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ORIGINAL RESEARCH ARTICLE

Microplastic polymers in shellfish and fish in the coastal area

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ABSTRACT

BACKGROUND AND OBJECTIVES: The coastal area of Jeneponto Regency, South Sulawesi, Indonesia, is heavily impacted by microplastic pollution, which poses a threat to marine organisms such as shellfish and fish. This aim of this study was to identifiy the presence of microplastic polymers, including vinylidene chloride, polyacetylene, polychlorotrifluoroethylene, polybutylene terephthalate, poly(isobutyl methacrylate), cellulose acetate butyrate, polybutadiene, and polyvinylchloride, in shellfish and fish in the coastal area of Jeneponto district, Indonesia.

METHODS: In total, 60 shellfish and fish samples were collected directly from 12 locations in the coastal waters of Jeneponto Regency. Sample preparation, including enzymatic digestion and mechanical destruction, was performed to separate the organic tissues of fish and shellfish into small particles. Optical microscopy (at 100× and 400× magnification) was used to observe the morphology and to count the number of particles per sample volume using a modified Neubeuer Improved Counting Chamber. Fourier-transform infrared spectroscopy was used to determine the type of polymer.

FINDINGS: Feather clams contained the highest number of microplastics, with a total of 58 items ranging from 0.027 to 4.587 millimeters in size. The total abundance of microplastics in feather clams ranged from 0.25 to 2.14 items per gram. Kurisi fish contained 22 items ranging from 0.085 to 2.127 millimeters in size, with a total abundance ranging from 0.01 to 0.08 items per gram. The types of polymers identified in the fish and clams included vinylidene chloride, polyacetylene, polychlorotrifluoroethylene, polybutylene terephthalate, poly(isobutyl methacrylate), cellulose acetate butyrate, polybutadiene, and polyvinyl chloride. Vinylidene chloride was the predominant type of microplastic polymer, accounting for 42 percent of all microplastic polymers.

CONCLUSION: This study successfully identified eight types of microplastic polymers found in shellfish and fish in the coastal area of Jeneponto; the most common was vinylidene chloride. These findings indicate that marine organisms and humans are exposed to microplastics, which are potentially harmful, but further research is needed to understand the full extent of the associated environmental health impacts and risks.

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INTRODUCTION

Plastic production and use have continued to increase over the past 30 years (Paul *et al.,* 2020). Every year, approximately 400 million tonnes of plastic are produced worldwide (World Economic Forum, 2020). By 2030, plastic production is predicted to be 40 percent (%) higher today (Advisors *et al.,* 2019). This increase in plastic usage has resulted in the increasing accumulation of plastic waste, which can lead to environmental pollution (Daud, 2020). Asia has emerged as the world's most rapid producer of plastic waste. Five nations in Asia contribute more than half of the plastic waste found in oceans: China, Vietnam, the Philippines, Thailand, and Indonesia (World Bank Group, 2018). This issue is of particular importance in Indonesia as the country ranks second globally in terms of plastic waste generation (Kemenkeu, 2019). The amount of waste generated is related to the country's population, their activities, and their consumption levels (Birawida, 2021). In 2019, Indonesia produced approximately 67.8 million tons of plastic waste, but this value is expected to continue to increase along with the population growth (KLHK, 2020). Jeneponto Regency in South Sulawesi Province is known to generate a high amount of plastic waste. This regency ranks third within the provice for its contribution to the plastic waste issue (SIPSN, 2022f). The problem of inadequate plastic waste disposal has led to negative environmental impacts (Amato-Lourenço *et al.,* 2020). Over time, a substantial quantity of plastic waste has been released into the environment, where it eventually degrades slowly into microplastics (Liu *et al.*, 2020) owing to weathering and aging (Paul *et al.,* 2020). Microplastics, which are plastic particles smaller than 5 millimeters (mm) (Donoso and Rios-Touma, 2020), have emerged as a coastal environmental pollution issue and have been declared an extraordinary contaminant that affects all components within the environment (Campanale *et al.,* 2020; Dodson *et al.,* 2020). Over the past decade (Hahladakis, 2020), it has become a primary concern (Davarpanah and Guilhermino, 2019; Donoso and Rios-Touma, 2020) worldwide (McNeish *et al.,* 2018; Merga *et al.,* 2020) among scientists (Ahmad *et al.,* 2020), policymakers, media, and the general public (Barboza *et al.,* 2020). Microplastic pollution is increasing, increasing global environmental concerns (Asamoah *et al.,* 2020). There are significant implications for ecology, society (Nanninga *et al.,* 2020), economics (Lindeque *et al.,* 2020; Thushari and Senevirathna, 2020), and health (Angnunavuri *et al.,* 2020). As the concentration of microplastics in the environment increases, there is a higher probability that ecosystems will be exposed, increasing the chances of interaction, consumption, and more harmful effects throughout the food web (Horton and Barnes, 2020). Microplastic particles are dispersed in water, on the water surface, throughout the water column, and settle in sediments. Animals, including fish and shellfish, often ingest microplastics, which can enter the food chain (Wahdani *et al.,* 2020). They are frequently detected in the digestive tracts of aquatic organisms (Roc *et al.,* 2020); 35% of fish samples were found to contain microplastics (Merga *et al.,* 2020). Microplastics can adhere to the gills and skin of fish, with the flesh containing a higher concentration than other organs (Rao, 2019; Karami *et al.,* 2017). Lower trophic organisms, such as shellfish, face a high risk of exposure to microplastics (Walkinshaw *et al.,* 2020). Shellfish can disseminate microplastics through the entire food chain, accumulating in humans when consumed whole (Baechler *et al.,* 2020; Rochman and Neff, 2018). Shellfish are considered good environmental bioindicators because of their tendency to ingest anything within their surroundings, including microplastics (Sari, 2021). The coastal area of Jeneponto Regency, South Sulawesi, Indonesia, is a biodiverse ecosystem that is vital for the livelihoods of individuals in local communities and environmental sustainability (Jeneponto Regency Government, 2021). As with many coastal ecosystems worldwide, this area has faced serious challenges due to the dispersion of microplastics within its waters and habitats. Microplastics are recognized as a serious threat to marine organisms, including clams and fish (Rochman *et al.,* 2013). Despite clams and fish being crucial components of the marine ecosystem and significant food sources for humans (Mccauley *et al.,* 2016), there have been few studies of the contamination of microplastics in feather clam *(Anadara antiquata),* manila clam *(Venerupis philippinarum),* kurisi fish *(Nemipterus japonicus),* and gulamah fish *(Johnius sp.)*. Microplastics comprise various types of polymer. Some of the most common types are polyethylene (PE) and polypropylene (PP), which are often used in plastic products such as shopping bags, bottles, and food containers

(Hartmann *et al.*, 2019; Lusher *et al.*, 2015). Research on vinylidene chloride (VDC), polyacetylene (PA), polychlorotrifluoroethylene (PCTFE), polybutylene terephthalate (PBT), poly(isobutyl methacrylate) (PIBMA), cellulose acetate butyrate (CAB), polybutadiene (PB), and polyvinylchloride (PVC) in the context of microplastics is still scarce, indicating the potential for the discovery of knowledge regarding the sources and types of microplastic pollution in aquatic environments, especially in regions such as Jeneponto Regency, South Sulawesi, Indonesia. By expanding the scope of research to include less common polymers, more comprehensive understanding of the composition of microplastic waste can be gained and its impacts on marine organisms and humans. Understanding the presence of VDC, PA, PCTFE, PBT, PIBMA, CAB, PB, and PVC in shellfish and fish is crucial because each possesses unique chemical properties and potential toxicity. The findings of this study can strengthen the foundation on which health risks associated with the consumption of contaminated seafood are evaluated and facilitate the design of strategies to reduce the release of microplastic waste into the environment. The study aims to find the concentration of microplastic polymers vinylidene chloride, polyacetylene, polychloro-trifluoro-ethylene, polybutylene terephthalate, poly(isobutyl methacrylate), cellulose acetate butyrate, polybutadiene, and polyvinylchloride, in shellfish and fish on the coast of Jeneponto district, Indonesia, in 2024.

Climate data are presented in Fig. 1. Jeneponto experiences extreme seasonal variations in monthly rainfall, with the highest rainfall (402 mm) occurring in January. The average hourly wind speed in Jeneponto experiences significant seasonal variations throughout the year. The windier period of the year lasts for 4.7 months, from May 19th to October 9th, when the average wind speed is over 16.0 kilometers per hour (k/h). The windiest month in Jeneponto is August, with an average hourly wind speed of 20.7 k/h. The prevailing wind blows mostly from the east for 7.3 months (from April 5th to November 15th), with the highest percentage from the east reaching 92% on August 21st. The wind most frequently blows from the west for 4.7 months, from November 15th to April 5th, with the highest percentage from the west reaching 87% on January 1st. The average water temperature experiences significant seasonal variations throughout the year. The warm water period in a year lasts for 2.0 months, from November 3rd to January 1st, with an average temperature above 29°C; the warmest month for water in Jeneponto is November, with an average temperature of 29°C. The colder water period in a year lasts for 2.5 months, from July 4th to September 19th, with an average

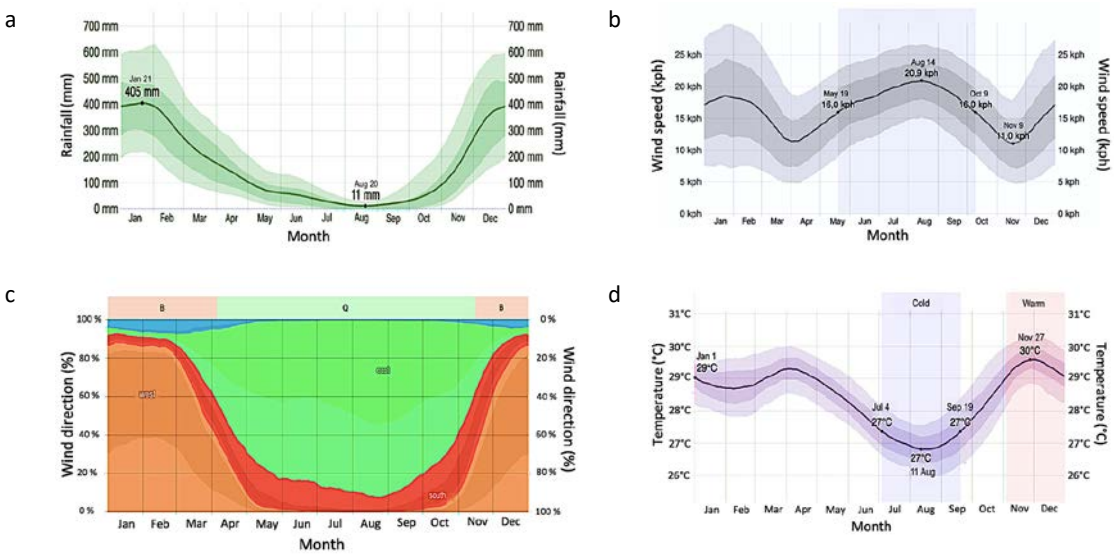

Fig. 1: Climate data for Jeneponto Regency, South Sulawesi, Indonesia: (a), rainfall (b), wind speed (c), wind direction (d), temperature

temperature below 27°C (Weather Spark, 2024).

MATERIALS AND METHODS

Sample collection

The samples for this study were feather clam *(Anadara antiquata),* manila clam *(Venerupis philippinarum),* kurisi fish *(Nemipterus japonicus)*, and gulamah fish *(Johnius sp.)* collected from the coastal areas of Jeneponto Regency, South Sulawesi Province. In total, 60 organisms, including fish and shellfish, were identified from 12 different sampling points in the coastal area of Jeneponto Regency, Indonesia. The collected samples comprised 30 individual fish and 30 individual shellfish. Each sampling point contributed five samples of organisms proportionally, including both fish and shellfish. The number of fish and shellfish collected was evenly distributed in this study. Preliminary surveys were conducted to identify areas where communities gather clams and fish for daily consumption and to identify the sources of plastic waste pollution in the coastal areas of Jeneponto Regency.

The areas for sampling clams and fish from the coastal region of Jeneponto Regency, Indonesia, are shown in Fig. 2. Jeneponto Regency has a total area of 749.79 km², located between 5°16'13"S and 5°39'34"S and between 12°40'19"E and 12°7'31"E. It is bordered by the Gowa and Takalar Regencies to the north, the Bantaeng Regency to the east, the Takalar Regency to the west, and the Flores Sea to the south.

Sample preparation

Prior to analysis, samples were frozen at −20°C. Quality assurance and quality control procedures were implemented in the field and in the laboratory. To prevent the cross-contamination of field samples,

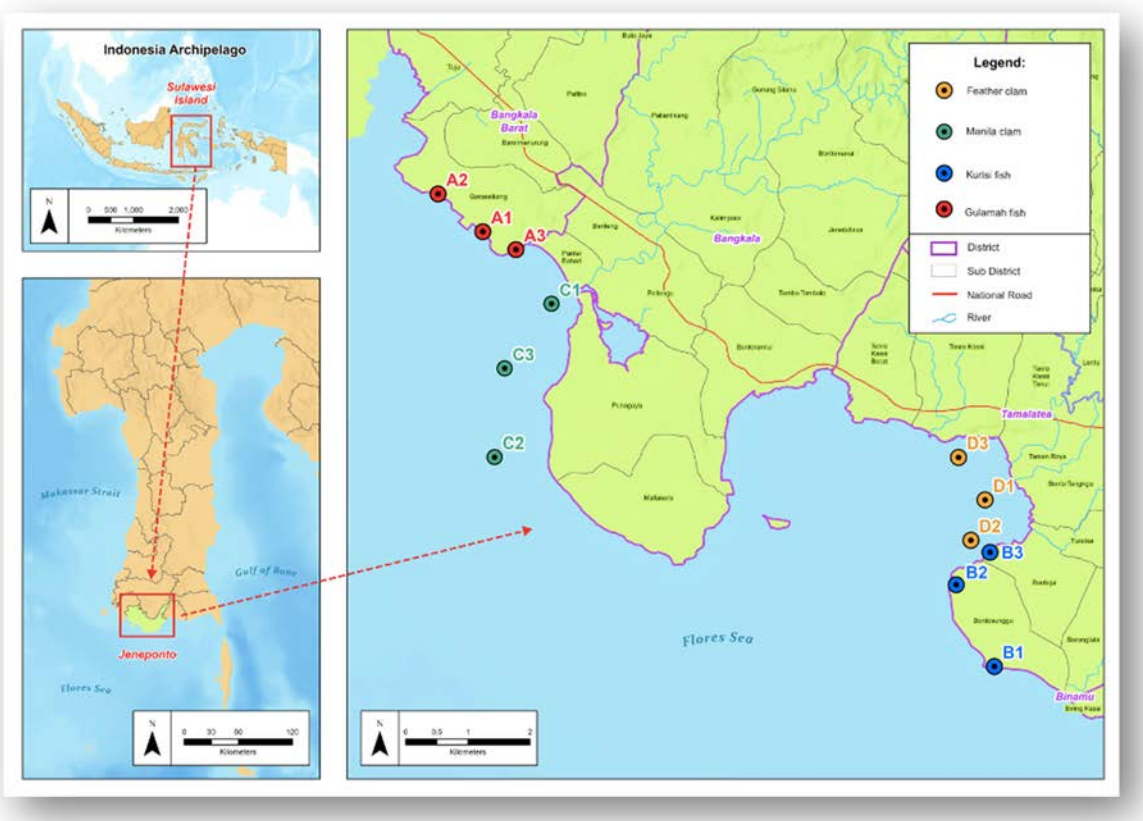

Fig. 2: Geographic location of the study area and sampling location of shellfish and fish in the coastal area of Jeneponto Regency, South Sulawesi, Indonesia

strict field protocols were applied, such as avoiding synthetic textiles that may release fibers, covering sampling equipment when not in use, minimizing sample exposure to ambient air by covering filters with foil, placing field samples and filters into closed containers such as coolers, and avoiding the use of plastic tools and equipment where possible (Hung *et al.,* 2021). All protocol-related equipment was meticulously cleaned three times with demineralized water before use (Lorenzoni *et al.,* 2022). During the trials, to prevent contamination, only nitrile gloves and clean cotton laboratory coats were used in the laboratory (Zhou *et al.,* 2021). The samples were removed from the freezer shortly before preparation for analysis. The samples underwent analysis to determine the presence and amount of possible microplastics. All samples were measured, weighed, and cleaned prior to processing after freezing for one hour. Filling the flask with soft tissue with 10% potassium hydroxide (KOH). The difference in weight between the soft tissue-filled flask and the empty flask was used to calculate the amount of 10% KOH, and the result was multiplied by three. The bottles were sealed with glass caps, shaken at 80 rotations per minute (rpm), and incubated for 48 hours at 40°C (Lorenzoni *et al.,* 2022). After preparation, visual inspection was performed to confirm the presence or absence of microplastic contamination. Observations were conducted using a microscope to identify the quantity and form of microplastics (Tuhumury and Ritonga, 2020).

Analysis of microplastic particle morphology

The identification of the types of microplastics in fish and shellfish involves a series of stages comprising careful and structured analyses. Sample preparation is first performed so that the organic tissue of fish and shellfish is separated and broken down into small particles using techniques such as enzymatic digestion or mechanical crushing. Visual analysis was conducted using an optical microscope to examine the morphology and physical characteristics of the microplastics contained in the samples. Residues on the filter were examined using an optical microscope (Leica ICC50 HD) at a magnification of 100× and 400× for morphological examination (fragments, fibers, pellets, films, etc.). To calculate the number of particles per sample volume, the morphological analysis was combined with optical microscope examination using a modified Neubeuer Improved Counting Chamber. This technique, widely used for counting cells or particles in biological fluids, is highly accurate. In this technique, samples were placed at a predetermined distance of 0.1 millimeters (mm) and observed under a microscope. Subsequently, the observed particles in the sample was counted; the sample was assumed to be homogeneous. The calculation results were translated into units of waste per liter. Fourier-transform infrared (FTIR) was used to assess microplastic residues filtered through a 0.45-micrometer porous nitrate cellulose filter using pure polymer references. This chemical analysis technique, known as FTIR characterization, was used to identify compounds in the samples. The functional groups or different types of bonds formed by atoms can be used to separate compounds from another and identify molecules. The FTIR characterization process is capable of identifying functional groups in compounds through the interpretation of infrared light signals sent by chemicals in the sample to the FTIR instrument (Dutta, 2017).

FTIR microscopy

The molecular composition of plastic particles can be determined by combining optical microscopy, vibrational spectroscopy, and/or electron microscope scanning. To prevent the formation of undesirable spectral peaks, suspected microplastic particles should be excluded from the sample matrix. This is important because the recorded signal intensity is dependent on the size of the particles being analyzed (Nguyen *et al.,* 2019). The discovery of microplastics is facilitated by effective and widely used FTIR microspectroscopy methods. The signals depend on changes in the molecular dipole moments caused by vibrations in the molecules. Molecules reach higher vibrational states through the absorption of infrared light, and these states are closely associated with the types of bonds that make up the molecules. Unlike energy-dispersive X-rays and electron microscopy scanning, infrared spectroscopy is a highly efficient method for collecting fingerprint data on the chemical arrangement of samples and specific bonds (Ramaiah and Ramesh, 2017). Although FTIR microscopes have specific wavelengths and are subject to predetermined diffraction limits, their spatial resolution is limited to 10–20 micrometers (µm). For the FTIR to function correctly, samples should

Table 1: Advantages and limitations of methods for identifying microplastics (Shim *et al.*, 2017)

Profit	Limitations
Microscopy	
Simple, fast, and cheap	- There is no chemical confirmation - False positives are likely - It is likely that small, transparent plastic particles are missing - There are no polymer composition data
- Microscopy (+FTIR/Raman)[a]	
- Plastic confirmation of subset samples - Polymer compositions of major or typical types of plastic	- Possible false positives - Possibly missing small, transparent plastic particles - Reliability of types of polymer determined spectroscopic examination of selected samples
FTIR spectroscopy[b]	
- With chemical validation of all plastic-like particles, false positive findings are not possible - Minimization of erroneous negative information - Non-invasive examination - Detection of plastic particles as small as 10 mm - The focal plane array (FPA)-reflectance mapping is automatic.	- Expensive instrument - Identification of all particles is tedious and time consuming - Contact analysis attenuated total reflection (ATR)
Raman spectroscopy[b]	
- With chemical validation of all plastic-like particles, false positive findings are not possible - Decrease in false negative data - Identification of plastic particles up to 1 mm in size - Non-destructive analysis - Non-contact analysis	- Expensive instrument - Identification of all particles is a tedious and time-consuming - Interference from pigments is possible
Thermal analysis	
Simultaneous analysis of polymer types and chemical additives Pyrolysis gas chromatography/mass spectrometry (pyro-GC/MS)	- Destructive analysis - Multiple polymer identification differential scanning calorimetry (DSC) - Complex data (pyro-GC/MS)

be stored on infrared (IR)-transparent substrates with a minimum thickness of 150 nanometers (nm). Although, FTIR works optimally on particles larger than 20 µm, smaller particle aggregates or layers can still be analyzed. Micro-FTIR spectroscopy is an excellent technique, as seen from its advantages presented in Table 1. In terms of identifying microplastics in the air, micro-FTIR spectroscopy is better than other methods for spotting particles as small as 20 µm. In the electromagnetic spectrum, the IR zone falls between visible light and microwaves. While the wavelengths of the IR zone range from approximately 700 nm to 1 mm, chemical fingerprints determined by FTIR spectroscopy are usually in the narrow frequency range of between 4,000 and 400 cm^{-1} (wavenumbers). Distinct atoms or groups of atoms can be identified to ascertain the composition of different substances by comparing their infrared spectra (Chen *et al.*, 2020).

[a]FTIR or Raman analysis of subset of particle samples
[b]FTIR or Raman analysis of whole particles

RESULTS AND DISCUSSION

Over the past two years, solid waste management has emerged as an important issue in waste management owing to the increase in solid waste, as shown in Fig. 3. Interestingly, plastic waste has become the second most abundant type of waste after organic waste. In 2022, organic waste accounted for approximately 44.28% of the total solid waste in South Sulawesi, with plastic waste comprising around 17.01% of total solid waste. In 2023, the percentage of organic waste slightly decreased (to 43.92%), although the percentage of plastic waste remained similar (17.02%). Plastic waste remains a major

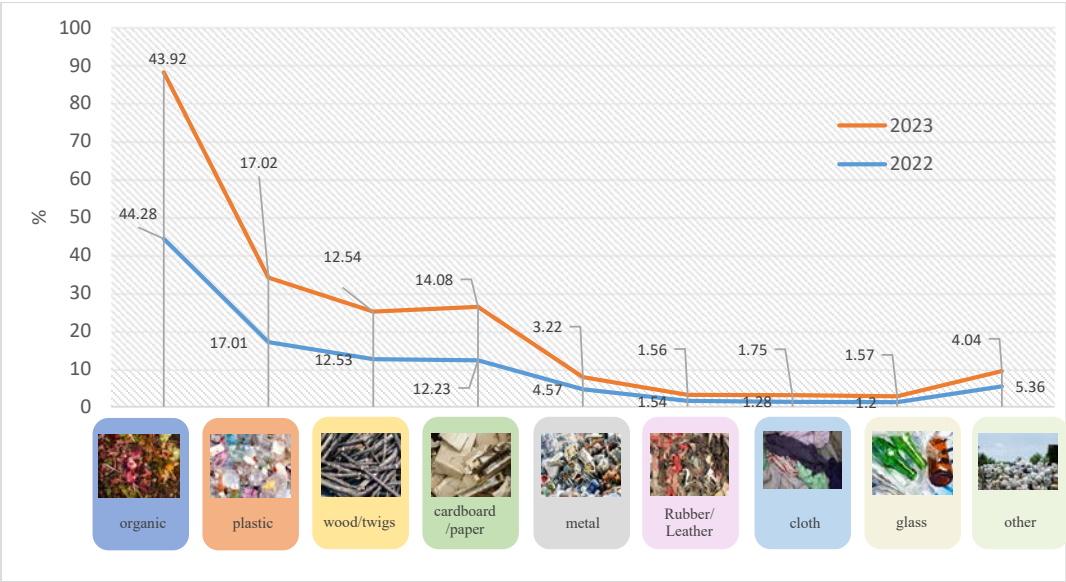

Fig. 3: Percentage of solid waste in South Sulawesi (SIPSN, 2022f, 2023)

Table 2: Solid waste generation rate, percentage of plastic waste, and availability of solid waste management infrastructure in South Sulawesi (BPS, 2022a, 2022b; SIPSN, 2022a, 2022b, 2022d, 2022c, 2022e, 2022f).

Regency	Plastic waste piles and their management								Resident	
	Percentage of plastic waste			Solid waste management infrastructure						
				BSU	BSI	TPS3R	TPA/ TPST	Sector Informal	Amount	Density
	%	(tons/day)	(ton/y)	units	units	units	units	units	soul	people/km^2
Selayar Islands	15.00	8.2785	3021.63	4	2	0	2	20	139145	103
Bulukumba	-	-	-	2	1	1	1	3	443292	345
Bantaeng	14.00	11,339	4138,732	64	2	4	2	6	199399	504
Jeneponto	19.50	31,629	11544.81	36	2	4	2	30	410639	581
Bone	10.70	43,421	15848.32	76	2	4	2	102	813188	178
Maros	6.69	10,805	3943,822	20	2	2	2	14	403774	249
Pangkajene	7.29	10,292	3756,577	9	1	1	1	11	351426	310
Barru	15.00	11,432	4172,585	1	2	2	1	13	186910	159
Soppeng	21.00	19,788	7222,698	48	2	8	2	68	236049	152
Wajo	17.03	25,862	9439,467	66	2	0	2	20	379706	152
Sidenreng Rappang	6.60	8.5325	3114,297	34	2	14	2	28	327416	174
Pinrang	10.00	18,044	6586,177	31	2	16	2	14	411795	210
East Luwu	15.00	18.03	6581,192	168	2	0	8	40	305521	44
North Toraja	-	-	-	2	2	2	1	3	268198	221
Parepare	12.20	9.4892	3463,454	12	2	1	1	7	154854	1559
Palopo	20.00	18,734	6837,582	10	2	2	1	5	190867	754

issue in waste management. Jeneponto Regency is one of the areas in South Sulawesi Province with a significant accumulation of plastic waste, as shown in Table 2. Plastic waste accounts for 19.50% of waste; the total annual production is 11544.81 tons. This regency is one of the main contributors to the plastic

waste problem. The plastic waste management infrastructure comprises two main waste banks, four waste bank units, two units of 3R waste management facilities (TPS3R), and two final disposal sites (TPA/TPST). The Regional Government manages the TPA waste processing facility located in Panaikang Village, Binamu District. The waste management system at this facility relies on manual book recording and open dumping practices. The informal sector also plays a role in plastic waste management; 30 informal sector units are involved in plastic waste management activities within this regency.

Despite the existing waste management infrastructure, plastic waste volumes have continued to rise significantly owing to various factors, including societal consumption habits, which now favor single-use plastics (Geyer *et al*., 2017; Hoornweg *et al.*, 2013). The extensive use of single-use plastics in packaging and daily items exacerbates the issue (Cózar *et al.,* 2014). A lack of awareness about correct waste management among the public contributes to increased plastic waste generation. Insufficient education and awareness lead to inadequate waste sorting and minimal efforts to reduce plastic consumption (Forti *et al.,* 2020). The long-term solutions to plastic pollution lie in environmental education (Liu *et al.,* 2023), which will foster the prevention of prevention, sustainable consumption, and the inclusion of plastic waste education in schools. Education also aids in understanding public perspectives on plastic pollution, informing effective interventions and mitigation strategies (Hartley *et al.,* 2015; Pahl *et al.,* 2017). Public knowledge is crucial for policymakers to develop aligned policies, with appropriate documentation assisting in identifying areas requiring increased awareness (McKinley and Fletcher, 2012). Suboptimal waste management policies contribute to plastic waste accumulation, with inadequate regulations, poor supervision of plastic-using industries, and insufficient funding hindering effective waste management (Geyer *et al.,* 2017). Improperly managed plastic waste can enter water bodies, reaching marine environments and forming microplastics through weathering (Jambeck *et al.,* 2015; Lebreton *et al.,* 2017). Microplastics pose significant threats to marine organisms, including disruption of the marine food chain (Andrady, 2011).

Districts with high population densities tend to generate more waste, including plastic waste (Table 2). Jeneponto district has a population density of 581 people/km². Highly populated areas, exemplified by Jeneponto district with 410,639 people, drive plastic waste production owing to the increased demand for plastic-packaged goods. Geyer *et al.* (2017) reported that humans have generated 6.3 billion tons of plastic waste since 1950, with projections indicating a continuing increase. Population growth, urbanization, and economic development have fueled this surge in plastic waste (Amasuomo and Baird, 2016); despite this, they are not the sole factors influencing plastic waste accumulation. Adequate waste management infrastructure is a component of the problem. Even though facilities exist, challenges persist, as highlighted by Browne *et al.* (2011). Insufficient recycling facilities, ineffective waste management, and public unawareness exacerbate plastic waste accumulation. Addressing these issues requires effective waste management infrastructure and systems, alongside public education on the correct waste management practices. Failing to address these challenges can result in the uncontrolled accumulation of plastic waste, underscoring the urgency of comprehensive waste management strategies. Microplastics can be consumed by a variety of animals and are found in aquatic habitats (Naidoo *et al.,* 2020; Pannetier *et al.,* 2020). Marine fish are a widely utilized source of human food (Barboza *et al.,* 2018); fish account for approximately 17% of all animal protein and 7% of all protein consumed worldwide (FAO, 2021) and for approximately 20% of the average animal protein consumption per person for approximately 3.3 billion individuals. Shellfish have also been identified as a possible entry point for microplastics into the human food chain. Shellfish are a source of protein and income for coastal communities (Mayoma *et al.,* 2020). Various studies have utilized shellfish as ecological indicators of microplastic pollution (Wardlaw and Prosser, 2020).

Shellfish and fish were obtained from Jeneponto coastal area. Through the analysis of samples taken from shellfish and fish, the quantity and types of microplastics present in their bodies were measured. As shown in Fig. 4, 112 microplastic items were identified; these items were primarily in line forms with just one item in fragment form. The microplastic pollution originates from plastic bottles and bags, fishing nets, and food packaging often seen around coastal areas. Fishing lines mostly come from broken

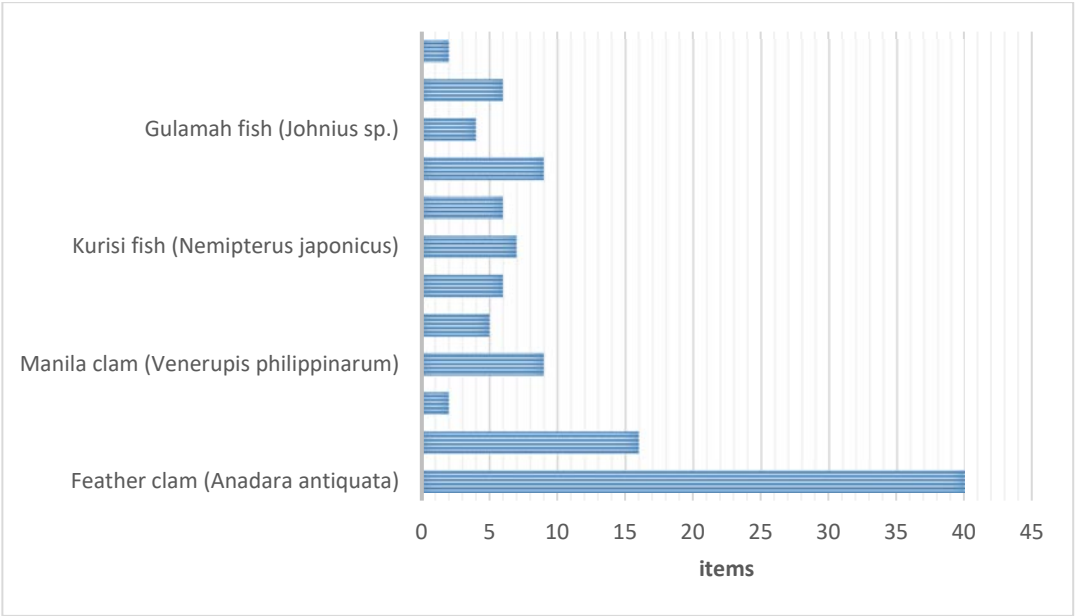

Fig. 4: Number of microplastic items in shellfish and fish

Table 3: The abundance of microplastics in the aquatic environment

Location	Location Specific	Abundance	Morphology	Sources
Lebanon	Coastal coast (Tripoli, Beirut, and Sidon)	6,7 MPs/m^3	Fragments, fibers, and microbeads	Kazour, *et al.* , 2019
Pakistan	Rawal Lake	0,142 item/0,1 L	Fibers and fragments	Filgueiras et al.,2019
	Ravi River, in Lahore,	16.150 ± 80 MP/m^3	Fibers and fragments	Irrfan *et al.*,2020
Dubai	Poyang Lake	5–34 item/L	Fibers	Yuan *et al.*, 2019)
Cina	Tuojiang River	911,57 ± 199,73 --3395,27 ± 707,22 items/m	Fibers	Zhou *et al.*, 2020
Korea	Korean Beach	1,12–4,74 particle/m^3	Fibers	Kwonm *et al.*, 2020
India	Gulf of Mannar	10–30 item/L	Fibers	Narmatha *et al.*, 2020
Iran	Persian Gulf, Hormozgan	3252 ± 2766 MPs/m^2	Foam, fragments, pellets	Nabizadeh *et al.*, 2019
Indonesia	Small Islands of Bintan, Riau	122.8 ± 67.8 pieces per station	Fragments, fibers, grains, and films	Syakti *et al.*, 2018

fishing lines. Once in the seawater, the plastic lines sink to the seabed, with only a small portion remaining in the water column. Palermo *et al.* (2020) revealed that microplastics can also be found in the form of fibers and films. The source of these particles is most likely discarded plastic bags, food wrappers, and fishing nets disposed of by fishermen (Maulana *et al.*,2023). A comparison of microplastic shapes is presented in Table 3.

The total number of microplastics varied across different shellfish and fish samples. The highest count was in the feather clam: 58 items ranging in size from 0.027 to 4.587 mm. Asadi *et al.* (2022) stated that microplastic contamination in clams is widespread in water bodies. Nearly all samples (99.23%) were contaminated with microplastics in fiber form, with the remaining microplastics in film form, ranging from 1 to 10 items in each feather clam.

The majority of feather clam species are sediment-dwelling clams and filter feeders, meaning they feed by filtering suspended matter and food particles from the water in their surroundings. Microplastics were discovered in clams from every sampling location in the study of Mayoma (2020); 48% of the 160 clams analyzed contained microplastics. The tissues of clams contained 138 different types of microplastics. There was variation in the frequency of occurrence (%FO) between the locales, ranging from 20% to 85%. After being hand-selected from the intertidal zone, the clams were brought to the lab and measured and weighed before being dissected. The clams were mature, as evidenced by their length (30–60 mm) and weight range (46.7–66.8 g). This aligns with other findings on feather clams found along the coastline of Tanzania. The manila clam had a total of 20 microplastics, ranging in size from 0.058 to 1.968 mm. This marine species has significant commercial value, with over 25 × 10^5 tons produced worldwide annually (FAO, 2014). Owing to its wide distribution, long life cycle, ease of acquisition, and high potential for accumulation of pollutants, the manila clam meets several criteria that are required for it to be considered a bioindicator species (Sacchi *et al.,* 2013). Research has shown that microplastics accumulate in the bodies of manila clams (Davidson and Dudas, 2016). In the study by Sıkdokur *et al.* (2020), manila clams exposed to microplastics and mercury experienced bioaccumulation, tissue pathology, immune modulation, and changes in antioxidant responses in marine organisms. The total microplastics shown in Fig. 4 also encompass microplastics in fish. The kurisi fish contained 22 microplastic items, with sizes ranging from 0.085 to 2.127 mm, and the gulamah fish contained larger sizes of microplastics, ranging from 0.090 to 2.623 mm, with a total of 12 microplastic items found. Studies on microplastics in kurisi fish and gulamah fish have been conducted in several locations in Indonesia: in the waters of Jakarta Bay (Dewi *et al.,* 2023), at Rebo Beach, Bangka Regency (Pratiwi *et al.,* 2024), and in Tuban sea waters (Fauziyah, 2020). Meanwhile, studies on gulamah fish have been conducted in Segara Bay, Bengkulu City (Johan *et al.,* 2021), and Baron Beach, Yogyakarta (Suwartiningsih *et al.,* 2020). This study did not include FTIR analysis. Comparing the levels of microplastics between shellfish and fish found in coastal areas with other marine environments is an important topic for understanding the effect of plastic pollution in marine ecosystems. Research conducted by Suaria *et al.* (2020) indicated that microplastics tend to be more concentrated in coastal waters, primarily owing to higher human activities in these areas. Studies by Lusher *et al.* (2017) also demonstrate that the levels of microplastics in shellfish and fish in coastal waters are generally higher owing to the degradation of plastic waste that occurs on land and enters the sea through river flows.

The results of the statistical analysis of mean differences among various types of fish and clams are provided in Table 4 along with the statistical significance of these differences. From the provided values, it is evident that feather clam was significantly different from three other types: manila clam ($p = 0.002$), kurisi fish ($p = 0.000$), and gulamah fish ($p = 0.000$), with each 95% confidence interval indicating considerable differences. This suggests that the feather clam exhibits distinct characteristics from the other three types of fish and clams considered in this analysis, providing valuable insights into the differences among the species under consideration. The sampled shellfish contained a higher amount of microplastics than fish because they are filter feeder organisms that trap particles in the water, including microplastics, and their habitat is often close to the coast where microplastic pollution tends to be higher (Chae and An, 2016). The ability of shellfish to ingest sediment containing higher concentrations of microplastics compared to fish also contributes to the higher levels of microplastics in their bodies (Van Cauwenberghe *et al.,* 2015). Rochman *et al.* (2015) showed that shellfish were able to accumulate small particles dissolved in water, including microplastics, through adhesion mechanisms in their tissues and internal organs. Shellfish are generally sedentary, whereas fish are mobile in aquatic environments. Research on microplastic distribution in fish and shellfish can offer varied insights into aquatic microplastic exposure. Rochman *et al.* (2013) studied the impact of microplastics on fish. Understanding these behavioral differences provides a comprehensive view of microplastic exposure and its effects on aquatic life. Kusumawati *et al.* (2015) found that shellfish with larger shells contain fewer microplastics than those with smaller shells, because shellfish can expel pseudofeces in response to

Table 4: Average differences between biota types

(I) Biota	(J) Biota	Mean Difference (I–J)	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
Manila clam	Feather clam	-.3187*	.002	-.5102	-.1271
	Kurisi fish	.1760	.071	-.0155	.3675
	Gulamah fish	.1813	.063	-.0102	.3729
Feather clam	Manila clam	.3187*	.002	.1271	.5102
	Kurisi fish	.4947*	.000	.3031	.6862
	Gulamah fish	.5000*	.000	.3085	.6915
Kurisi fish	Manila clam	-.1760	.071	-.3675	.0155
	Feather clam	-.4947*	.000	-.6862	-.3031
	Gulamah fish	.0053	.956	-.1862	.1969
Gulamah fish	Manila clam	-.1813	.063	-.3729	.0102
	Feather clam	-.5000*	.000	-.6915	-.3085
	Kurisi fish	-.0053	.956	-.1969	.1862

particle accumulation on the labial palp, reducing the absorption of particles from water. Under normal conditions, particles are filtered to the gill surface, but if there are too many, they can saturate the gills and be expelled again as pseudofeces through the ciliary tract. Given their abundance worldwide, many scientists consider microplastics a vital indicator of the modern era (Campanale *et al.,* 2020). In the current study, microplastics were abundant in shellfish and fish spread sampled at 12 points in the Jeneponto coastal area. There was a variation in the abundance of microplastics for each type of fish and clam in three different areas, as shown in Fig. 5. Feather clams contained varying levels of microplastic abundance, ranging from 0.25 to 2.14 items per gram (items/g) across different locations. Manila clams contained microplastic levels ranging from 0.14 to 0.80 items/g. In contrast, kurisi fish had microplastic levels ranging from 0.01 to 0.08 items/g and gulamah fish had microplastic levels ranging from 0.01 to 0.07 items/g. This variation highlights the complexity of microplastic exposure in various marine habitats and coastal environments. Anthropogenic input and environmental mechanisms that govern transit, transformation, and accumulation have a major impact on the distribution of microplastics (Yao *et al.,* 2019).

The abundance of microplastics in coastal waters stems from various sources. In the case of clams and fish commonly consumed by the Jeneponto coastal community, microplastic contamination results from fishing activities, seaweed cultivation, and household practices. Coastal fishers in Jeneponto employ plastic nets and fishing lines to harvest marine life, which can become sources of microplastics. Friction or damage to these plastic gears during use can lead to the detachment of small plastic particles, releasing them into the water. Fishing boat operations can contribute to microplastic release: plastic ropes commonly used on fishing vessels endure wear and tear from constant exposure to pressure and oceanic conditions, shedding small plastic fragments that morph into microplastics in the water. The distribution of microplastics is influenced by fishing practices using degraded fishing gear (e.g., lines and nets). Ayuningtyas *et al. (*2019) reported that fishing activities, such as the use of nets and fishing gear, are the main cause of microplastics in water. Fishponds in the open sea often use nets or plastic ropes as fish traps. The frequent operation of fishing vessels in the area is also a significant contributor to microplastic pollution. Another source is seaweed cultivation. In the seaweed cultivation activities of the coastal community in Jeneponto, ropes made of plastic fibers are used. These ropes are arranged in the sea to serve as a growing medium for seaweed. After some time, these ropes are dried along with the seaweed to be reused for planting subsequent seaweed. When these

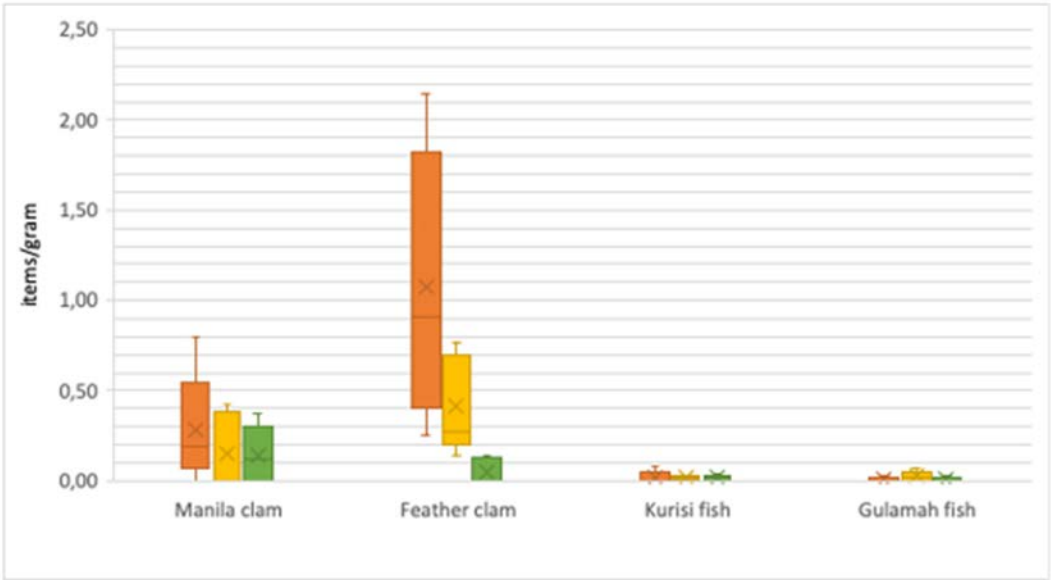

Fig. 5: Abunance of microplastics in shellfish and fish

ropes are exposed to sunlight, oxidation, and physical degradation begin to occur. This process affects the strength and integrity of the ropes, causing small fragments or microscopic particles to detach from them. In the cultivation area, the use of ropes for planting seaweed seedlings and fish nets serves as a potential source of synthetic microfiber for aquatic environments and organisms (Mathalon and Hill, 2014; Severini *et al.,* 2019; Su *et al.,* 2019). To manage seaweed, plastic bottles are also used. According to PAIR comodities (2023), this industry heavily relies on plastic bottles as buoyancy aids to support the seaweed lines as they are inexpensive and readily available compared with other alternatives. Owing to the lack of plastic waste management schemes, this practice leads to the accumulation of waste and large-scale microplastic pollution. These bottles deteriorate quickly and are replaced frequently. The scattered waste not only enters the seaweed cultivation sites and coastal areas but also hampers the national effort to reduce plastic waste from land to sea by 70% by 2025. Seaweed cultivation is crucial for the livelihoods of 62,000 households in Indonesia, with over 24,000 of them located in South Sulawesi. Its increasing popularity has brought environmental challenges. Plastic waste also originates from domestic waste from coastal settlements in Jeneponto. The irrigation conditions that directly lead to the coastline are one of the contributors to microplastic contamination in the coastal areas of Jeneponto. Irrigation channels flow freely towards the beach after passing through settlements and aquaculture areas. Irrigation channels filled with plastic waste, owing to indiscriminate waste disposal activities and direct discharge of domestic wastewater, result in the contamination of the irrigation water column, with microplastics being carried to the sea. According to recent research, 88% of the ocean's surface is thought to be polluted by plastic garbage, with 80% of that debris originating from land (Alberghini *et al.,* 2023). The land sources of microplastic waste are predominantly domestic waste or from household activities (Basri *et al.,* 2021). One of these sources is clothing fibers from domestic waste (Ismi *et al.,* 2019). In a global study of microplastic contamination along beaches, Browne *et al.* (2011) found evidence that synthetic fibers from washing clothes are the primary cause of microplastic pollution. Microplastics also originate from beverage bottles, discarded jars, plastic folders, gallon remnants, and small pieces of PVC pipes (Dewi *et al.,* 2015). Other sources include packaging waste and single-use consumer goods (Coyle *et al.,* 2020).

Another factor that can be observed besides abundance is color of microplastics. The color of microplastics is useful for identifying the potential

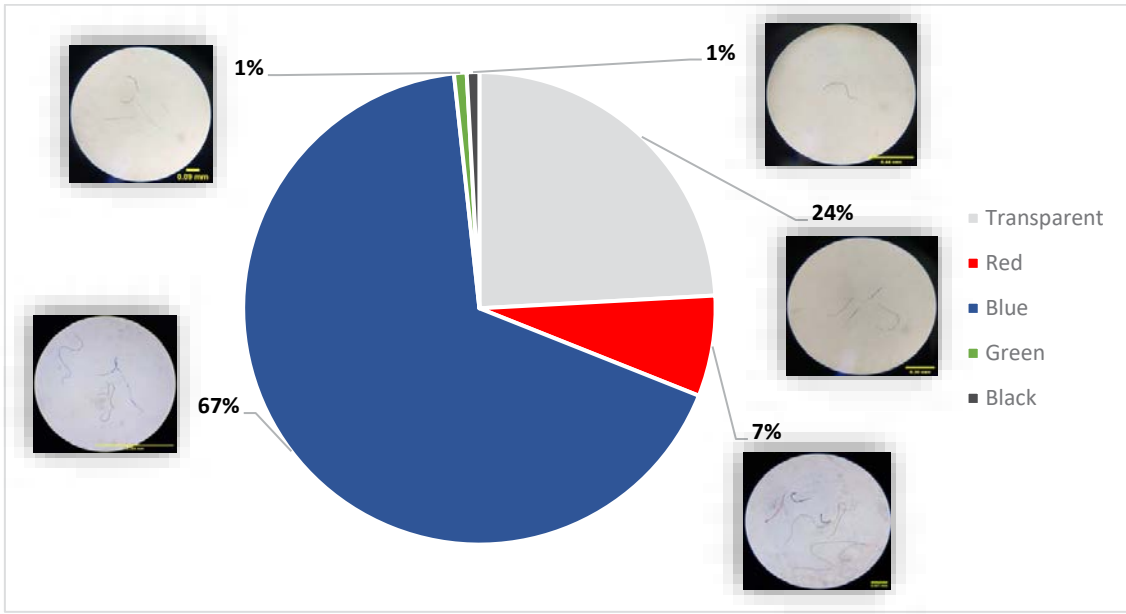

Fig. 6: Different colors of microplastics observed

sources and the contamination potential (Ren *et al.,* 2020). Microplastic colors can originate from additional pigments added during plastic production or from color changes arising from sunlight exposure and chemical reactions in the environment (Zhao *et al.,* 2022). Generally, microplastics are transparent, white, black, blue, red, green, and yellow. The color of microplastic particles in the environment increases the potential for biota consumption owing to their similarity to natural prey (Hastuti *et al.,* 2019). According to the data presented in Fig. 6, the recorded microplastics in the coastal region of Jeneponto were transparent, red, blue, green, and black. The analysis reveals that blue microplastics are the most prevalent, accounting for 78 (67%) of the total, with minimal amounts of green and black microplastics (1 (1%) each). Transparent and red were also found: 28 (24%) and 8 (7%), respectively. The predominance of blue microplastics in this sample underscores previous studies indicating that blue is the preferred color for marine organisms (Rezania *et al.,* 2018). The easiest colour to recognise is blue, which is followed by green and red. According to Monteto-Martínez *et al.* (2020), marine trash is often more prevalent in shallow coastal regions (depth <40 m). This is because the color of the microplastic particles is similar to that of marine species' prey (Kain *et al.,* 2016; Rios-Fuster *et al.,* 2019). Planktonic fish have been shown to have a preference for blue-colored microplastics because blue copepods are their natural prey (Ory *et al.,* 2017). The color of plastics plays an important role in photoaging, microplastic formation, microorganism colonization, pollutant adsorption and release, and biological toxicity. Darker colors absorb more light, causing slower photoaging, but color can also impact other aspects of plastic degradation and microplastic formation (Zhao *et al.,* 2022). Coloring in plastic can pose potential ecotoxicological risks to aquatic biota due to the release of chemical pigments (Lestari *et al.,* 2020). Through the FTIR analysis presented in Fig. 7, the microplastic polymers found in fish and shellfish include VDC, PA, PCTFE, PBT, PIBMA, CAB, PB, and PVC. These findings are different from other studies in which the most common microplastic polymers found in the environment are polyethylene, polypropylene, and polystyrene. Previous studies consistently identified these three types of polymers as the most dominant in environmental samples, including water, sediment, and marine organisms (Andrady, 2011; Law *et al.,* 2010; Rochman and Browne, 2013).

The most dominant polymer type, based on the amount, as shown in Fig. 8, is VDC, which accounted for 42% of microplastics. VDC is used as an intermediate

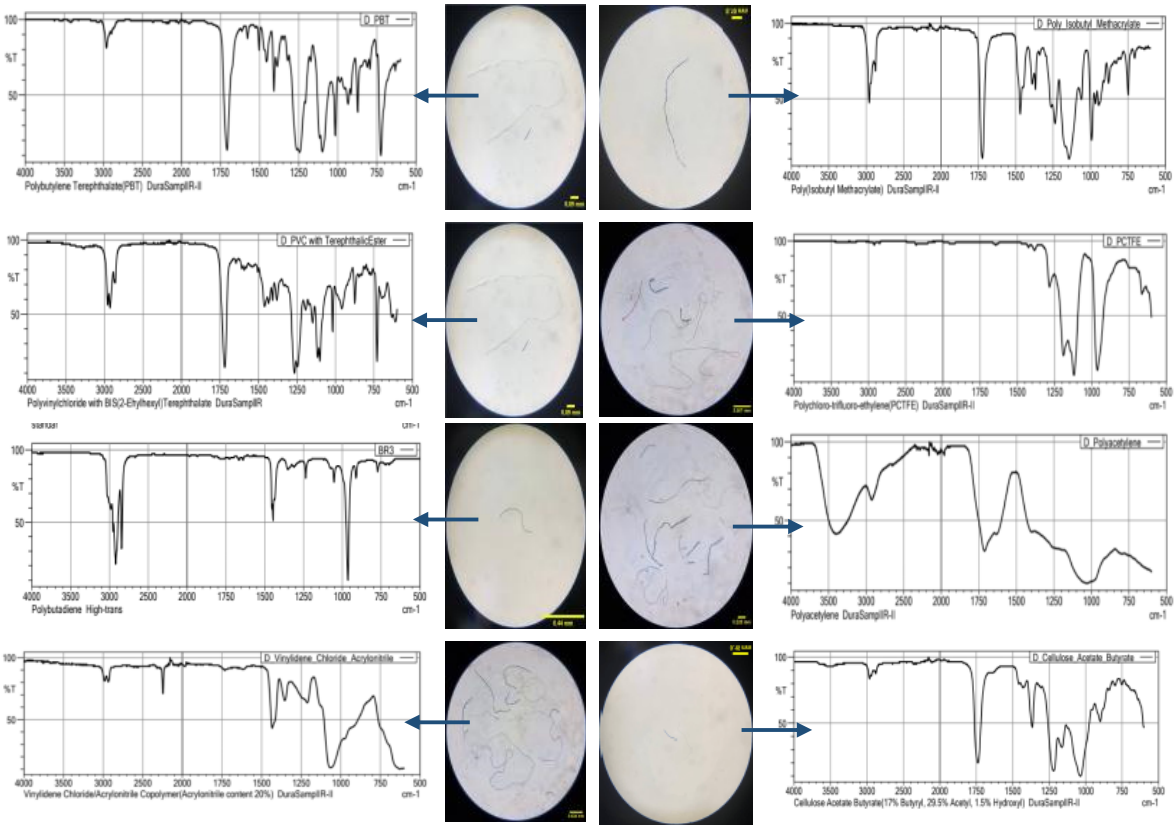

Fig. 7: Results of FTIR analysis of microplastics in shellfish and fish

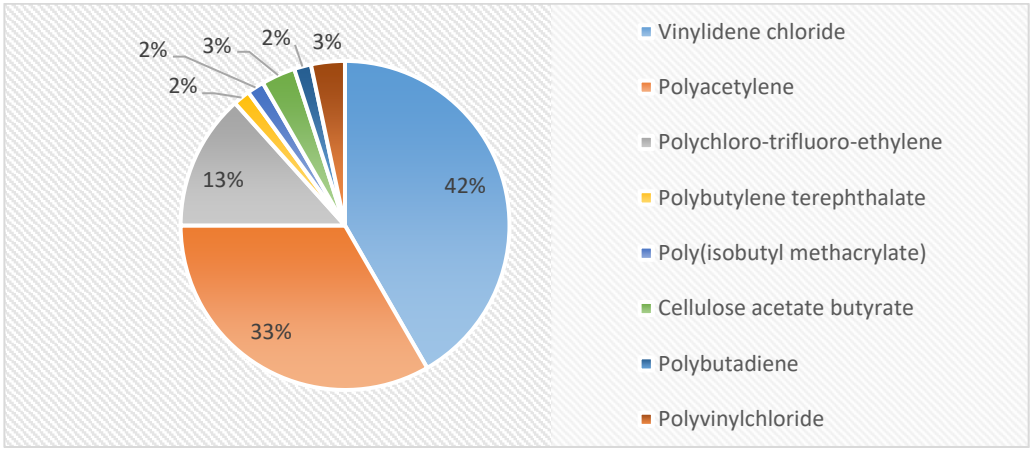

Fig. 8: Percentage of polymer types in microplastics

substance in organic synthesis reactions and widely employed in the production of various polymers that are easily volatile and chlorinated (Astuto *et al.*, 2024; NTP Technical Report, 2015). Most VDC in the plastics industry is utilized in the production of copolymers with polyvinylidene polymers, which have a broad spectrum of applications, including in films for household and industrial food packaging,

as coatings on various products, in flame-resistant fibers and carpet backing, as binders in paints, and for making filaments, pipes, pipe coatings, and gaskets (NTP Technical Report, 2015). VDC is widely present in the environment owing to contamination and is considered hazardous to aquatic life (Astuto *et al.,* 2024). The study conducted by Syamsu *et al.* (2024) contrasted with the present findings. In their research, the most dominant type of microplastic found was PP and PE. PE was identified as the polymer that is easiest to identify owing to its lower density than water. PE and PP are types of plastic that are more common and widely used in various industrial and consumer applications. Research by Andrady (2017) emphasizes that PE and PP are the predominant raw materials in various plastic products, such as food packaging, beverage bottles, and household items, this finding has sparked significant research interest in the field. The initial hypothesis of this research found differences in the types of microplastic polymers compared with previous research such as PP and PE. This study confirms that there are microplastic polymers in fish and shellfish, namely VDC, PA, PCTFE, PBT, PIBMA, CAB, PB, PVC, and VDC as the most dominant types. VDC is often used as a protective coating in food packaging, but its contribution to microplastic pollution remains poorly understood. This may be one reason why there are few studies on VDC. However, research on VDC is gaining importance due to its potential environmental and human health impact, leading to increased interest among researchers to conduct further studies.

There are significant concerns regarding the potential health risks associated with human exposure to VDC. The central nervous system (CNS) is particularly vulnerable to the primary acute (short-term) effects of VDC exposure. At high concentrations, these effects may manifest as CNS depression, intoxication symptoms, convulsions, seizures, and unconsciousness (EPA, 2016). Chronic (long-term) health effects following exposure to VDC can occur some time after exposure and may last for months or years. The mechanism of VDC toxicity is related to the production of reactive metabolites formed through oxidation catalyzed by CYP2E1 in the main target organs—the lungs, liver, and kidneys (Astuto *et al.,* 2024). Vinylidene chloride may be a human carcinogen as it has been shown to cause kidney cancer in animals. Many scientists believe that there is no safe level of exposure to carcinogens (NJS Health, 2010). The second most dominant polymer in the present study is PA, accounting for 33%. Studies in India have found PA in the Ganga River with an abundance of 1.47×10^{-3}–5.69×10^{-3} items/L and in the Yamuna River with an abundance of 4.00×10^{-3}–4.62×10^{-3} items/L, including various types such as beads, films, fibers, and fragments (Vaid *et al.,* 2021). The risks posed by microplastics to both humans and other species are increasing as their prevalence increases in water bodies. Microplastics pose harm when ingested through multiple routes and mechanisms. Toxic substances present in plastic manufacturing, such as polymer compounds and additives such as copper ions, contribute to their hazardous nature. Microplastics absorb a range of toxins from the water, including hazardous compounds, which they may subsequently release into the organisms that consume them (Toxics Link, 2020). PCTFE accounted for 13% of the total polymers identified. The combination of fluorine and chlorine in PCTFE's molecular structure are key to its exceptional qualities as a high-performance thermoplastic (Ebnesajjad, 2021). Engineering plates, rods, pipelines, corrosion-resistant pumps, and valves are made using PCTFE. To achieve film products, electrical insulation, and corrosion protection, it can also be used as a suspension (Zou *et al.,* 2022). PVC and CAB each accounted for 3%, indicating that they have an equivalent level of abundance in the list. PBT, PIBMA, and PB each accounted for 1%. PVC is a polymer known for its exceptional resistance to degradation, and owing to its hard nature, it poses serious environmental problems during production and waste disposal (Barili *et al.,* 2023). PVC can release hazardous additives such as phthalates, bisphenol A, dioxins, Pb, and Cd throughout its life cycle. These substances can leach from PVC microplastics into organisms if ingested, making it one of the most dangerous plastics with serious health and environmental risks (Proshad *et al.,* 2017). In PVC, the addition of plasticizing agents is essential for flexibility and plastic stability. Although phthalate esters, often known as phthalates, are frequently utilized as plasticizers in PVC goods, they are thought to be harmful to human health. They are also harmful to a variety of aquatic creatures and can have endocrine disruption effects in men and male rodent species (Henkel *et al.,* 2022). In CAB, this polymer is

used in various applications, including the glass film industry, coatings, and layers. Although CAB is generally considered a relatively safe material, there is evidence of the potential toxicity associated with exposure to this substance. Research conducted by Zhang *et al.* (2016) indicate that CAB has toxic effects on human cells. The effect of CAB on human hepatoma cells was tested, and it was found that CAB could disrupt cell growth and induce oxidative stress. Exposure to microplastics through food increases health risks owing to the high ratio of microplastic pollutants in seafood (Sharma *et al.,* 2020). Galloway *et al.* (2018) showed that microplastics in shellfish and fish can release harmful chemicals when consumed, potentially damaging organs and causing chronic diseases such as cancer and hormonal disorders. Microplastic particles ingested can adhere to intestinal tissue cells, coat lymphoid tissues, and then be excreted through feces (Stock *et al.,* 2019). The absorption of microplastics by human intestinal epithelial tissue cells leads to cytotoxic effects, although only a small proportion of particles penetrates the intestinal wall (Stock *et al.,* 2019). Patients with increased gut permeability, such as in cases of chronic inflammatory bowel disease, may be more vulnerable to microplastic particle absorption and potential damage (Schmidt *et al.,* 2013). Research on controlling microplastic pollution is crucial for environmental sustainability. Several studies have explored effective strategies. Microplastics are often found in various contaminated aquatic environments processed through wastewater treatment plants (Priya *et al.,* 2023). Wright *et al.* (2019) investigated the potential of filtration technology to reduce microplastics in wastewater and aquatic environments, providing insights into its effectiveness. Mintenig *et al.* (2019) evaluated plastic waste management strategies to reduce microplastic input, offering a foundation for more sustainable policies and practices. To mitigate microplastic pollution in coastal areas, periodic beach cleanups should be conducted to remove accumulated microplastics (Santos *et al.,* 2020). Implementing efficient waste management systems can prevent plastic waste from entering the sea (Hahladakis *et al.,* 2018). The use of monitoring and detection technologies for microplastics in coastal waters (Murray and Cowie, 2011) and public education on the dangers of microplastics and the importance of reducing single-use plastic consumption (Horton *et al.,* 2017) are also essential. Through these approaches, it is hoped that the sources and impacts of microplastic pollution in coastal areas can be reduced. To raise awareness among coastal communities and fishermen about microplastic pollution, active participation through workshops, seminars, and community meetings is vital. These events can provide education on microplastic impacts and mitigation strategies (Zhang *et al.,* 2021). Specialized training on waste management and eco-friendly fishing gear can deepen comprehension and support the reduction of coastal microplastic pollution. Direct involvement in mitigation efforts aims to foster stronger and sustainable awareness of protecting coastal environments from microplastic harm (Van Sebille *et al.,* 2015). Clear steps to address microplastic pollution include drafting policies to limit single-use plastics and promote recycling (Geyer *et al.,* 2017), enacting public awareness campaigns about microplastic impacts and reducing plastic use (Horton *et al.,* 2017), allocating resources for advanced monitoring technologies (Löder and Gerdts, 2015), and fostering collaboration among stakeholders for effective implementation (Worm *et al.,* 2017). These efforts aim to achieve better control of microplastic pollution. Exposure to microplastics through ingestion pathways can occur when these polymers are present in foods consumed by humans. Microplastics contained in food have the potential to enter the human body and negatively impact health. However, the exact impact of exposure to microplastics through ingestion pathways are still not fully understood. In terms of the health and environmental hazards of the types of microplastic polymers through ingestion pathways, further research is needed. Although the available information is still limited, potential concerns have been highlighted relating to exposure to microplastics through ingestion pathways, especially concerning the long-term effects on human health and ecosystems. A key recommendation for further research is to conduct an environmental health risk analysis by expanding the scope of the study to a wider area, particularly in the South Sulawesi Province. The current study is limited to biota and does not investigate the impact of microplastics on humans. It is important to continue this study by examining the effects of consuming shellfish and fish contaminated with microplastics on

human health.

CONCLUSION

This study has shown that Jeneponto Regency in South Sulawesi is currently experiencing a serious problem related to the high volume of plastic waste. The focus of the study was to find the types of microplastic polymers in shellfish and fish sampled from the Jeneponto coastal area. The results of the study results show that microplastics are present in various species of marine organisms, including feather clams, manila clams, kurisi fish, and gulamah fish. In total, 112 microplastic items were identified; most of them were in line form and only one item was in fragment form. The varying abundance of microplastics in shellfish and fish at 12 points in the Jeneponto coastal area indicates the complexity of microplastic exposure in different marine habitats and coastal environments. Feather clams had the highest microplastic content, with sizes ranging from 0.027 to 4.587 millimeters. The total microplastic abundance in feather clams ranged from 0.25 to 2.14 items/gram. Kurisi fish had 22 microplastic items, with sizes ranging from 0.085 to 2.127 millimeters, and a total abundance ranging from 0.01 to 0.08 items/gram. Statistical analysis confirmed significant differences between microplastic abundance in feather clams and manila clams, kurisi fish, and gulamah fish ($p < 0.05$). Blue was the most common color of microplastic; f transparent, red, blue, green, and black items were also found. The microplastic polymers identified in fish and shellfish included VDC, PA, PCTFE, PBT, PIBMA, CAB, PB, PVC. VDC was the predominant polymer, accounting for 42% of items. The results show that this study succeeded in identifying eight types of microplastic polymers. The exploration of rarely studied microplastic polymer types in this study will have a crucial impact on the study understanding of their effects on the environment and human health; different polymers have have unique properties and various impacts when they come into contact with organisms or enter the food chain. Further research and analysis of the health risks are needed for a comprehensive understanding of the impact of these microplastic polymers. Efforts to develop more sensitive detection methods, reduce single-use plastic consumption, and promote environmentally friendly polymer use are necessary to minimize microplastic exposure and its impacts. Effective waste management and conservation measures are essential for preserving coastal environments. Collectively, a commitment to reducing plastic use, recycling, and sustainable solutions is vital to address the global problem of plastic waste and protect marine ecosystems.

AUTHOR CONTRIBUTIONS

S. Basri K., contributed to conducting literature reviews, designing and conducting experiments, sample collection, and drafting the manuscript. A. Daud contributed to managing and developing research ideas, data analysis, and critically analyzing the substantive value of the manuscript. A.B. Birawida, the corresponding author, compiled the map of sampling station locations, interpreted data, enriched discussions, edited, and revised the manuscript. Maming. M. assisted in data collection, sample extraction, characterization of MPs, and data analysis. H.J. Mukono was responsible for supervision, investigation, and reviewing. D.S. Arsyad sampling method, performed supporting analysis, and linked findings with existing literature.

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CONFLICT OF INTEREST

The authors declare no conflict of interest related to the publication of this manuscript. Ethical issues, including plagiarism, informed consent, violations, data falsification and/or manipulation, duplicate publication and/or submission, and redundancy, have been fully addressed by the authors.

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ABBREVIATIONS

=	Equal
µm	Micrometer
<	Less than
%	Percent
-	Until
°C	Degree Celsius
ATR	Attenuated total reflection
BSI	Bank sampah induk (main waste bank)
BSU	Bank sampah unit (unit waste bank)
CAB	Cellulose acetate butyrate
CNS	Central nervous system
DSC	Differential scanning calorimetry
E	East
FAO	Food and Agriculture Organization
FO	Frequency of occurrence
FPA	Focal plane array
FTIR	Fourier transform infrared
g	Gram
Kemenkeu RI	Kementerian keuangan republik Indonesia (ministry of finance republic of Indonesia)
k/h	kilometers per hour
KLHK	Kementerian lingkungan hidup dan kehutanan (ministry of environment and forestry)
km²	Square kilometre
KOH	Potassium hydroxide
mm	Milimeter
nm	Nanometer
PA	Polyacetylene
PAIR	Partnership for Australia-Indonesia research
PB	Polybutadiene
PBT	Polybutylene terephthalate
PCTFE	Polychloro-trifluoro-ethylene
PIBMA	Poly(isobutyl methacrylate)
pyro-GC/MS	Pyrolysis gas chromatography/ mass spectrometry
PVC	Polyvinylchloride
rpm	Rotations per minute
SIPSN	Sistem informasi pengelolaan sampah nasional (national waste management information system)
S	South
sp	Species
SW	Solid waste
TPA/TPST	Tempat pengolahan akhir/tempat pengolahan sampah terpadu (final processing site/integrated waste processing site)
TPS3R	Tempat Pengelolaan Sampah Reuse, Reduce, dan Recycle (Reduce, Reuse, Recycle Waste Management Site)
VDC	Vinylidene chloride
y	Year

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