereomicroscope.

The distribution and frequency of MPs by shape reveal significant differences between freshwater fishponds and marine cages. The presence of irregular-shaped MPs in both environments is consistent with recent studies, which have shown that the breakdown of larger plastic debris is a major source of MPs in aquatic systems (Wang et al 2020; Pothiraj et al 2023). The higher frequency of irregular-shaped MPs in marine cage fish samples (34.56 items pc^{-1}) suggests a greater exposure or ingestion rate in marine environments, potentially due to higher levels of plastic pollution in marine waters (Zhu et al 2019), as compared to freshwater fishponds (13.40 items pc^{-1}), where the fragmentation is attributed to the degradation of plastic wastes from aquacultures such as the use of fishing equipment, factory farming facilities, natural and synthetic feed, animal health products, aquaculture fortifiers, and aquatic food additives (Zhou et al 2021). Elongated MPs, including fibers and filaments, were found in both environments but in varying concentrations. Freshwater fishponds had high frequencies of elongated MPs in sediments (2.23 items g^{-1}) and fish (1.50 items pc^{-1}). This variation could be attributed to differences in waste management practices and the types of activities surrounding the aquaculture sites, which is similar to the study of Ding et al (2019). Marine cages showed a higher frequency of fibers in fish samples (3.33 items pc^{-1}), which indicates the widespread issue of fiber pollution from clothing from hotels and resorts, and fishing gears and mariculture facilities in marine environments (Barrows et al 2018; Cabansag et al 2021). Rounded MPs were found to be more prevalent in freshwater fishponds (2.78 items g^{-1} in sediments and 4.20 items pc^{-1} in fish) compared to marine cages, potentially due to different sources of plastic pollution such as pellets. Conversely, flat MPs were minimal in both environments, indicating limited sources or slower degradation. This observation aligns with previous studies demonstrating the influence of MP shapes on their environmental impact.

The distribution of MPs by color highlights potential sources and behaviors of plastic pollution in different aquaculture environments. In freshwater fishponds, the predominance of black MPs, particularly in fish samples, suggests sources related to aquaculture activities like feeding practices, materials used in water pumping, and fishing gears used, which are common pollutants in freshwater systems (Li et al 2018; Wu et al 2023). The moderate frequency of gray MPs in fish and water samples may also indicate the degradation of consumer plastic products and wastes commonly used in nearby communities. According to Xiong et al (2021), a variety of colored MPs have been found in freshwater fishponds, highlighting the various sources of plastic pollution impacting these environments. In marine cages, the high-frequency levels of white MPs are significant, particularly in fish (47.78 items pc^{-1}) and water (9.2 items mL^{-1}). This points to the widespread problem of plastic packaging waste and fishing gear debris, which are major contributors to marine plastic pollution (Wang et al 2020). The presence of white MPs in marine environments aligns with global observations of high levels of white plastic pollution, primarily due to their prevalent use in packaging and fisheries (Lyu et al 2020). The differences in the frequencies of blue, red, and orange MPs in freshwater and marine aquaculture systems highlight differences in local sources of pollution. For instance, the high frequency of blue MPs in milkfish (10.11 items pc^{-1}) compared to tilapia (1.22 items pc^{-1}) may be linked to the breakdown of fishing nets and ropes commonly used in marine aquaculture. Fishing-related waste can also be a potential source of colorful fibers (Sajorne et al 2022). The presence of red and orange MPs, although less frequent, suggests contributions from colored plastic products and industrial activities (Zhu et al 2019). The lower frequency of certain colors such as green and pink MPs reflects their less common usage in products that eventually end up in aquatic environments.

The FTIR analysis of MP samples from freshwater fishponds and marine cages revealed the types of polymers present and their likely sources. This analysis is crucial for understanding MP pollution’s origins and potential impacts in these aquaculture environments. In the freshwater fishponds, rayon fibers were detected in the water samples, indicating contamination from textile waste, likely domestic sewage from the hotels and resorts near the cages. This aligns with the findings by Peng et al (2020) and Huang et al (2022), who emphasized that rayon was widely present in recirculating aquaculture systems and other aquatic environments. Moreover, polyethylene fragments were discovered in the sediments, indicating pollution from household and aquaculture items such as bottles, packaging, plastic bags, and polyester fibers. The abundance of microfragments is also influenced by polyethylene plastic bags, as heat can rapidly degrade these materials into fragments (Limbago et al 2021). Polypropylene fibers were identified in the fish samples, implying that fish are ingesting MPs that may originate from household waste and agricultural sources. In the marine cages, polypropylene fragments were detected in the water samples, reflecting contamination and possibly sourcing from the nearby fishing port at the study site and other fishing activities, and the sources could be the residue of rope and utilization of fishing gear (Saipolbahri et al 2020) in the marine cages. Both water and sediment samples from marine cages contained polypropylene, indicating significant pollution from similar sources. Additionally, nylon fibers were identified in marine fish samples, suggesting MP ingestion from fishing equipment debris. This observation aligns with Welden & Cowie (2017), who reported the impact of lost and discarded fishing gear on marine wildlife (Lusher et al 2016).

The statistical analysis indicates significant differences in the frequencies of MPs in water, sediments, and tilapia in freshwater fishponds. These differences are due to the various feeding practices of the fishpond owners, such as mixed feeding and fully complete feeding, as well as the use of plastic materials in aquaculture facilities. Similarly, there are significant differences in the frequencies of MPs in water, sediments, and milkfish at mariculture sites, which can be attributed to tourism destinations and environmental deposition influenced by sea currents and waves. The higher concentration of MPs in marine cage water, in comparison to freshwater, implies a greater exposure to external MP sources, such as ocean currents and coastal runoff. This aligns with the findings of Pothiraj et al (2023), who also reported higher MP contamination in marine environments. Sediment concentrations in both environments are similar, indicating comparable deposition processes. The significantly higher levels of MP in fish from marine environments suggest greater bioaccumulation, as supported by studies such as Wang et al (2020), which demonstrate greater MP bioaccumulation in marine organisms. Conversely, according to Bordós et al (2019), fish ponds may serve as deposition areas for MPs.

In the Philippines, research by Sajorne et al (2022) and Gabriel et al (2023) support these findings. They found that pollutants such as microplastics, or having baseline data documented in the current study, will help achieve the sustainable development goal. The data from this study will help in developing new prevention strategies or updating current policies based on scientific evidence. This emphasizes the need for targeted mitigation strategies (Pham et al 2022). The pollution of MPs can be reduced by implementing a proper regulatory framework. It is the responsibility of individuals and organizations to ensure that regulations are enforced to protect ecosystems from the negative effects of plastic litter (Sarma et al 2022).

Conclusions. The study used isolation and extraction processes to identify significant frequencies of MPs in both freshwater fishponds and marine cages. This study provides substantial data and information on MP pollution in freshwater fishponds and marine cages in Baler, Aurora. The results reveal that marine cages have higher MP concentrations in water and fish than freshwater fishponds, with similar concentrations in sediments. These MPs originate from various sources in marine cages, including currents and waves, as well as fishing activities, particularly the sampling site, which is located near a fishing port and commercial and tourist destinations. In contrast, freshwater fishponds may be sourced from aquaculture facilities and materials. At the same time, the site is near household areas, so improper waste disposal can contribute to the occurrence of MPs in the fish culture area.

The analysis revealed that fragments and fibers are the predominant MP types in both systems, with fibers being more prevalent in marine environments. Irregular-shaped MPs mostly in black, white, or transparent colors are the most common in all sample types. The polymer analysis identified rayon, polyethylene, and polypropylene in freshwater systems and polypropylene and nylon in marine systems. Independent t-tests showed no significant differences in MP concentrations between freshwater and marine environments, suggesting that both aquaculture sites are affected by MP pollution. These results provide a basis for the comprehensive evaluation and development of practical approaches to deal with MPs in aquaculture ponds and cages, which is of great significance to the healthy development of ponds and cages aquaculture. Finally, the need for establishing micro FTIR imaging for accurate analysis and identification of MPs is also suggested for future research.

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