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Impact of the COVID-19 outbreak on the microplastics in fishery harbor: occurrence, composition, and potential risks

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Abstract

Microplastics (MPs) are recognized as a global environmental problem with wide-ranging ecological and human health implications. This study evaluated the occurrence, composition, and potential ecological risks of MPs in two fishery harbors in Taoyuan City, Taiwan, comparing data collected before and during the COVID-19 lockdown. MP concentrations generally declined in most sampling sites during the lockdown, yet localized spikes at sampling sites Zhuwei Fishing Harbor (FA)1 and Yongan Fishing Harbor 4 highlight the influence of site-specific activities. Additionally, we observed a shift toward smaller size fractions (25-50 μm) and a predominance of white/transparent fragments, suggesting ongoing plastic weathering and continuous MP inputs. Notably, rayon abundance decreased significantly, indicating reduced textile-related discharges, whereas polyethylene and polymethyl methacrylate (PMMA) emerged as key polymers, presumably linked to heightened reliance on delivery services and protective materials. A hazard-based risk assessment revealed that the emergence of PMMA elevated ecological risk at FA, underscoring the complex relationship between anthropogenic behaviors and MP pollution. Our findings emphasize the intricate dynamics of MP distribution and composition under altered socioeconomic conditions, demonstrating that even short-term shifts in human activity can reshape MP assemblages and associated risks. Targeted management strategies, particularly those addressing industrial, fishing, and consumer-sourced plastic inputs, are critical to mitigating the environmental impacts of MP contamination. Further work is needed to pinpoint specific MP sources, refine risk assessments for varying polymer types and sizes, and explore the long-term efficacy of interventions aimed at curbing plastic pollution. Collectively, these results reinforce the urgency of integrated policies and research to safeguard ecosystems.

Keywords: MPs, risk assessment, lockdown, COVID-19 pandemic, pollution characteristics

INTRODUCTION

Microplastic (MP) pollution has become a serious global environmental issue due to its ubiquitous existence and possible ecosystem threats[1-5]. In 2020, global plastic production reached 367 million tons, with an estimated 4.8-12.7 million metric tons discharged into the marine environment[6]. The prevalence of MPs in the marine environment poses several threats to marine organisms and their habitats. Larger marine animals, in particular, have been reported to suffer from entanglement, choking, malnutrition, and even premature death as a result of encounters with large plastic debris during feeding and locomotion[7,8]. In addition to the physical hazard, the hydrophobicity of plastics has been related to the metabolic transfer of many organic pollutants, including persistent organic pollutants and contaminants of emerging concern that adsorb to the surface of these MPs[9-14].

MPs have also been reported to directly or indirectly affect human health by acting as vectors of environmental contaminants or physical stressors[15-17]. Recently, MPs were detected in human blood samples and lungs, demonstrating that MP particles are bioavailable for uptake into the human bloodstream and human lung tissue. In addition, the particle toxicity of MPs is affected by their size and shape. The toxicity of non-spherical MPs, such as fibers and fragments, is relatively higher than that of spherical MPs[15,18,19]. According to the research by Gray and Weinstein[20], MPs smaller than 50 μm were less toxic to shrimp samples than those larger than 50 μm.

Recently, we have all been severely affected by the more or less extensive lockdowns, quarantines, smart working, and the closing of a wide variety of recreational and personal care activities due to the COVID-19 pandemic, which has not only drastically changed our habits and behaviors but also had consequences on the release of several types of pollutants[21-28]. Furthermore, lockdowns and quarantines have compelled and continue to confine many individuals to remain at home, thereby influencing their behaviors in ways that impact plastic release, including activities such as cooking, engaging in sports, and laundering clothes. A tremendous increase in the use of plastic personal protective equipment such as facemasks, gloves, protective suits, hand-sanitizer bottles, and medical test kits, most of which are one-time-use products that can be improperly disposed of and left in the environment. Benson *et al.*[29] reported that China and India have the highest daily facemask disposal rates in the world, at approximately 700 million and 400 million masks per day, respectively, followed by Russia, Germany, the United Kingdom, France, and Italy. The potential hazard to aquatic ecosystems and organisms resulting from improper disposal of plastic personal protective equipment such as facemasks, has been demonstrated by several studies[28,30-32]. To date, numerous articles have focused on the increased utilization of plastic products and subsequent plastic pollution during the pandemic[23-28,33-36]. However, limited research has addressed the characteristics of MPs in fishery harbors before and during the lockdown period[32].

This study provided insights into the impacts of the COVID-19 outbreak on the composition and distribution patterns of MPs in fishery harbors in Taiwan. The abundance, compositional patterns, morphology, size and color distribution, and potential risks associated with MPs in the surface water of fishery harbors were compared between the pre-lockdown and lockdown periods. Understanding MP pollution in fishery harbors is crucial for exposure assessment. In Taiwan, this issue is particularly pressing given that seafood constitutes a high proportion of the local diet[37]. MP contamination in coastal waters can thus directly translate into human exposure via the consumption of contaminated fish and shellfish[38]. For instance, a recent study estimated that Taiwanese seafood consumers might ingest thousands of MP particles annually through their normal diet[37]. Furthermore, marine wildlife in and around polluted harbors are likewise at risk: MPs are ingested by a wide range of organisms, from planktonic larval fish to adult fish and shellfish[38,39]. Such ingestion not only threatens wildlife health but also indicates that MPs can bioaccumulate and transfer through the food web, potentially reaching human consumers. These exposure considerations underscore the importance of investigating MP pollution in harbors within a human and ecological health context.

MATERIALS AND METHODS

Study area and sampling strategy

This study was conducted at two fishery harbors in Taoyuan City, Taiwan: Zhuwei Fishing Harbor (FA) and Yongan Fishing Harbor (FB) [Figure 1]. Both harbors were selected due to their diverse anthropogenic pressures, including fishing, recreation, industrial activities, and market operations, which potentially influence MP occurrence. Four sampling sites were established at each harbor (FA1-FA4, FB1-FB4) to capture spatial variability in MP distribution. FA1 is characterized by intensive fishing practices, including the use of synthetic nets and monofilament lines that can contribute fragments of nylon or polyethylene (PE). These activities are often accompanied by routine net repairs and occasional disposal of damaged gear. FA2 is located near a light industrial area, including plastic packaging and fish processing facilities, which may generate PE and polypropylene (PP) residues. In particular, secondary MPs can arise from material handling, transport, and wastewater discharges associated with these industries. FA3 is adjacent to fishing boat docks, where ropes, nets, and operational debris could introduce a variety of polymers (e.g., polyester, nylon). FA4 is situated near a bustling fish market, where single-use plastic packaging and polystyrene foam boxes are frequently utilized for preserving and transporting seafood. Poorly managed waste can break down into fragments, contributing to local MP pollution. Similarly, FB1 is situated near a seaside park, relatively distant from industrial operations, thus serving as a baseline reference point with lower anthropogenic input. FB2 was influenced by fishing activities, including the deployment of synthetic nets, lines, and other gear that can produce fiber- or fragment-type MPs. FB3 is exposed to both fishing and fish market operations, leading to polymer inputs from gear, packaging films, and containers. FB4 is positioned adjacent to an industrial cluster, including processing and manufacturing units. Potential discharges from these facilities, such as plastic waste and by-products, can introduce diverse polymers (e.g., PE, PP, and polystyrene) into the harbor environment. Surface water samples were collected in two periods: before lockdown (October to December 2019) and during lockdown (October to December 2020). Approximately 10 L of surface water was obtained at each site using a stainless-steel sampler, with three replicates collected per site. All solutions used in sampling and processing were filtered through a 5 μm filter. Glassware and stainless-steel containers were rinsed thrice with Milli-Q water to minimize contamination.

MP extraction and characterization

The ACS-grade sodium chloride (NaCl) and hydrogen peroxide (H_2O_2) solution employed in this research were acquired from Sigma-Aldrich (St. Louis, MO, USA). A Milli-Q water purification system, produced by Millipore (Bedford, MA, USA), was utilized to obtain deionized (DI) water for the study. MP extraction followed a modified protocol based on previous studies[40]. In summary, filter samples were kept in pristine

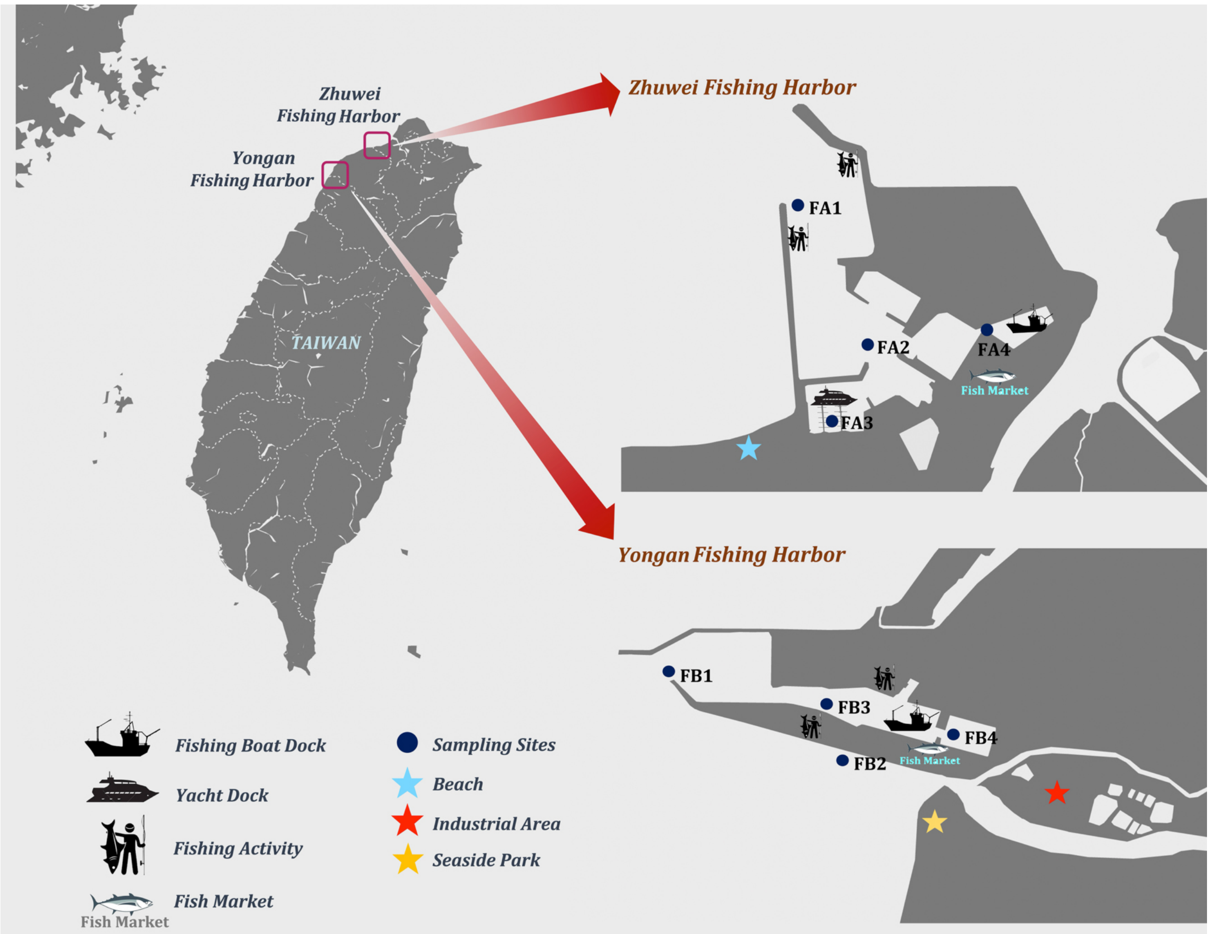

Figure 1. Study area and sampling sites. FA: Zhuwei Fishing Harbor; FB: Yongan Fishing Harbor.

glass containers and subjected to 30% H_2O_2 treatment at 65 °C for 24-48 h to eliminate organic matter. Following digestion, the samples underwent pretreatment with NaCl (1.20 g/cm^3) to enhance density, and were agitated for 4 h to ensure MP suspension. The resulting supernatants were filtered through 0.45 μm filter paper, placed in glass Petri dishes, and examined using a stereoscopic microscope (Olympus, IX83, Japan). Suspected plastic particles were identified on the filter, then photographed and measured to determine their maximum dimension. Particles ranging from 20-5,000 μm were enumerated. Established identification methods were employed to recognize and photograph potential MPs based on their morphology[41]. The suspected plastic particles were classified into five distinct shapes (fragment, film, fiber, microbead, foam) and three color categories (white/transparent, black, and others) according to their morphological characteristics. Subsequently, micro-Fourier transform infrared (μ-FTIR) spectroscopy (Shimadzu, AIM-9000, Japan) with attenuated total reflectance (ATR) mode was utilized to analyze all suspected particles (n = 1,628). Each scan comprised an average of 64 scans within the spectral range of 4,000-700 cm^{-1} at a resolution of 0.25 cm^{-1}. For this study, triplicate ATR-FTIR spectra were obtained from different areas of each suspected particle. All spectra were directly compared against the Shimadzu polymer library to confirm the polymer type. Matching ranges with a quality index of 70% or higher were deemed acceptable.

Quality assurance and quality control

To mitigate potential external contamination effects on results, stringent quality control measures were implemented. Precautions included using cotton lab coats, pre-cleaning sieves and sample bottles, and conducting all sample handling in a laminar flow cabinet to prevent airborne MP contamination. All solutions underwent filtration through a 5 μm pore size membrane prior to use. The study exclusively utilized glass containers, and all purified water was pre-filtered through glass fiber filters. Cross-checking for ambient contamination involved field and procedural blanks. Field blanks were executed by flushing the stainless-steel sampler with pre-filtered Milli-Q water and processing it identically to field samples during each sampling event. Pre-filtered Milli-Q water was chosen for blanks to avoid introducing contamination. The procedural blank involved subjecting pre-filtered Milli-Q water to the same processing and analysis steps as water samples. Both blank tests revealed no observable MPs, indicating negligible contamination from containers, lab environment, and processing. Furthermore, to assess the sample extraction recovery efficiency, the study employed a 0.3-1.0 mm size fraction of PE, polyethylene terephthalate (PET), and acrylonitrile butadiene styrene (ABS) granular particles (50 items/L) in water. Recovery rates were 99% for PE, 98% for PET, and 97% for ABS, confirming the reliability of the sample processing method.

Risk assessment

To evaluate the potential ecological risks posed by identified MP polymers, the hazard-based risk index (H) was calculated following the methods of Lithner *et al.*[42] and Li *et al.*[43]. The risk index was determined as:

$$H = \sum P_n \times S_n \tag{1}$$

where H denotes the computed MP risk index, P_n indicates the percentage of each MP polymer, and S_n is the hazard score assigned to each polymer type. The values of S_n and the corresponding risk categories for H are based on previous research by Lithner *et al.*[42].

Ecological risks associated with the detected MPs were further evaluated using a risk quotient (RQ) approach commonly applied in marine environments[44]. The RQ was calculated as:

$$\text{RQ} = \text{MEC}/\text{PNEC} \tag{2}$$

where measured environmental concentration (MEC) is the measured environmental concentration of MPs at each sampling site, and predicted no-effect concentration (PNEC) denotes the predicted no-effect concentration, below which adverse biological effects are unlikely. An RQ value less than 1 indicates negligible ecological risk, whereas an RQ value greater than 1 suggests a high potential risk, as environmental concentrations surpass the threshold considered safe for aquatic organisms.

RESULTS AND DISCUSSION

Occurrence of MPs before lockdown and during lockdown

MPs were detected at all four sampling sites in both FA and FB prior to and during the lockdown [Figure 2]. At FA, pre-lockdown concentrations ranged from 69.5 items/L at FA4 to 127.3 items/L at FA1, with FA2 (84.0 items/L) and FA1 (81.3 items/L) showing similar values. Notably, during the lockdown, FA1 exhibited a marked increase in MP abundance, rising from 81.3 items/L to 127.3 items/L, representing the only increase observed in FA. In contrast, FA2 displayed the most pronounced decrease, dropping from 84 items/L pre-lockdown to 22.3 items/L during the lockdown. Concentrations at FA3 (37 items/L) and FA4 (68 items/L) also decreased relative to pre-lockdown levels.

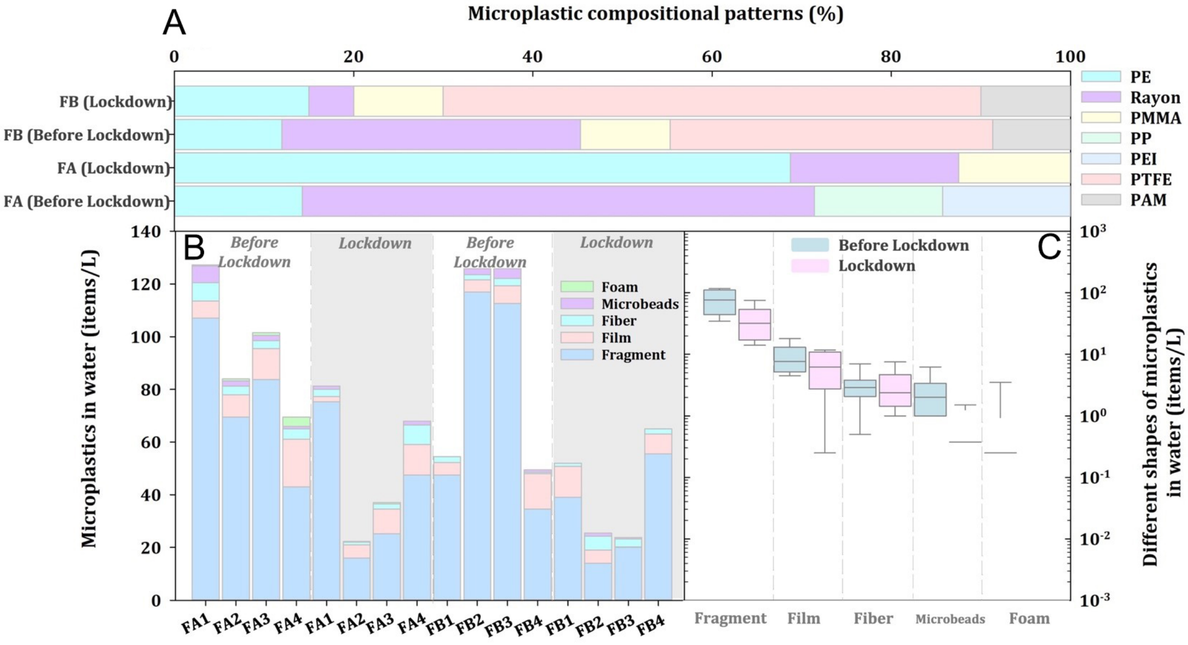

Figure 2. Occurrence of MP compositions and shapes in this study: (A) compositional patterns of MPs before lockdown (January) and lockdown (May); (B) the shape distribution of MPs at sampling sites before lockdown and during the lockdown; and (C) different shapes of MPs before lockdown and during the lockdown. FA: Zhuwei Fishing Harbor; FB: Yongan Fishing Harbor; MP: microplastic.

A similar pattern was observed at FB, where FB2 and FB3 initially recorded the highest pre-lockdown concentrations (125.6 items/L). FB4, however, had the lowest concentration prior to lockdown (49.5 items/L). Following the imposition of lockdown measures, MP concentrations at FB2 and FB3 declined sharply to 25.5 items/L and 23.8 items/L, respectively, whereas FB4 was the only site at FB to exhibit an increase relative to pre-lockdown levels.

Overall, these results suggest that MP concentrations in both harbors were not uniformly influenced by the lockdown, likely reflecting differences in local sources and hydrodynamic conditions. While these harbors do attract local visitors, particularly for leisure activities such as recreational fishing, strolling, or dining, our data indicate that the observed decrease in MP concentrations during the lockdown cannot be attributed solely to reduced tourism. Instead, we believe a combination of factors is responsible: (1) Reduced Human Activity: Local businesses and markets operating near the harbors experienced lower foot traffic and fewer daily activities due to lockdown measures. This likely curtailed the consumption and improper disposal of single-use plastics, thus diminishing point-source plastic inputs; (2) Changes in Fishing Operations: Fishing activities, along with the use and repair of plastic-intensive gear such as nets and lines, may have declined under lockdown restrictions. As a result, fewer discarded fragments or fibers would have contributed to the overall MP load in certain areas; (3) Spatial Variability and Hydrodynamics: Despite the overall trend of decreasing concentrations, sites like FA1 showed an increase in MP abundance. This discrepancy underscores the influence of localized anthropogenic activities, circulation patterns, and transport pathways. Even though fewer people might have visited certain sites for leisure, upstream or adjacent industrial processes may have continued, contributing additional MPs to some harbor zones.

Taken together, these findings suggest that decreased tourism was one factor among several that influenced local MP levels during the lockdown. The interplay of socioeconomic restrictions, site-specific activities, and hydrodynamic conditions likely shaped the heterogeneous patterns of MP distribution we observed. Additional investigation into potential land- and sea-based anthropogenic activities in each harbor may help clarify the temporal shifts observed.

Shape, size, and color distribution

The size distribution of MPs across both harbors was dominated by particles ranging from 25 μm to 50 μm before and during the lockdown [Figure 3A and B]. At FA, pre-lockdown MP size fractions were 3.56% (< 25 μm), 56.9% (25-50 μm), 27.5% (50-100 μm), 11.2% (100-300 μm), 0.72% (300-1,00μm), and 0.15% (1,000-5,000 μm). During the lockdown, the 25-50 μm fraction increased by 18.8 percentage points to 75.7%, whereas fractions < 25 μm, 50-100 μm, and 100300 μm declined slightly. Minor increases in the 300-1,000 μm and 1,000-5,000 μm fractions were also observed. At FB, the 25-50 μm size class likewise dominated before lockdown (67.6%), followed by 50-100 μm (25.1%), < 25 μm (2.76%), 100-300 μm (3.57%), 300-1,000 μ m (0.76%), and 1,000-5,000 μm (0.21%). During the lockdown, the 25-50 μm fraction rose to 77.2%, whereas the 50-100 μm fraction decreased by approximately 10.4 percentage points to 14.7%. Similar to FA, changes in other size categories were modest but indicated a slight shift toward smaller particle sizes (25-50 μm) during the lockdown.

Color characterization of MPs can offer insight into their origin and weathering processes[45] and may affect organismal intake[7]. In the present study, MPs were categorized as white/transparent, black, or other. Despite minor changes in color proportions during lockdown, white/transparent MPs consistently dominated in both harbors [Figure 3C and D]. At FA, white/transparent MPs ranged from 86.3% to 95.7% pre-lockdown, compared with 77.70% to 92.7% during lockdown. Black MPs ranged from 4.00% to 12.8% before lockdown and 7.07% to 22.3% during lockdown, whereas 'other' colors remained below 3.37%. Notably, no 'other' colors were detected at FA3 during either sampling period. A similar trend was recorded at FB, where white/transparent MPs accounted for 88.9%-96.8% pre-lockdown and 86.3-93.8% during lockdown. Black MP proportions (3.18%-11.1% pre-lockdown) rose slightly to 5.77%-21.6% during lockdown, and other colors remained ≤ 1.05%. The dominance of white/transparent MPs is frequently attributed to environmental weathering and fading of colored plastics through exposure to UV light and water[45].

Across both harbors and sampling periods, fragments were the most abundant MP shape (73.5%-84.8%), followed by film (11.2%-17.3%), fibers (2.23%-9.68%), and microbeads (1.70%-2.06%). At FA, foam was present in small amounts pre-lockdown (1.73%) and decreased to 0.44% during lockdown. Notably, the proportion of film, fiber, and microbeads increased during the lockdown at both harbors, whereas fragment proportions decreased by approximately 6.41 percentage points at FA and 9.97 percentage points at FB. The predominance of fragments likely reflects the mechanical and UV-driven breakdown of larger plastic items such as buoys, food packaging, containers, and toys[46,47]. Fibers, which showed a modest increase during lockdown, are commonly derived from textiles, ropes, and fishing gear, suggesting ongoing inputs from domestic and fishing-related activities[46]. The slight rise in microbeads (0.23-0.05 percentage points) points to additional, albeit minor, sources such as personal care products. Overall, these findings reveal dynamic shifts in MP concentrations and characteristics at FA and FB associated with the lockdown period. The increase in smaller-sized fractions (25-50 μm), coupled with altered shape and color proportions, suggests continuous inputs of MPs and ongoing fragmentation of larger plastics. Spatial heterogeneity in MP occurrence further emphasizes the need for targeted management strategies and robust monitoring to mitigate the prevalence of MPs, particularly in coastal and harbor environments. Although our study employed widely used mechanical methods for MP collection (e.g., filtration and sieving with static, solid

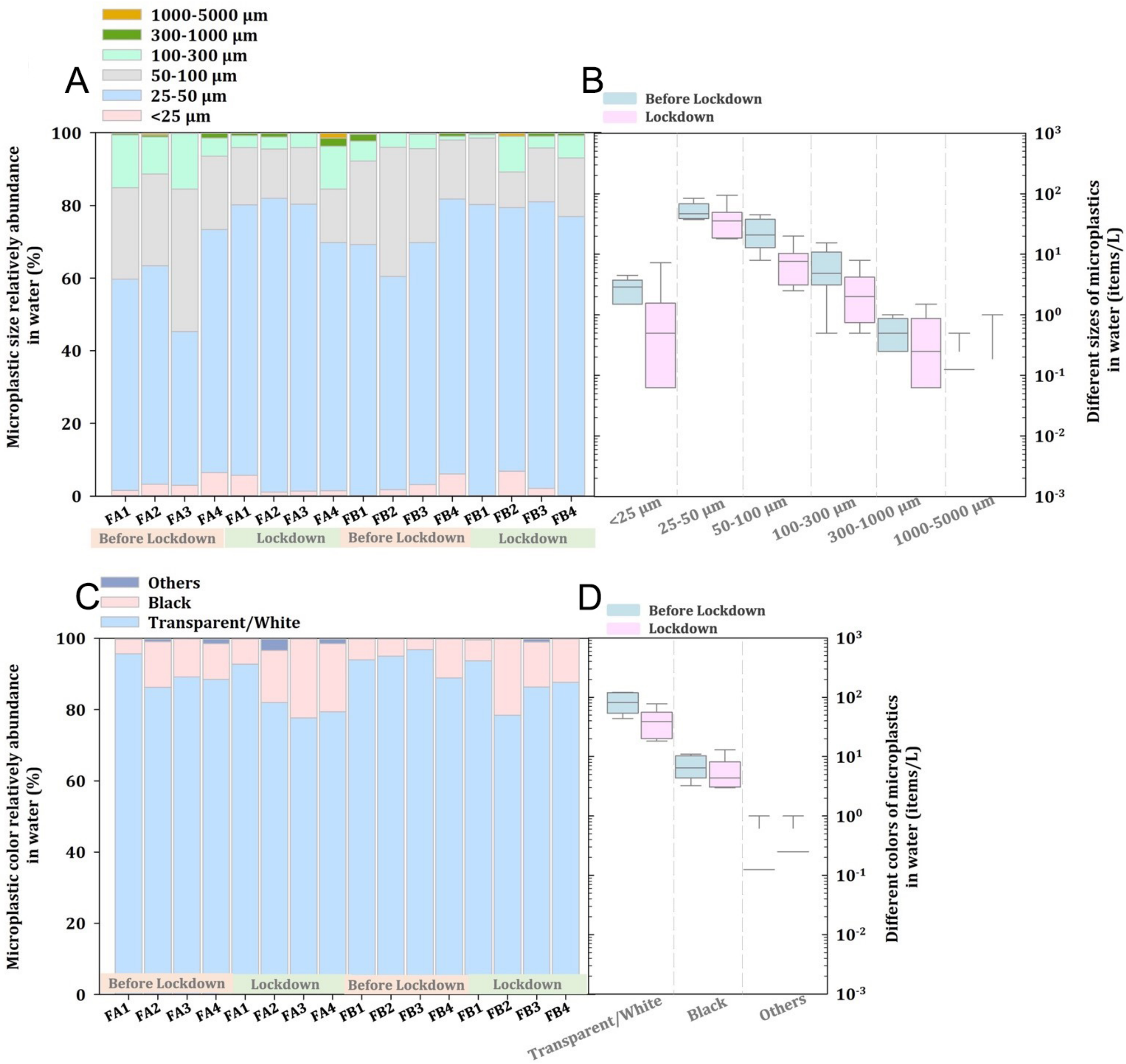

Figure 3. The characteristics of MPs before lockdown (January) and lockdown (May): (A) the relative size distribution of MPs; (B) different sizes of MPs; (C) the relative color distribution of MPs; and (D) different colors of MPs. FA: Zhuwei Fishing Harbor; FB: Yongan Fishing Harbor; MP: microplastic.

structures such as filters, rakes, or meshes), recent technological analyses[48] indicate a shift toward more advanced MP collection systems. These emerging techniques include chemical methods (e.g., adsorption and chemical binding) and magnet-based capture systems (e.g., electromagnetic collection devices), which offer improved sensitivity and broadened applicability to MPs of diverse chemical composition, key advantages over conventional mechanical collection methods. Consequently, adopting such advanced methods is expected to yield higher MP capture efficiencies in future applications, particularly for smaller MP particles or those with varied chemical compositions.

From an exposure standpoint, these temporal changes in MP abundance suggest corresponding fluctuations in the potential risk to local biota and human populations. For instance, a reduction in MP levels during the COVID-19 lockdown could imply a temporary decrease in MP ingestion by fish and shellfish in these harbors, which in turn might lower human dietary exposure for people consuming local seafood during that period[38]. Conversely, if certain MP types (e.g., fibers or fragments) remained prevalent or even increased, those could continue to be ingested by marine organisms and possibly accumulate in seafood[38]. People living near or working in the harbors (such as fishers) might also experience changing exposure: lower harbor activity could reduce the disturbance of MP-laden sediments and water, potentially diminishing incidental inhalation or dermal contact during the lockdown. Although our study did not measure exposure in humans or wildlife directly, the observed trends in MP pollution serve as an indicator of how exposure risks might rise or fall with changing human activities.

Composition patterns and potential sources

The μ-FTIR analysis revealed distinct shifts in MP composition at FA between the pre-lockdown and lockdown periods. Prior to the lockdown, four MP polymer types were identified: polyethylene (PE, 14.3%), rayon (57.1%), polypropylene (PP, 14.3%), and polyetherimide (PEI, 14.3%). Among these, rayon was the most abundant component (57.1%). During the lockdown, three polymer types were detected, with a notable increase in the relative abundance of PE (68.8%) and a decrease in rayon (18.8%). In addition, polymethyl methacrylate (PMMA, 12.5%) emerged as a new component, whereas PP and PEI were not detected during this period. At FB, five MP components [PE, rayon, PMMA, polytetrafluoroethylene (PTFE), and PAM] were detected during both sampling periods. Prior to lockdown, PTFE represented the most abundant fraction (36%), followed by rayon (33.3%), PE (12%), PMMA (10%), and polyacrylamide (PAM, 10%). Under lockdown conditions, PTFE increased in dominance (60%), while rayon decreased to 5%. Concomitantly, the proportions of PE (15%) and PMMA (10%) rose slightly, and PAM (10%) remained relatively stable.

Overall, the proportion of rayon, commonly associated with textile fibers, declined at both harbors during the lockdown (a 38.4 percentage point decrease at FA and a 28.3 percentage point decrease at FB). This reduction may reflect decreased human activity such as fewer visitors and less apparel-associated fiber input. In contrast, PE, ubiquitous in packaging materials, showed an increasing trend at both sites during lockdown. This finding aligns with heightened reliance on delivery services and takeout options during COVID-19 restrictions, as evidenced by reports of increased use of food delivery apps in Taiwan[49].

Principal component analysis (PCA) was employed to further elucidate temporal shifts and harbor-specific patterns in MP composition, with the first principal component (PC1) accounting for 38% of the total variance and the second principal component (PC2) explaining an additional 37%. The resulting score plots [Figure 4] revealed a clear separation between FA and FB, as well as distinct pre- and during-lockdown groupings.

Prior to the lockdown, PC1 indicated that rayon and PE were key contributors at FA, with PE emerging as the primary factor. During lockdown, the relative importance of PE decreased at FA, and rayon no longer dominated. At FB, rayon, PMMA, PAM, and PTFE influenced PC1 before lockdown, with rayon exhibiting a prominent role. This influence diminished during the lockdown and was replaced by other sources such as PAM and PMMA.

The PC2 component further underscored changes in polymer dominance over time. At FA, PMMA became a significant contributor during lockdown, though it was not previously detected. At FB, rayon was the most prominent polymer in PC2 prior to the lockdown, but other polymer types gained importance during the lockdown. The increased presence of PMMA at FA during the lockdown may relate to its chemical stability and extensive usage in protective barriers and medical equipment amid the COVID-19 outbreak[50,51]. These

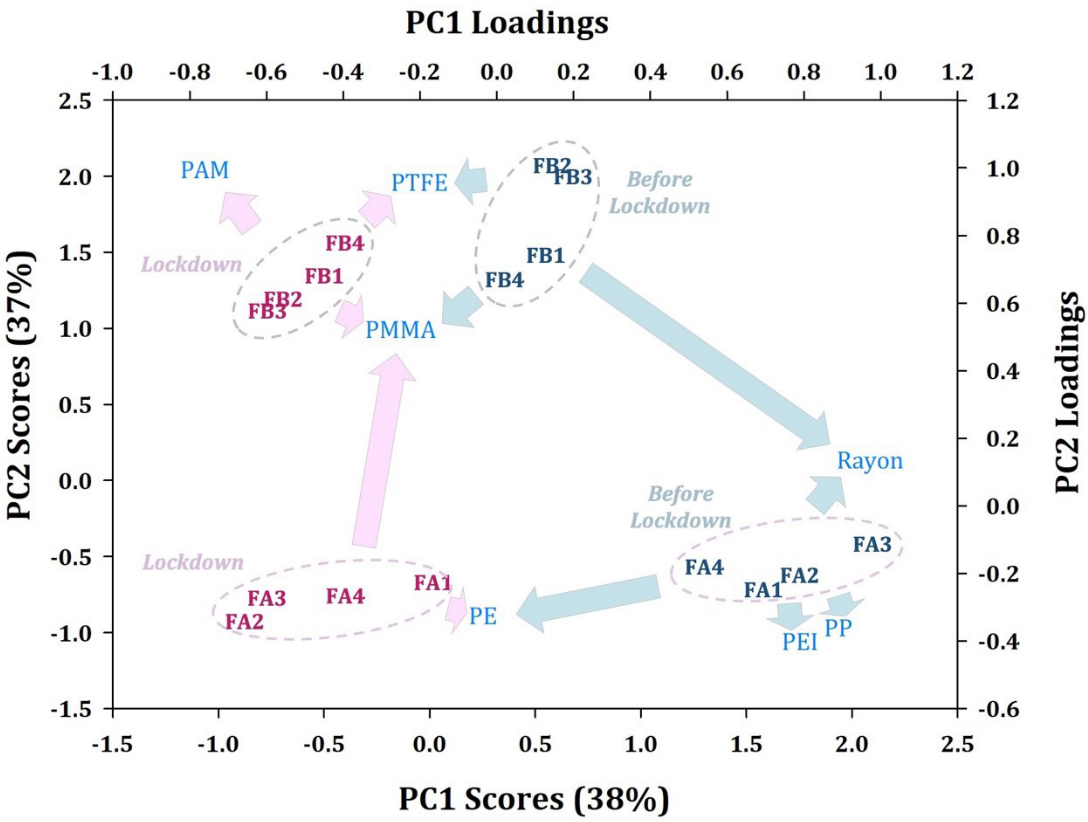

Figure 4. Principal component analysis (PCA) score and loading plots for MP polymer categories at all sampling sites. FA: Zhuwei Fishing Harbor; FB: Yongan Fishing Harbor; PC1: First principal component; PC2: second principal component; PCA: principal component analysis; MP: microplastic.

findings collectively indicate that the reduction in human activity and the modification of consumer behaviors during the lockdown period resulted in changes in both the type and abundance of MP polymers. Changes in local industries, reduced fishing activity, and increased packaging usage all likely contributed to these observed patterns.

Potential risk

The ecological risk associated with identified polymers was assessed using the hazard-based RQ and risk degree (H values), as shown in Figure 5. The H value categorizes the environmental hazard of MP monomers into four categories (I: < 10, II: 10-100, III: 100-1,000, IV: > 1,000). Prior to the lockdown, FA fell within the low-risk Category I, whereas FB was categorized as medium-risk (Category II). During lockdown, FA's risk level increased to Category II, while FB remained consistently within this category. This escalation in ecological risk at FA coincided with the detection of PMMA, which was absent before the lockdown. PMMA has been classified under Level IV hazard for its monomers[42], indicating potential allergenic effects. The emergence of PMMA, likely related to the heightened use of protective materials during the pandemic, may have contributed to the observed increase in risk levels.

A mismatch in the sizes and shapes of MPs analyzed in field monitoring and laboratory bioassays has made ecological risk assessment difficult. To overcome this mismatch, Jung *et al.*[18] analyzed MPs with sizes down to 20 mm for the purpose of ecological risk assessment. In our study, we adopted the PNEC of 12 particles/L from Jung *et al.*[18], who derived this value using a species sensitivity distribution (SSD) approach and

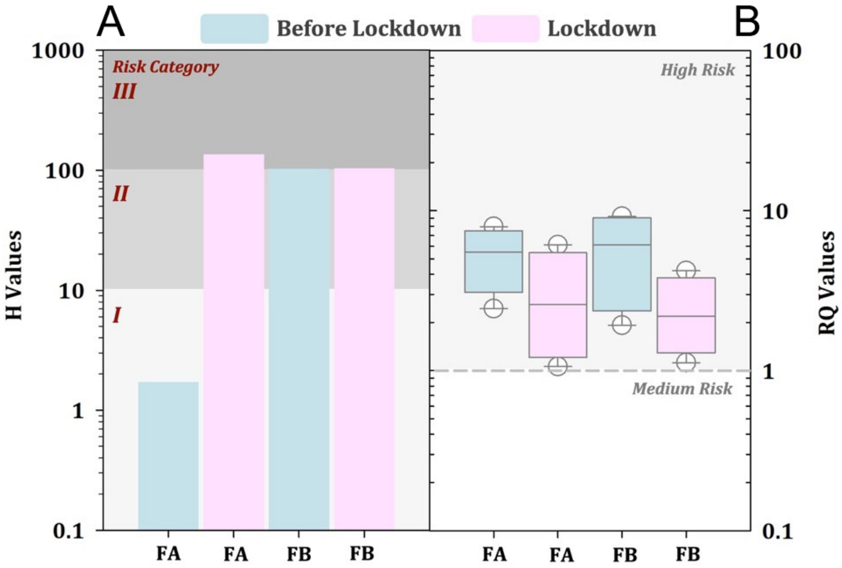

Figure 5. (A) Risk degree (H values) and (B) hazard-based RQ of MPs in this study. RQ: Risk quotient; FA: Zhuwei Fishing Harbor; FB: Yongan Fishing Harbor; MP: microplastic.

focusing on non-spherical MPs in the 20-300 μm size range. This approach was chosen to align the laboratory bioassay data with actual field monitoring, recognizing that discrepancies in MP size and shape can complicate ecological risk assessments.

The RQ values [Figure 5B] further support these findings. Prior to the lockdown, both harbors presented variable RQ values, with some exceeding the high-risk threshold (RQ > 1). Although RQ values generally decreased during lockdown, indicating a reduction in some forms of ecological risk, certain sites continued to pose medium to high ecological risks. These persistent risks highlight the complexity of MP pollution dynamics. Even with reduced human activity, shifts in polymer types and sources may maintain or modify overall ecological hazards.

In summary, changes in human behavior, industrial activities, and protective material use during the COVID-19 lockdown influenced both the composition and potential ecological risks of MPs at the study sites. The levels of MP pollution detected in the two fishery harbors carry direct implications for both human and ecological health. From a human exposure perspective, the presence of MPs in harbor water is concerning because these particles can be taken up by seafood species that are later consumed by people[38]. For example, a pilot survey of commonly consumed Taiwanese seafood (clams, oysters, and squid) found an average of approximately 88 MP particles per kilogram, translating to an estimated few thousand MPs ingested per person annually via seafood consumption[37]. Findings from our harbor study suggest that locally caught fish and shellfish may exhibit similar contamination levels, potentially contributing significantly to individual dietary intake of MPs. This dietary pathway is recognized as a major route of human exposure to MPs and their associated chemicals[38], raising food safety concerns. Meanwhile, wildlife exposure is also a critical aspect. Organisms dwelling in these harbors are continuously exposed to MPs in their environment. Studies have shown that larval fish and various marine species around Taiwan readily ingest MPs[38,39]. Such ingestion can lead to physical harm or toxicological effects on the wildlife (e.g., internal injuries, reduced feeding, or leaching of adhered chemicals), and it also represents a mechanism for MPs to move up the food web. Predatory fish, seabirds, or marine mammals could accumulate MPs by preying on smaller contaminated organisms, potentially magnifying exposure in higher trophic levels.

Additionally, other exposure pathways merit consideration. Residents and fishers in the vicinity of these harbors might be exposed to MPs through routes beyond diet. For instance, occupational exposure can occur via the handling of fishing gear and direct contact with contaminated water, and recreational exposure could happen through activities such as swimming or boating in polluted harbor waters. MP particles (especially fibrous fragments) can become airborne in sea spray or when dried sediments are resuspended, leading to possible inhalation exposure for people nearby. While our study did not measure these pathways directly, acknowledging them is important for a comprehensive exposure assessment. Future studies could, for instance, analyze local seafood for MPs or monitor airborne and waterborne particles in harbor environments to quantify these exposure pathways.

CONCLUSIONS

This study provides evidence that the COVID-19 lockdown had discernible impacts on the distribution, composition, and potential ecological risks of MPs in two harbors. While overall MP concentrations declined in most sampling locations during the lockdown, notable exceptions (e.g., FA1 and FB4) underscore the importance of localized influences and highlight that reduced human activity does not uniformly decrease MP abundance. The observed shift toward smaller particle sizes (25-50 μm) and the predominance of white/transparent fragments suggest ongoing plastic weathering and continuous MP inputs. A pronounced reduction in rayon, coupled with an increased proportion of PE and the emergence of PMMA, indicates changes in polymer sources likely driven by altered consumer behaviors (e.g., heightened reliance on food delivery and protective materials). These compositional changes, along with hazard-based risk assessments, demonstrate that even short-term alterations in anthropogenic activities can influence MP assemblages and their associated ecological risks. Although some risk parameters decreased during the lockdown, PMMA emergence at FA elevated the local risk category. These findings underscore the multifaceted nature of MP pollution and the need for adaptive management strategies. In conclusion, this study not only characterizes MP pollution trends in Taiwanese fishery harbors but also underscores the potential exposure risks associated with such pollution. The presence of MPs in harbor waters implies that humans and wildlife are at risk of exposure, notably humans through the consumption of local seafood and marine organisms through continuous environmental contact. Our findings, therefore, highlight a need for integrated monitoring of MPs in both the environment and biota (e.g., in fish and shellfish destined for the market) as a means to assess and mitigate exposure via the diet. Future work should focus on pinpointing specific land-based and marine sources, incorporating time-series data to better understand the persistence of polymer-specific changes, and evaluating the effectiveness of regulatory or educational interventions aimed at reducing MP inputs. Such efforts will be essential for mitigating MP-related hazards and preserving coastal and marine ecosystems.

DECLARATIONS

Authors' contributions

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Availability of data and materials
Further data are available from the corresponding author upon reasonable request.

Conflicts of interest
Dr. Jheng-Jie Jiang is a Junior Editorial Board member of *Journal of Environmental Exposure Assessment*. Dr. Jheng-Jie Jiang was not involved in any steps of editorial processing, notably including reviewer selection, manuscript handling, or decision making. The other authors declared that there are no conflicts of interest.

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Not applicable.

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