PAIR
PARTNERSHIP FOR AUSTRALIA-INDONESIA RESEARCH

COMMODITIES

End-of-life of plastics used in seaweed aquaculture in South Sulawesi

Australian Government

The Australia-Indonesia Centre

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Designed by:
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Report date: December 2023

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To cite this report:

This report is the result of research funded by the Australian government through the Australia-Indonesia Centre under the PAIR program.

Werorilangi, S., Hovey, R., Umar, W., Hasyim, H., Harusi, N.M.R., Dexter, K.F., Langford, A., Ruhon, R., Zach, Z. (2023). ‘End of life of plastics used in seaweed aquaculture in South Sulawesi’, the Australia-Indonesia Centre.

The Partnership for Australia-Indonesia Research (PAIR) has launched a series of small-scale initiatives that employ a dual focus to shed light on the interplay between governance, policy and capacity building in key sectors. These initiatives are aimed at supporting four main research themes in the areas of commodities, transport, young people's health and young people's development.

The research adopts a dual strategy, focusing on both governance and policy, as well as capacity building, to reach its objectives. The study also takes into consideration important issues such as gender equality, disability and social inclusion.

This report provides policymakers with a rich source of information and up-to-date evidence that can inform their decision-making. The findings of these PAIR initiatives are essential reading for anyone interested in the future of these key sectors in Indonesia.

Warm regards,

Dr Eugene Sebastian
PAIR Program Director
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EXECUTIVE SUMMARY

Seaweed farming is crucial for the livelihoods of 62,000 Indonesian households, with more than 24,000 of these in South Sulawesi. However the increasing popularity has brought an environmental challenge.

The industry has come to rely heavily on plastic bottles for buoyancy to hold up seaweed lines. These are cheap and readily available compared to alternatives. But as there is no management scheme for plastic waste, the practice leads to a significant garbage pile-up and microplastic pollution.

The bottles degrade quickly and are frequently replaced. The waste left lying around not only finds its way into seaweed cultivation sites and coastal areas but also undermines national efforts to reduce land-to-ocean plastic waste by 70 percent by 2025.

This report explores the environmental impact of plastic use in seaweed aquaculture, focusing on Pitu Sunggu, a village in South Sulawesi, Indonesia. It assesses the presence, distribution and impact of microplastics in the local marine environment of Pitu Sunggu.

We employed a combination of qualitative and quantitative methods. The quantitative aspect involved analysing samples from various sources in the marine environment – specifically seawater, seaweed, epibiota and crabs. Advanced techniques like Fourier Transform Infrared Spectroscopy (FTIR) to analyse the chemical composition of tiny plastic pieces and a straightforward visual examination to identify them by their appearance.

On the qualitative side, we conducted interviews and field observations to understand how the local community manages the plastic waste associated with seaweed farming. This comprehensive approach was designed to provide a thorough understanding of the scale and effects of microplastic pollution in this region, which is heavily dependent on seaweed farming.

Our findings revealed widespread microplastic contamination. In each of the points below, we underscore the critical environmental impact of microplastic pollution in seaweed cultivation and coastal areas. It is also an urgent call for comprehensive measures to address this growing concern.

- **Widespread microplastic contamination:** The study revealed a significant presence of microplastics throughout the local environment, indicating a serious pollution issue. Notably, water samples from areas outside seaweed farming zones showed a 93 percent contamination rate, averaging around 0.81 microplastic items in every litre. But in the places where seaweed is grown and in the river mouths or estuaries, the situation is worse. We found every single water sample contained microplastics, with about 1.5 pieces in every litre of water in seaweed farms and 1.45 pieces in river mouths. This shows that these small plastics are contaminating our waters.
- **Microplastic pollution found in marine life:** Microplastics impact many aspects of marine life, not just seawater. These tiny plastic particles are found throughout ocean environments. For example, 93 percent of the seaweed tested has these microplastics, with about 0.29 tiny plastic pieces in every gram. Marine organisms that live on the ropes and lines used for seaweed farming are also highly affected. About 90 percent of the organisms on the main ropes and 75 percent on the longlines had microplastics, averaging 0.29 and 0.14 pieces per gram, respectively. Even the organisms living on floating bottles showed a 77 percent contamination rate. Crabs, which are important for local meals, were not spared either – a third of them contained microplastics, with about 0.09 pieces per gram.

- **Types and origins of microplastics:** The microplastics come in different size, form and colour, ranging from less than one millimetre to five millimetres. They are found primarily in the form of lines, fragments and foam-like pieces. The colour that showed up the most was blue. Seeing all these different sizes, shapes and colours shows that microplastics come from materials used in plastic bags and water bottles that are broken down in different ways before ending up in the areas where the seaweed is grown.
- **Degradation of plastic bottles:** The study highlighted the problem with how plastic bottles are used in seaweed farming, especially in places like Pitu Sunggu. Farmers typically use plastic bottles in farming practices, which over time degrade and significantly add to the accumulation of marine waste.
- **Problems with following waste rules in Pitu Sunggu:** There are already rules set by the Ministry of Marine and Fisheries for managing waste (known as Regulation Number 1/KEPMEN-KP/2019). But in Pitu Sunggu, these rules are not being followed well. This failure to enforce the rules is adding to the environmental problems the local community is facing.

The study conducted in Pitu Sunggu village has highlighted the potential existence of toxic compounds within microplastics associated with seaweed farming. This finding is significant due to the potential health risks these contaminants pose to humans. The government should consider investigating other seaweed-producing regions in South Sulawesi. This should include exploring the distribution and concentration of microplastics and an analysis of the toxic substances they contain.

The study proposes several recommendations based on the findings.

1. **Implementing the regional strategy policy for waste management:** It is recommended that local and regional authorities cooperate to implement the regional strategy policy (No.35/2018). This implementation should specifically focus on establishing and maintaining comprehensive waste management facilities, including the Waste Management Site Reduce, Reuse, Recycle (TPS3R) within the village. These facilities should be equipped to handle the specific waste challenges posed by seaweed farming, including the disposal of plastic bottles. This initiative should include the provision of resources and training for local staff, ensuring the efficient operation of these facilities and facilitating easy access for community members to promote responsible waste disposal. Integrating advanced waste processing technologies that prioritise reducing, reusing and recycling plastics will be vital. To support this initiative, collaboration with local and regional authorities is necessary to secure funding and resources.
2. **Improving community waste management through education initiatives:** Targeted education initiatives in local communities are needed to significantly improve waste management practices. These initiatives should focus on raising awareness of the TPS3R – the Waste Management Site Reduce, Reuse, Recycle - and promoting environmental literacy, with a particular emphasis on understanding and addressing the issue of microplastics. Initiatives could include the development of education programs designed and introduced in schools, community organisations and through local media that emphasise the importance of waste reduction, reuse and recycling practices. Workshops and seminars could be organised to provide practical guidance on minimising waste and responsibly managing waste materials, including the proper disposal and recycling of plastics used in seaweed farming. Collaboration with environmentalists, scientists and waste management experts at universities and non-government organisations to provide accurate, evidence-based information and practical solutions to the community.
3. **Innovating sustainable seaweed farming practices:** There needs to be a collaborative effort between academics, the government and the seaweed industry to research and develop sustainable materials for seaweed farming. The priority should be creating alternative materials for floating devices to replace less durable and eco-harmful plastic bottles and nylon ropes currently used. The focus must be on solutions that are not only environmentally friendly but also practical, affordable, and able to withstand the weather challenges seaweed farmers face. This cooperation between sectors is vital to progress sustainable practices, lessen plastic pollution in oceans and foster environmental stewardship within seaweed farming communities. By working together, from idea to application, stakeholders can pave the way for innovation that protects both livelihoods and marine life.

Image credit: Pahala Basuki on Unsplash

1.0. INTRODUCTION

Seaweed cultivation has flourished across Indonesia in the last two decades, supporting the livelihoods of 66,000 coastal households (BPS, 2021). As a vital component in food and pharmaceuticals, Indonesia's seaweed production reached 9.11 million tonnes in 2021, with South Sulawesi contributing up to 3.7 million tonnes annually (KKP, 2021).

Beyond its economic importance, seaweed plays a crucial role in marine ecosystems, providing nourishment for diverse species, including crabs and epifauna like crabs and bivalves - such as clams and mussels (Taylor and Cole, 1994). It also serves as animal feed, biofuel and habitat for numerous marine organisms. In Pitu Sunggu village, for example, crab farming is a key community resource and an alternative protein source.

The prevalent seaweed cultivation method in Indonesia, particularly in Pitu Sunggu in Pangkep regency, is the longline method. This approach utilises disposable plastic bottles as floats to keep seaweed ropes near the water's surface (Langford et al., 2022). Their affordability, light weight, ease of transport and buoyancy control make plastic bottles a popular choice in seaweed farming (Hendrawati, 2016; Waters et al., 2019). However, their limited lifespan leads to plastic waste, posing a challenge to this vital industry. To address marine debris, including plastic waste, the Indonesian government issued Presidential Regulation No. 83 of 2018 which aims to reduce marine waste by 70 percent by 2025.

Image credit: Naja Bertolt Jensen on Unsplash

Plastic waste constitutes 80-85 percent of global marine debris (Auta et al., 2017), largely originating from land sources. In Indonesia, about 80 percent of marine debris is from the land with 30 percent being plastic. The increase in plastic waste pollution is attributed to widespread use, inadequate management and the inherent non-biodegradability of plastic (Andrady, 2015). As plastics degrade, they break down into secondary microplastics that are less than 5mm in size, whereas the primary material is micro-sized plastics which are intentionally produced by eg: the cosmetic industry (GESAMP, 2015).

Many reports have shown microplastics are common in various environments and at different trophic levels of marine life, including in surface water, sediments, rivers and marine organisms such as fish, shellfish, seaweed, bivalves and more.

This study investigates potential microplastic contamination from seaweed farming to marine organisms and surrounding areas.

We also examine waste disposal management from seaweed cultivation. The three study areas provide insight into the end-of-life of plastic bottles used in marine seaweed farming and the findings can improve understanding of seaweed farming environmental risks and policy response options.

Objectives:

1. Determine the distribution, abundance and potential source of microplastics from seaweed farms and control locations away from seaweed farms by sampling seaweed, seawater, epibiota and crabs.
2. Investigate biofouling organisms contributing to the degradation of seaweed line plastic components.
3. Assess current plastic bottle use and disposal means by seaweed farmers after use.

(Browne et al., 2011; Cauwenberghe et al., 2013; Tahir et al., 2020; Tahir et al., 2019; Cózar et al., 2014; Hansen et al., 2013; Wicaksono et al., 2020; Barnes et al., 2009; Cole et al., 2011; Von Moos et al., 2012; Lusher et al., 2013 Rochman et al., 2015; Li et al., 2020). Microplastics can obstruct digestion, disrupt feeding patterns and accumulate toxins, threatening organism survival (Von Moos et al., 2012).

2.0. METHODOLOGY

Research approach

This research involves both qualitative and quantitative components.

Quantitative study

The quantitative component collected data on the abundance of microplastics in seaweed, water, bottle epibiota, longline epibiota, main rope epibiota and crabs.

Qualitative study

The qualitative component involved semi-structured interviews with multiple stakeholders such as local government, used-bottle suppliers, seaweed farmers and a grocery store owner. Interviewees were asked open-ended questions related to various themes associated with their occupational background. Interviews with seaweed farmers continued until saturation. We also interviewed the Pangkep Environmental Agency (Dinas Lingkungan Hidup) to understand current waste management regulations in the seaweed sector and their perception of unmanaged plastic waste from seaweed farming in Pitu Sunggu.

Surveys and field observations

This 12-month ethnographic study is based on data collected through field observations and interactions with communities in their natural environment. Additional information came from a household survey from PAIR's overarching commodities report (Langford et al., 2022), which includes data on village livelihoods, seaweed farming routines, harvest cycles, use of plastic buoys and farmers' business plans.

Location and dates

Field research was conducted from July to November 2022 in Pitu Sunggu Village, Ma'rang District, Pangkep Regency, South Sulawesi Province. Microplastics were prepared and identified at the Marine Ecotoxicology Laboratory, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar.

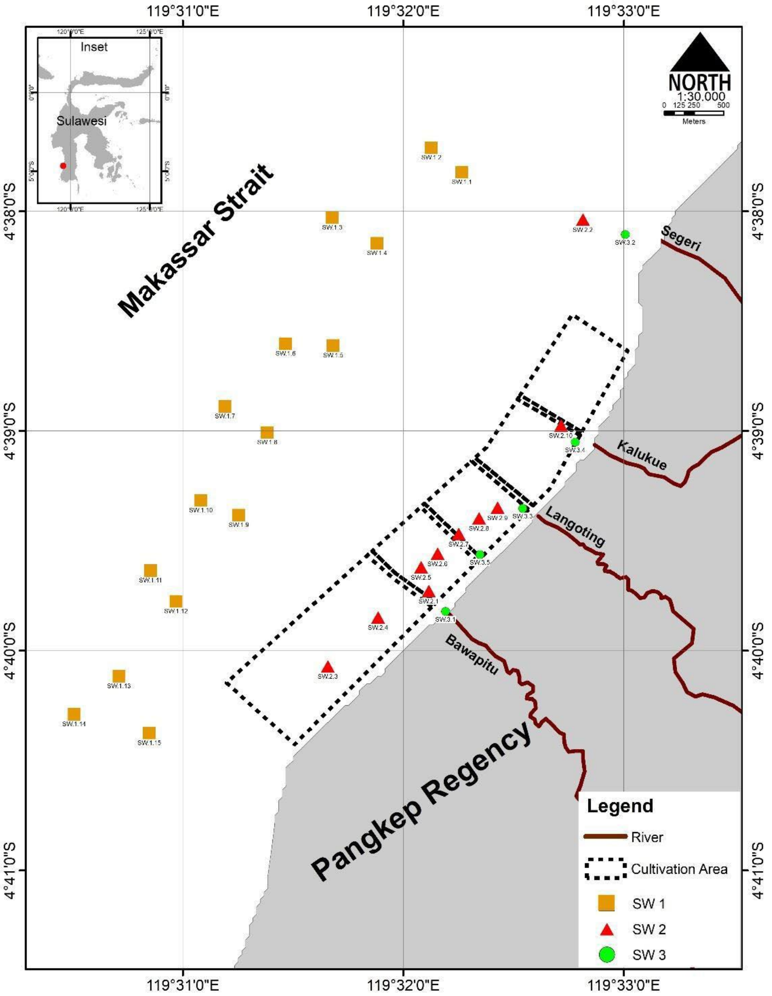

Figure 1. Sampling site in Pitu Sunggu village, Pangkep regency, showing control sites (orange squares), cultivation sites (red triangles) and estuarine areas (green dots).

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Collection and preparation of samples for microplastics

This section outlines our methodologies for collecting and preparing samples for microplastic analysis in various marine environments and organisms:

- **Seaweed sample collection:** Seaweed samples were gathered from thirty longlines across ten seaweed farmers, with each sample prepared by weighing, treating with Fenton's solution, incubating and filtering for microplastics analysis.
- **Epibiota collection from float bottles and lines:** Epibiota, organisms living on seaweed cultivation float bottles and lines, were collected, ground and prepared using a KOH solution to dissolve organic matter before microplastic identification.
- **Water surface collection:** To assess microplastic distribution, seawater samples were taken from thirty stations, including open sea, cultivation areas and estuaries. These samples were collected, filtered and prepared for microplastic analysis.
- **Crab collection:** Blue swimmer crabs were used to investigate microplastic contamination in the food chain. Crabs were collected, dissected and prepared with a KOH solution for microplastic analysis.
- **Current measurement:** Currents were measured in two locations using a Marotte HS current metre to identify patterns and speeds.
- **Identification of microplastic characteristics and polymers:** Microplastics were identified from filter papers using a stereo microscope with further analysis of polymer types conducted using FTIR technology.
- **Contamination prevention and quality control:** Strict procedures were followed to prevent microplastic contamination in field and laboratory settings, including cleaning, sterilisation and the use of control blanks during observation.
- **Statistical analysis:** Microplastic abundances were statistically analysed using One-Way ANOVA.
- **Research ethics:** The study adhered to ethical guidelines, avoiding the use of endangered species and following human research ethics procedures.

3.0. ANALYSIS AND RESULTS

Research site overview

The Pitu Sunggu region primarily engages in aquaculture farming, with a limited amount of land available for agriculture. Local authorities note that Pitu Sunggu village pioneered seaweed cultivation and it now has the largest seaweed farming compared to its neighbouring villages.

Fisheries officers and the village community report that around 150 households in Pitu Sunggu engage in seaweed farming (FN_ZZ_250522). Most of these farmers specialise in cultivating cottoni (*Kappaphycus alvarezii*) and sacol (*Kappaphycus striatus*). Notably, six percent of these farmers have been cultivating seaweed for over two decades, while nearly half, around 48 percent, began their operations within the last ten years.

Seaweed cultivation in Pitu Sunggu takes place in specific areas of the ocean, each offering unique growing conditions. February is generally regarded as the best month for seaweed farming in this region but some also find the month unfavourable for their experience. This variation in farming practices is due to the different conditions of the plots used by individual farmers and so even adjacent plots may have different optimal times of the year for cultivating various seaweed varieties.

Microplastics

Sample description

Kappaphycus striatum is the seaweed grown at the research site. The number of epibiota species observed in the field was lower than usual. This decrease is attributed to the fact that the sampling occurred during the dry season, from May to October, when cultivation activities are closer to the mainland. Among the epiphytes identified in the samples were *Cystoseira* sp., *Gracilaria* sp., *Sargassum* sp., and *Cladophora* sp.,.

The most commonly identified epifauna from the samples included *Perna viridis* and *Balanus* sp. These samples help indicate the impact of plastic pollution on marine ecosystems.

Microplastic abundance

The buoyant and persistent properties of microplastics facilitate their easy and widespread distribution through a hydrodynamic effect. The distribution of these particles in the marine environment is also affected by their density. Observation of microplastic in both the living organisms (biota) and water samples is detailed in Table 1.

Table 1. Sample morphometric and abundance of microplastics in epibiota, seaweed, crabs and water in Pitu Sunggu village.

	Sample morphometric			
No	Sample categories	Amount of samples	Length / diameter (cm, average)	Weight/volume (gr/L, average)
1.	Epibiota on the main rope of seaweed	10	-	20
2.	Epibiota on the longline of seaweed	16	-	20
3.	Epibiota on the bottle of seaweed	30	-	20
4.	Seaweed (Kappapycus striatus)	30	-	20
5.	Crabs (Portunus pelagicus)	30	10.55	75.67
6.	Seawater outside cultivation	15	-	20
7.	Seawater in the cultivation area	10	-	20
8.	Seawater in the estuary area	5	-	20

	Microplastic				
No	Contaminated samples	Amount of microplastic (items)	Abundance (items/ind)	Abundance (items/gr or items/L)	% Contamination
1.	9	58	-	0.29 ± 0.07	90
2.	12	44	-	0.14 ± 0.05	75
3.	23	69	-	0.12 ± 0.07	77
4.	28	173	-	0.29 ± 0.03	93
5.	10	22	0.73	0.09 ± 0.004	33
6.	14	242	-	0.81 ± 0.13	93
7.	10	104	-	1.5 ± 0.23	100
8.	5	145	-	1.45 ± 0.44	100

All eight samples showed contamination with microplastics, though the degree varied. Surface seawater samples exhibited the highest percentage of microplastic contamination, with levels ranging from 90-100 percent. In contrast, small crab samples had the lowest contamination level at 33 percent. Microplastic contamination in the epibiota (organisms living on surfaces in the marine environment) ranged between 75 - 90 percent. These varying levels of contamination are linked to the sources, feeding habits and life cycles of marine biota (McNeish et al., 2018; Walkinshaw et al., 2020).

The eight categories of samples observed differed in microplastic abundance. These were divided into two groups: surface water samples and biota samples, including seaweed, crab and epibiota. The highest mean abundance of microplastics was in surface water samples from the cultivation area (1.5±0,23 items/L), while the lowest was in crab samples (0.09±0,00 items/gr) (Table 1).

Microplastic amounts in surface water samples varied across three locations. Samples from the shoreline waters, overlapping with cultivation areas and estuaries, showed significantly higher microplastic abundance compared to samples from outside the cultivation area (the One-way ANOVA, F=3.536; df=2; p=0.43). This suggests that microplastic concentrations are higher in coastal environments and decrease with distance.

While there is no global standard for describing the level of microplastic pollution, we can compare our results to similar studies. Several studies have shown a lower microplastic abundance than our discovery in Pitu Sunggu (Table 2). However, our results for the mean abundance in water samples from the cultivation area (1.5± 0.23 items/L; 1500 items/m3) have similar results to those in Manila Bays, Philippines (Osorio et al., 2021) and lower than that in Pear Estuary, China (Yan et al., 2019).

Table 2. A comparison of studies on the abundance of microplastics in surface water in various countries.

Samples	Mean abundance	Study location and country	Size	Reference
Water surface (Items/^{m3})	**1.5 items/L (1500 items/^{m3})**	**Pitu Sunggu water, Pangkep regency, Indonesia (cultivation area)**	**<0.1 – 5 mm**	**this study**
	0.73	Lake Victoria (Uganda)	0.3–5 mm	Egessa et al., (2020)
	3.5	Ebro Estuary (Spain)	0.005–5 mm	Simon-Sánchez et al., (2019)
	11	Deep Bay (Hongkong)	<5 mm	Tsang et al., (2017)
	259	Chongming Island in the Yangtze Estuary, (China)	<5 mm	Li et al., (2020)
	279	Northeast Pacific Ocean (Canada)	<5 mm	Desforges et al., (2014)
	751,7	Cochin Estuary (India)	0.25–5 mm	Suresh et al., (2020)
	833	Makati Creeks (Philippines)	0.3–5 mm	Lumongsod and Tanchuling (2019)
	1580	Manila Bay (Philippines)	0.075- 3 mm	Osorio et al., (2021)
	8.902	Pearl Estuary (China)	0.050–5 mm	Yan et al., (2019)

The abundance of microplastics in organisms, such as seaweed, epibiota and crabs varies (Bentotage, 2021; Klomjit et al., 2021). In this study, seaweed had a higher average abundance of microplastics (0.29 ± 0.03 items/gr) than crab organisms (F=6.488; df=4; p=0.00). The high concentration in seaweed in comparison to the blue swimming crab sample might be due to seaweed's position in the water column as well as its sedentary and static life cycle. The blue swimming crab's life cycle, with the adult form mainly residing on the seafloor, might reduce the possibility of microplastic ingestion, letting it pass through the digestive tract.

Studies have found that blue swimming crabs accumulated fewer microplastics than white shrimp (*Penaeus merguiensis*) which might be due to different feeding habits with crabs less aggressive in acquiring their food because they will bury themselves in the sand and wait for their prey compared to shrimp which will eat any species they encounter (Oktafira et al., 2021). Other studies in the Gulf of Thailand (Kleawkla et al., 2019) and Pangandaran Village in Indonesia's West Java province (Oktafira et al., 2021) found an average of 0.73 items/ind and 0.03 items/gr of microplastics in blue swimming crabs. These studies showed a similar abundance of microplastics in blue swimming crabs in our study.

Our study found that the microplastic content in *Kappaphycus striatum* seaweed is lower than in other seaweeds like *Caulerpa* sp. (2.57 items/gr) and *Gracilaria* sp. (9.55 items/gr) as reported by Klomjit et al. (2021). Factors like water depth and sampling location impact microplastic abundance in seaweeds, as noted by Kooi et al. (2016). Gutow et al. (2016) demonstrated that microplastics adhere to the surface of seaweeds such as *Fucus vesiculosus*, correlating with suspended particle concentrations in water. Li et al. (2020) found plastic microfibres in nori ranging from 0.9 to 3.0 items/gr positively correlated with seawater microplastic levels.

Research on different macroalgae, *Pelvetiopsis limitata* and *Endocladia muricata*, by Saley et al. (2019) showed microplastic densities of 2.34 ±2.19 items/g and 8.65 ± 6.44 items/g respectively (macroalgae are classified into three major groupings of brown, green and red). Feng et al. (2020) found that during the cultivation period in Haizhou Bay, *Pyropia yezoensis* had higher microplastic levels (0.17 ± 0.08 particles/gr) compared to other macroalgae. Notably, *P. yezoensis* contained more microplastic fibres during cultivation than during non-cultivation periods.

This data suggests that seaweed farming could be a microplastic source which might transfer to humans through consumption.

Bhattacharya et al. (2010) found that microplastics inhibit algae photosynthesis by blocking light and oxygen absorption. This issue is exacerbated in seaweeds grown using the floating method, as surface water typically has higher microplastic concentrations (Kooi et al., 2016).

The abundance of epibiota in the three sample groups also varied but there was no significant difference detected (F=0.803; df=2; p=0.453). As filter feeders, the diet of the epifauna allows them to influence the level of microplastics in the organisms. The greatest microplastic abundance found on the epibiota of the main rope (0.29 ± 0.07 items/gr) could be due to the epibiota being on it for a longer time. The microplastics in epibiota in the longline and float bottles were lower, and that could be due to frequent cleaning by fishermen after the harvest period.

Other aquaculture activities, such as raft and cage farming, commonly use a variety of plastic equipment, such as fishing nets, floating materials and net cages. These tools are a potential source of microplastics for the coastal environment but yet to be determined as relevant data are limited. Chen et al. (2018) investigated the impact of marine aquaculture activities on microplastics in seawater and sediments in China's Xiangshan Bay and discovered that microplastics derived from mariculture accounted for approximately 55.7 percent of microplastics in seawater. This means that microplastic abundance was 8.9 ± 4.7 grains/m3 (mean±SD, n = 18).

We observed that seaweed, epibiota (including Perna viridis), and the blue swimming crab ingest microplastics at our study site. While the difference in microplastic abundance between these organisms wasn't statistically significant, the abundance in biota compared to water varied significantly. This implies that waterborne microplastics significantly influence biota microplastic levels.

This raises the question of the effects of seaweed farming on the surrounding environment. Green mussels (Perna viridis) and crabs, commonly consumed by the public, are at risk of microplastic contamination. Microplastics, which can absorb toxic chemicals from the environment (Foley et al., 2018), may be ingested by humans when found in clams and the digestive tracts of crabs, posing potential health risks.

This means that monitoring the level of microplastic contamination in marine organisms is crucial.

Further, our Pearson Correlation analysis, a statistical method used to measure the strength of a relationship between two variables (like microplastic levels in different parts of the ecosystem), revealed a significant positive correlation ($p<0.05$) between microplastic abundance in epibiota attached to main ropes and float bottles, and microplastic levels in external cultivation areas and estuaries. Additionally, a positive correlation was observed between microplastic levels in epibiota from longlines and crabs with those in water samples from cultivation areas. These findings highlight the interconnectedness of microplastic pollution within marine ecosystems.

Microplastic characteristics

The shape of microplastics

The study revealed that microplastics can be categorised into three shapes: line, fragment and foam. The line shape was most commonly found in six sample groups (Figure 2). Similar findings were reported in the Spermonde archipelago - off the Southwest coast of Sulawesi - where a high proportion of line-shaped microplastics were observed in both water and sediment (Tahir et al., 2019; Tahir et al., 2020). In addition, a study focusing on estuaries flowing into the Makassar Strait indicated that line-shaped microplastics were prevalent in the water and the local biota primarily ingested these shapes (Wicaksono et al., 2020).

Klomjit et al. (2021) identified the highest concentration of line shapes or fibres in cultivated seaweed of Caulerpa sp. and Gracilaria sp. These line or microfibre shapes often originate from laundry waste and rope (Browne et al., 2011). Dai et al. (2018) noted that more line shapes are found on the water's surface than within the water column, attributed to their lower vertical advection velocity, which causes them to remain on the surface longer.

The fragment shape was most abundantly found in epiphytic samples from the main seaweed rope, totalling 55 items. This type of fragment typically results from the degradation of larger plastics into smaller debris through processes like photolysis, thermal oxidation, hydrolysis and fragmentation by organisms (Andrady, 2011; Andrady, 2015; Davidson, 2012; Corcoran et al., 2009; Cooper and Corcoran, 2010; O'Brine and Thompson, 2010). Li et al. (2020) also observed that line or fibre and fragment shapes were dominant in estuarine samples.

Foam-shaped microplastics were found in two samples, specifically the epiphytic samples of the main rope and float bottles, containing two and ten items respectively. The presence of microplastic particles in water is influenced by their density compared to seawater. Foam-type microplastics, being less dense than seawater, tend to float on the sea's surface. Although less commonly studied, foam microplastics are used extensively in industries like insulation, construction, textiles and packaging (Shah et al., 2007) and are frequently found on beaches, mariculture sites and tourist areas (Zhou et al., 2018) (Figure 2).

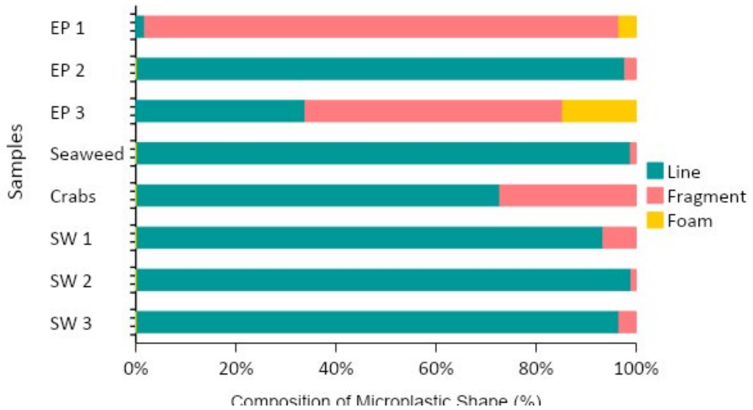


Figure 2. The composition of microplastic shapes in main rope epibiota (EP 1), longline epibiota (EP 2), bottle epibiota (EP 3), Kappaphycus striatum (seaweed), Portunus pelagicus (crabs), waters outside the cultivation area (SW 1), regional waters cultivation (SW 2) and estuaries (SW 3).

Microplastic colour:

Our study identified nine different colours in the microplastic particles (Figure 3). This colour classification is based on the pigments that make up microplastics. Blue was the most common colour, accounting for 35 percent, followed by red at 34 percent, black at eleven percent and transparent at twelve percent.

Colour plays a significant role in the ingestion of microplastics by aquatic biota. Many marine organisms rely on vision to find food and often mistake microplastics for natural prey due to their similar appearance. For instance, epiphytic organisms, which include filter feeders and static seaweed, cannot selectively choose their food intake, leading to a positive correlation between the contaminants in seawater and their presence in these organisms (Rochman et al., 2015).

Marine biota, like fish and other creatures, often eat small, brightly coloured microplastic in the ocean. They particularly consume particles that are white, blue and yellow (Crawford and Quinn, 2017; Wicaksono et al., 2020). This is because these colours stand out in the water and look similar to their natural food. (Ory et al., 2017; Xiong et al., 2019) (Sudirman et al. 2011). In an aquatic environment, the visual appearance of colour is highly dependent on the absorption of light waves in the water. In other words, the way colours look underwater can change depending on the depth. For example, red light does not go very far in water. At anything less than 10 metres deep red light is absorbed by the water. So anything red starts to look dark or black. On the other hand, blue and violet light can go deeper in the water, so these colours stay visible longer as they go deeper. (Land and Osorio, 2011).

The prevalence of certain microplastic colours ingested by organisms might reflect their abundance in the water. Blue is frequently ingested and was the most common colour in our study, possibly due to its high prevalence in aquatic environments (Lusher et al., 2015; Vendel et al., 2017; Ferreira et al., 2018).

Red and blue microplastics may originate from fishing activities using plastic nets. Anthropogenic activities can lead to the production of these non-natural organic pigments. Seaweed cultivation in plastic-polluted waters is another source of microplastic pollution. Black microplastics often come from degrading plastic bags and have a high capacity to absorb pollutants, affecting the texture of microplastics (Hiwari et al., 2019).

Klomjit et al. (2021) found that red microplastics predominate in cultivated seaweeds Caulerpa sp. and Gracilaria sp. Blue, transparent and red microplastics are also common in estuaries (Fan et al., 2019; Jiang et al., 2019). Translucent microplastics often result from the breakdown of food packaging, textiles and fishing lines (Cole et al., 2014).

Microplastics are often coloured with additives that contain metals. Some examples of the metals used are zinc, lead, chromium, cobalt, cadmium and titanium (Hansen et al., 2013). These metals are incorporated into plastics during production to achieve desired colours. Even though certain coloured plastics have been banned in some European countries, research shows that plastics in water still have metals like iron and cadmium in them. These metals are used to make red and yellow colours (Imhof et al., 2016; Rodriguez-Seijo et al., 2016; Nematollahi et al., 2020). So, the different coloured microplastics can transfer harmful substances, including the metals they contain, into the environment around them (Rochman et al., 2015). The metals act like toxins that pollute the water and can build up in animals and plants.

Microplastic size

In this study, the size proportions of microplastics were classified into four categories (Figure 4). The largest size ranged from 1–5 millimetres, representing half of the samples, while microplastics smaller than 0.1 millimetres accounted for the smallest proportion at four percent. The abundance of 1–5 millimetre microplastics is likely due to their formation in coastal areas, where various sources contribute to microplastic accumulation. The distribution of microplastics in the water column is influenced by factors like wind-induced turbulence including surface wave breaking and bubble injection. This vertical distribution is affected by advection transport – the movement of particles by the bulk motion of water – as well as buoyancy and turbulence mixing, which displace the particles from their original position.

Our findings align with these observations, with the highest frequency of microplastic lines in the 1–5 millimetre range. Chen et al. (2018) also reported similar results in Xiangshan Bay, China, finding the average size of seawater microplastics to be 1.54 ± 1.53 millimetres. These spatial variations in microplastic abundance and size suggest that aquaculture-origin microplastics are transported from the gulf to the open sea (Chen et al., 2018)

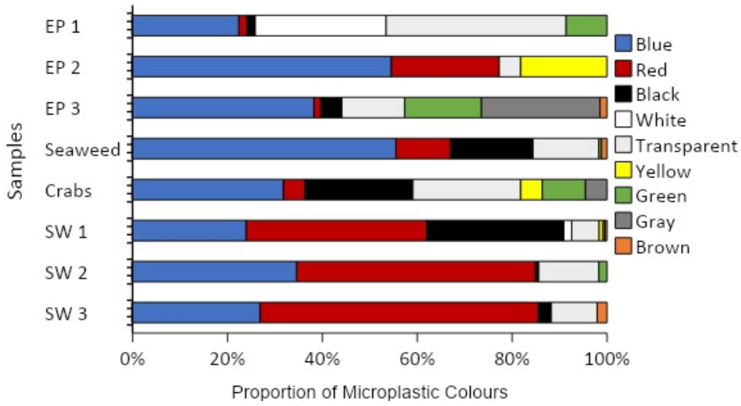


Figure 3. The proportion of microplastic colour in main rope epibiota (EP 1), longline epibiota (EP 2), bottle epibiota (EP 3), Kappaphycus striatum (seaweed), Portunus pelagicus (crabs), waters outside the cultivation area (SW 1), regional waters cultivation (SW 2), and estuaries (SW 3).

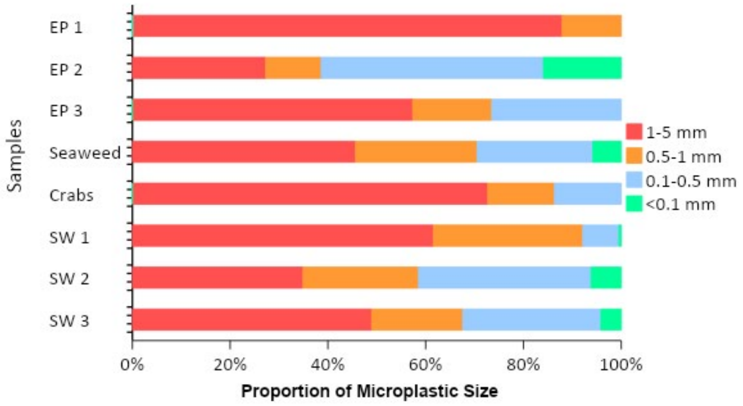


Figure 4. Microplastic size proportions in main rope epibiota (EP 1), longline epibiota (EP 2), bottle epibiota (EP 3), Kappaphycus striatum (seaweed), Portunus pelagicus (crabs), waters outside the cultivation area (SW 1), regional waters cultivation (SW 2), and estuaries (SW 3).

Several studies have identified larger microplastic sizes, specifically 1-5 millimetres, in nori seaweed (*Pyropia* spp.) (Li et al., 2020), and sizes ranging from 0.2 to 2 millimetres in *Caulerpa* sp. and *Gracilaria* sp. (Klomjit et al., 2021). The size of microplastics can serve as an early indicator of the extent of their physical and chemical degradation (Firdaus et al., 2020). In aquatic environments, the size of microplastics can gradually diminish due to various factors such as photodegradation, physical-mechanical impacts, weathering and biodegradation (Andrady, 2011). The longer plastics remain in an environment, the smaller and more abundant they become, making them increasingly available to aquatic organisms (Cole et al., 2013).

Polymer identification

The extensive use of bottles and ropes by seaweed farmers has led them to rely on trash collectors for sourcing used bottles. These farmers typically prefer thick bottles due to their greater resistance to weathering and biofouling. Our FTIR (Fourier Transform Infrared Spectroscopy) testing of these plastic bottles revealed that the farmers predominantly use PET (Polyethylene Terephthalate) and HDPE (High-Density Polyethylene) polymers, as evidenced in the polymer graphs (Figures 5 and 6). Both HDPE and PE (Polyethylene) polymers were detected on longlines.

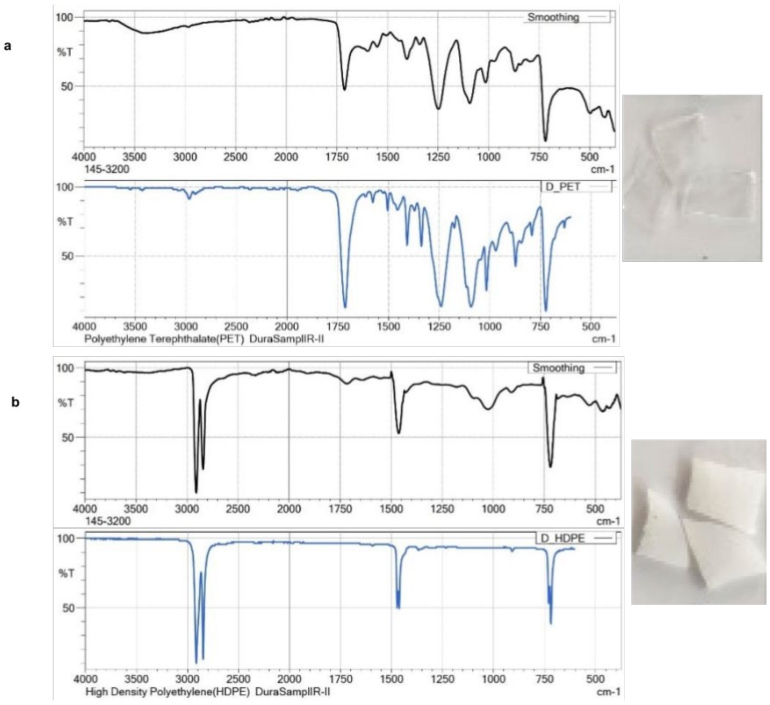


Figure 5. Polymer plastic bottles are used by Pitu Sunggu seaweed farmers. (a) Polyetylene Terephtalate (PET) and (b) High Density Polyetylene (HDPE).

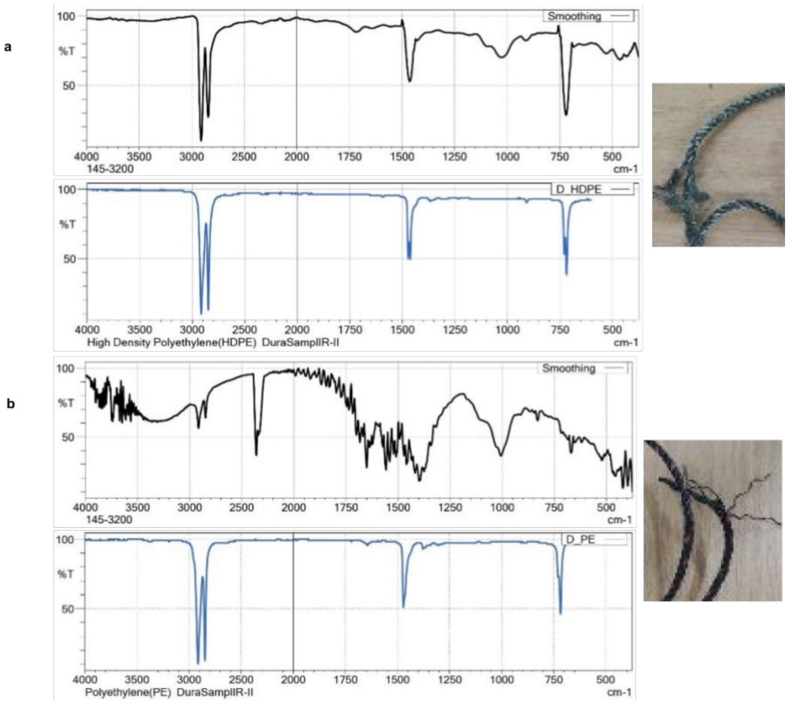


Figure 6. Polymer on the longline used by seaweed farmers in Pitu Sunggu Village. (a) High-Density Polyetylene (HDPE) and (b) Polyetylene (PE).

FTIR testing on 221 microplastic samples revealed 1044 particles, with 98 percent comprising 26 types of synthetic and semi-synthetic polymers (Figures 7 and 8). The top seven polymers identified, which are common in plastic production and dominate the global market, include polyester, polystyrene (PS), polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), high-density polyethylene (HDPE), and styrene monomer (Lithner et al., 2011). Research by Chen et al. (2018) indicates that aquaculture activities impact the quantity of microplastics in seawater and sediments. Identified polymers from marine cultivation include PE foam, PE nets, PE films, PP ropes, PS foam and rubber, with PE foam being the most abundant (38.6 percent) in seawater samples due to its high wear rate and porous structure. However, our study found polyester to be the most prevalent polymer, differing from these results.

Polyester polymers were the most abundant at 34 percent in water, seaweed and crab samples. Polyester is widely used in textiles and clothing fibres (Browne et al., 2011), often originating from microfibres shed during land-based laundry activities and entering waterways through rivers (Wicaksono et al., 2020). This aligns with cultivation areas near river estuaries, such as the Bawapitu and Limangan Rivers to the south and the Lagoting and Segeri Rivers to the north. Moreover, the content of microplastics in the three water sampling stations revealed MP-PS with higher line form category heights (Figure 2). Other polymers found, apart from polyester, included cotton fibre, silk, Tencel, cellophane and silicon rubber.

Polystyrene polymers accounted for 12 percent, with the highest concentration in the epiphytic sample group (EP 1 and EP 2). This study did not explore the effects on *Perna viridis*, but *Mytillus* spp. has shown tissue and cell damage, and even death, due to microplastics (Paul-Pont et al., 2016). Polystyrene microplastics have also been observed in copepod organisms and cultivated algae, affecting reproductive function and diet (Cole et al., 2014). Lu et al. (2016) noted that polystyrene plastics can cause inflammation, lipid accumulation in the liver and metabolic disturbances in zebrafish.

In this research, PE polymer was found to be seven percent, with the total of PE derivatives, including PET and HDPE at 24 percent. To corroborate FTIR results across eight sample categories, 480 plastic bottles from waste collectors in Pitu Sunggu were analysed, all identified as polyethylene terephthalate (PET). PE polymers, commonly found in fishing nets, ropes and seaweed farming float bottles, can degrade into substantial microplastic quantities (Andrady, 2011; Remy et al., 2015; Cheng et al., 2018; Feng et al., 2020). Egger et al. (2020) found polyethylene fragments, a major component of plastic bags and bottles, consistent with the presence of such items in the area. PE can also come from synthetic textile fibres in home wastewater from clothes washing (Feng et al., 2020).

Polypropylene constituted four percent of the polymers found in this study. Due to its wide applications in products like food containers, bags, ropes, pipes and shelves, polyethylene is extensively used (Crawford and Quinn, 2017). Additionally, PBT and PVC with phthalates, known for their hydrophobic properties and persistence in water, were found to contain harmful toxic substances (Mato et al., 2001; Rochman et al., 2013).

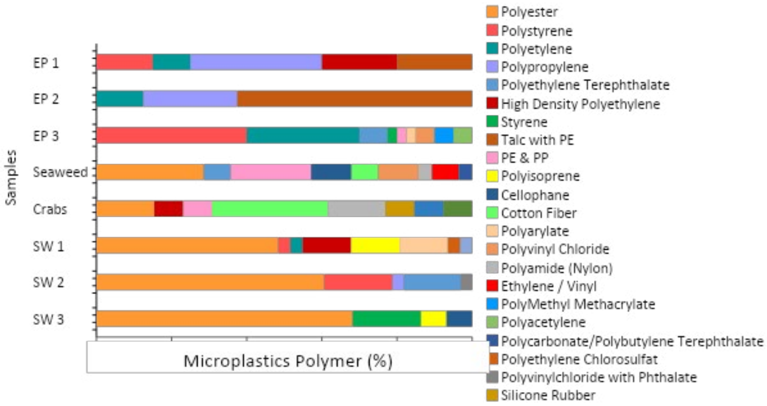


Figure 7. Polymers on microplastics identified in main rope epibiota (EP 1), longline epibiota (EP 2), bottle epibiota (EP 3), Kapaphycus striatum (seaweed), Portunus pelagicus (crabs), waters outside the cultivation area (SW 1), regional waters cultivation (SW 2) and estuaries (SW 3).

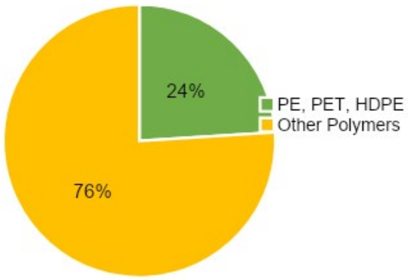
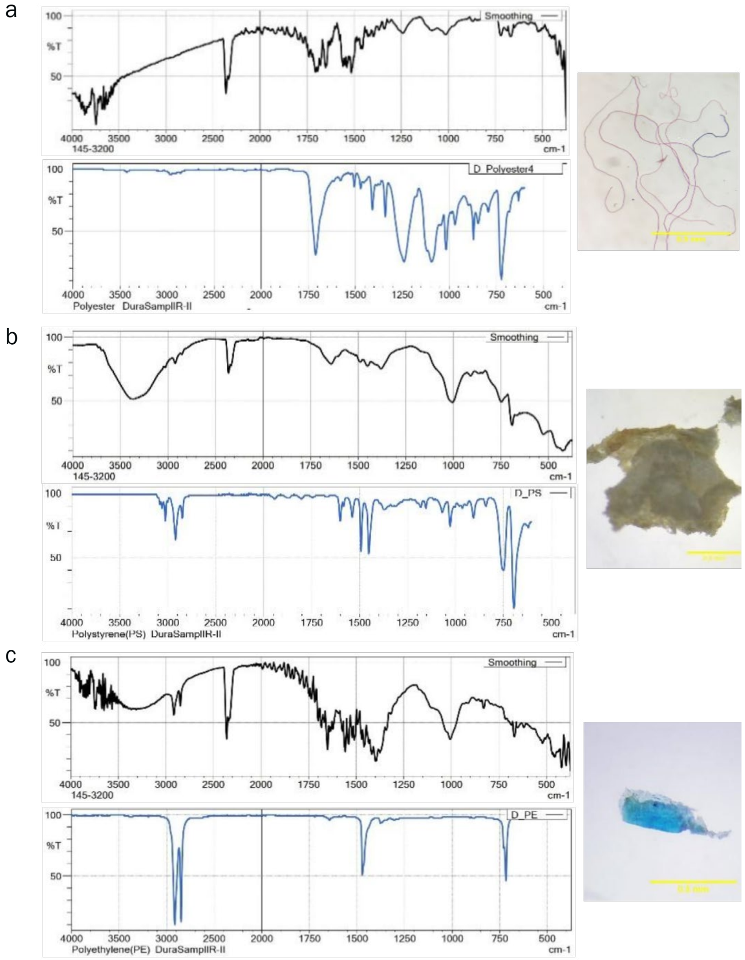


Figure 8. The total percentage of polymer types found from all sample categories. The green colour indicates the percentage of polymer types associated with plastic material used in seaweed farming). The orange colour represents other types of polymers unrelated to seaweed farming.

FTIR (Fourier Transform Infrared Spectroscopy) analysis of microplastic particles from eight sample categories revealed that 24 percent were composed of PE (Polyethylene), HDPE (High-Density Polyethylene) and PET (Polyethylene Terephthalate). This composition correlates with the types of polymers found in plastic bottles and ropes used in seaweed cultivation (Figure 8). The figure also highlights plastic contamination from other sources, including land-based activities. For instance, plastics used in laundry can enter coastal areas via rivers. This aligns with data from the Indonesian government which indicates that 70 percent of ocean waste originates from land-based activities (TKN-PSL, 2020).



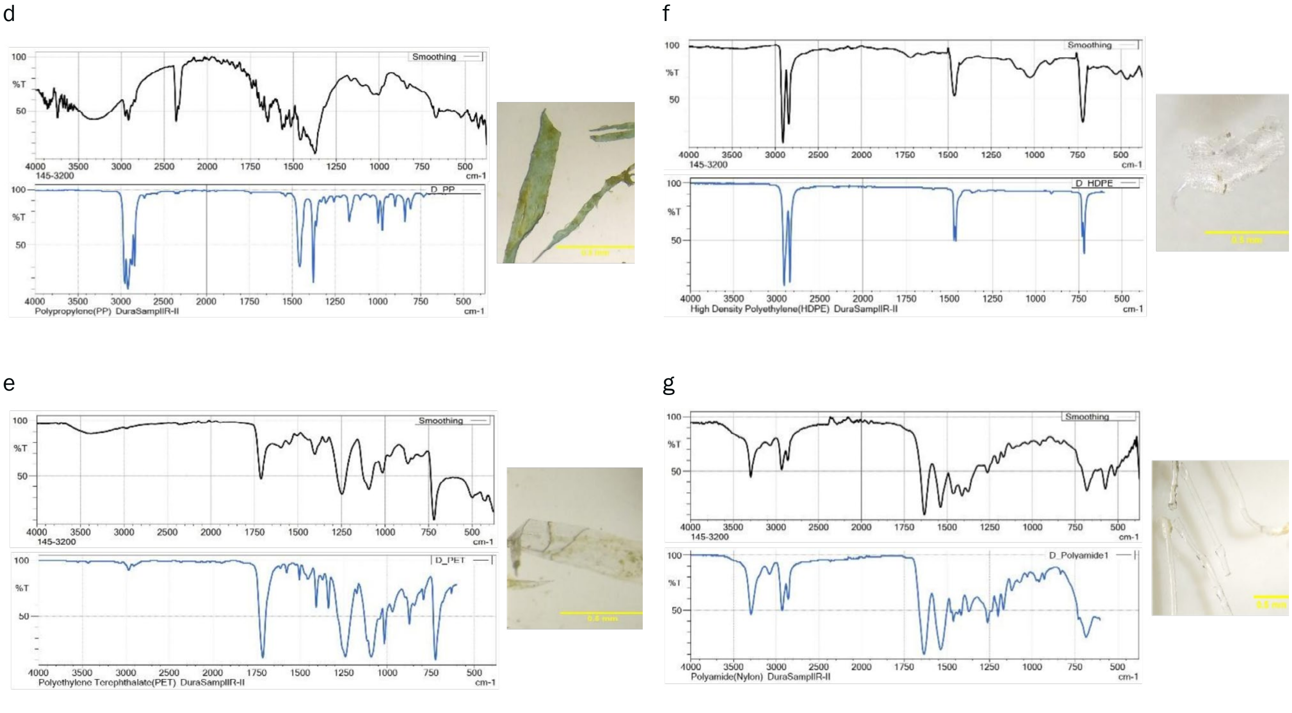


Figure 9. FTIR results of microplastic polymers found in samples (black: sample spectra, blue: pure polymer spectra). (a) Polyester, (b) Polystyrene (PS), (c) Polyethylene (PE), (d) Polypropylene (PP), (e) Polyethylene Terephthalate (PET), (f) High-Density Polyethylene (HDPE) and (g) Polyamide (Nylon).

Microplastic media transport

Ocean currents play a significant role in the movement of substances within seawater including microplastics. Together currents and wind are responsible for transporting and dispersing marine debris, enabling them to travel great distances from the original location (NOAA, 2016). In our study, we conducted measurements at three distinct locations around the Pitu Sunggu cultivation area. This involved a detailed focus on the northern Segeri River and the southern Bawapitu River. We also established a measuring station in the waters near the cultivation area.

At the Bawapitu River station, the current velocity at the river's mouth significantly influences the tidal period. During low tide, the current speed increases to reach 0.05–0.1 metres per second and then decreases during high tide, as Manson (1981) notes. The highest velocity recorded here is 0.62 m/s, averaging 0.18 metres per second. The main flow direction ranges from east to southeast (50°-130°) which is an area extensively used for seaweed cultivation.

At the Segeri River station, observations indicate a predominant current direction from southwest to the west (230°-180°). The current speed is notably fast, categorised as 'very fast' at 1 metre per second (Manson, 1981). The maximum velocity recorded is 1.2 metres per second, with an average of 0.77 metre per second due to high river water discharge and the prevailing current flowing towards the Pitu Sunggu area.

In contrast, the waters outside the cultivation area have a slower current speed of 0-0.25 metres per second (Manson, 1981), with the highest velocity being 0.14 metres per second and an average of 0.08 metres per second. The dominant current direction in the Pitu Sunggu cultivation area is from north to east (350°-100°). Given that ocean currents primarily flow towards the coast, this suggests that pollution in the region is likely confined within the agricultural area. Figures 10 and 11 provide detailed information on the direction and speed of these currents.

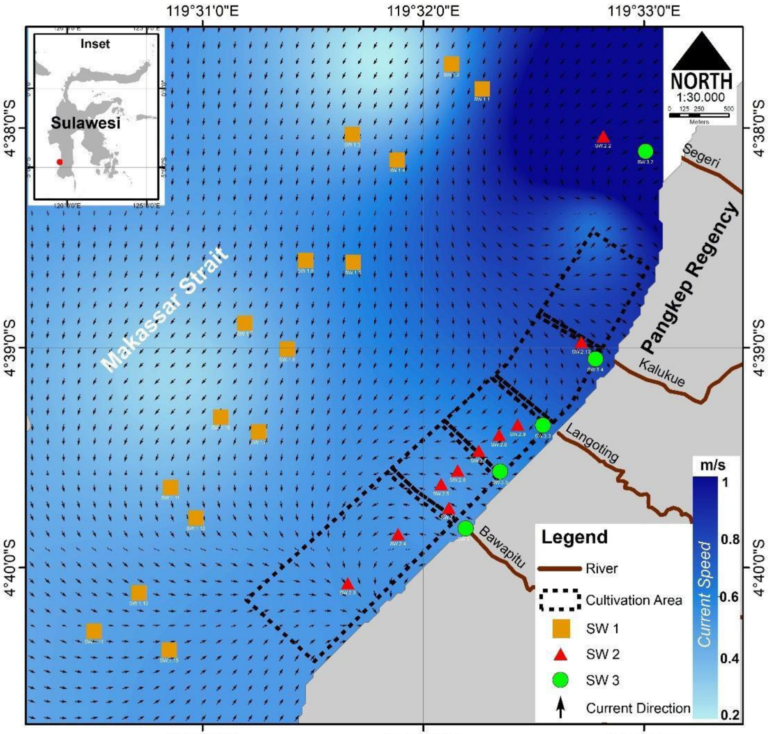


Figure 10. Graph of high tide current speed and direction in Pitu Sunggu.

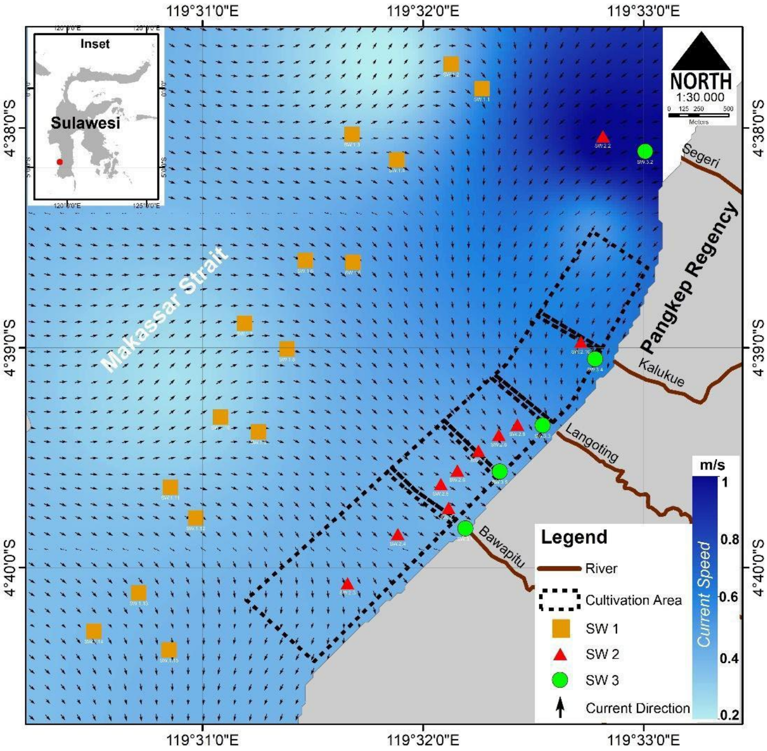


Figure 11. Graph of low tide current speed and direction in Pitu Sunggu

Waste management in Pitu Sunggu

The source and distribution of the used plastic bottles around the village

Our study highlights the widespread presence and accumulation of microplastics in the coastal environment, especially near the estuary and their impact on local organisms like seaweed and crabs. This underscores the importance of understanding the contribution of human activity to plastic pollution.

In this section, we consider the sources and distribution of the used plastic bottles, which are traded in the village for farming purposes. We conducted interviews with four plastic bottle suppliers in Pitu Sunggu. Among them, one respondent operates as a second-hand collector and is the largest distributor of used plastic bottles in the village (WM_RR_02). The other three respondents belong to seaweed farming families and also work as seaweed collectors/traders in the supply chain (WM_RR_03, WM_RR_04, WM_RR_05).

According to the interviewees, these used plastic bottles are primarily acquired from collectors in Pangkep. Some suppliers also mentioned regular procurements from Maros and Makassar (WM_RR_03, WM_RR_05). Two suppliers (WM_RR_03, WM_RR_04) indicated that their supply comes from the village's largest bottle distributor.

This information sheds light on the plastic bottle market's dynamics and identifies key influencers and controllers of this critical resource.

Understanding these aspects is crucial for developing strategies to reduce plastic waste and promote sustainable practices.

Used-bottle suppliers have categorised the bottles into two types for this trade. The first category includes small bottles, holding about 500-650 millilitres, and the second comprises larger bottles with a capacity exceeding one litre. The cost for a sack of small bottles, containing about 200, is 40,000 rupiah, while a sack of large bottles, with 100 bottles , costs 45,000 rupiah. This pricing translates to 150 rupiah per small bottle (just under one US cent) and 350 rupiah for a large bottle. Seaweed farmers typically do not purchase bottles smaller than 500ml as these are unsuitable for use as floats in seaweed longlines (WM_RR_02, WM_RR_05, WM_RR_09, WM_RR_12).

The distribution of bottles is significant with one respondent estimated sending more than 50 sacks of used plastic bottles monthly to various buyers, including seaweed farmers, other village suppliers and plastic processing factories in Pangkep's sub-districts (WM_RR_02). Three other respondents noted that their sales, approximately 30 sacks monthly, cater exclusively to seaweed farming (WM_RR_03, WM_RR_04, WM_RR_05). All suppliers confirmed that their bottles are purchased by farmers in Pitu Sunggu village and neighbouring areas.

The interviewed suppliers acknowledged that several factors affect monthly bottle sales. An increase in seaweed prices impacts the cost of used bottles sourced from outside collectors which is then passed on to customers. In response to a seaweed market downturn, one respondent reduced her prices (WM_RR_02), while the others did not even though there was a sharp decline in seaweed prices (WM_RR_03, WM_RR_04, WM_RR_05). A rise in seaweed prices has had the effect of spurring more Pitu Sunggu residents to enter the seaweed industry, leading to a high demand for used-plastic bottles and occasional shortages. Consequently, suppliers and some farmers have had to seek bottles from farther away.

One supplier mentioned that seasonal changes also influence bottle sales. One observed decreased sales of small bottles (500-650 ml) during the rainy season as farmers reduced their usage (WM_RR_04), while another reported increased operations and bottle sales in the rainy season. The same respondent noted lower sales in the dry season due to reduced farming activities and limited seaweed farming areas (WM_RR_03).

The use of plastic materials in seaweed farming

A typical seaweed farming plot is anchored to the seabed with wooden stakes, which can number in the hundreds depending on the plot size. These stakes are linked by a main rope, usually nylon rope which is 7 - 10 millimetres in diameter. A longline about 25 metres long and 4 - 5 millimetres thick is also used and this too is usually made of nylon. Smaller 'ring ropes,' one millimetre in diameter, are tied to the longline, and the seaweed is attached to these. On average, a longline contains over 400 ring ropes, spaced approximately 4 - 5 hand knuckles apart.

Farmers report that the larger stakes and main ropes are the least likely to break. Many farmers, 54.1 percent of whom have been cultivating seaweed for more than ten years, have not replaced these components for several years. The longline ropes also tend to be durable if used and maintained regularly, with breakages mostly occurring due to storms or rat bites while stored. In contrast, the ring rope is the most frequently replaced item, typically every cycle, with damage often occurring during seaweed harvesting or washing.

Another vital component is the float, which keeps the longline and mainline afloat. The floats are differentiated into buoys for the longline and mainline based on their specific uses. For longline buoys, farmers commonly employ single-use plastic mineral water bottles or soft-drink bottles. At least five bottles are attached initially, increasing to 10 or more as the seaweed grows. A larger float is used for the mainline buoys, positioned at the corners and around the farming plots to balance the main ropes. According to a survey by Langford et al. (2022) of 100 farmers, all respondents used bottles as floats for both the longline and mainline (Figure 12). Furthermore, 38.5 percent of farmers used styrofoam, 37.5 percent used jerry cans and 3.1 percent used ball buoys for their mainline buoys.

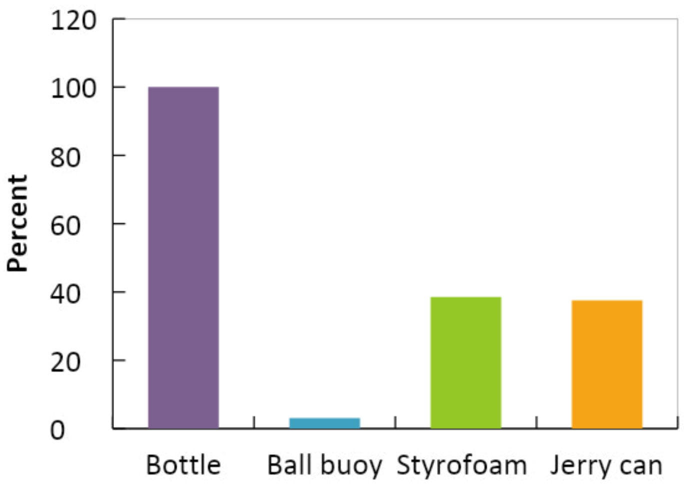


Figure 12. The type of floats in seaweed farming (Source: Langford et al., 2022).

The respondents noted that seaweed farmers typically use bottles as floats, a practice derived from their own experiences and adaptability to seasonal and weather changes. According to the Household (HH) survey report, bottles are the most practical type of float. This is particularly true during the rainy season when maintaining the crop is crucial. If it rains, the seaweed must be submerged to prevent freshwater from settling on its surface. In such cases, farmers either unplug the floats from the longline or fill them with water, causing the longline to sink deeper and more quickly into the water column. Though this requires 'drowning' hundreds of longlines, it's a relatively simple action and a necessary one to avoid losing the seaweed crop.

Conversely, during the dry season, farmers use more floats to keep the seaweed just below the water's surface. This strategy helps reduce the risk of pests and weeds, which are more likely to infest seaweed and ropes that sink too far in the water column. The use of plastic bottle floats is not only practical and effective but also economically advantageous due to their low cost and easy accessibility. For comparison, a five-litre jerry can float costs approximately 3000-5000 rupiah each whereas using four to six 1.5-litre plastic bottle floats costs only 350 rupiah per bottle. By opting for plastic bottles, farmers can save about 50 percent on capital costs. This was highlighted in the HH survey report.

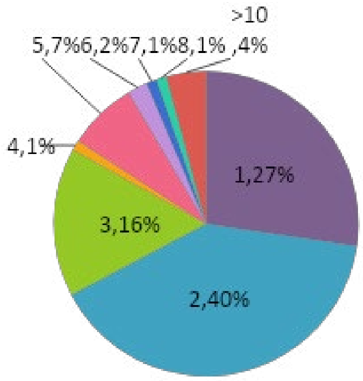


Figure 13. The durability of the bottles from one to up to ten cycles (Source: Langford, et al., 2022).

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[1] The applicable price when the data was collected

While using bottles as floats is practical and cost-effective, respondents recognise their susceptibility to damage due to their relatively thin construction material. As depicted in the survey results (Figure 13), 40 percent of respondents indicated that bottles could last up to two cycles, while 27.4 percent reported they typically last for only one cycle. Conversely, 15.8 percent of respondents suggested that bottles could endure for three cycles, with the rest stating that they could last for more than three cycles.

Other common plastic materials utilised in seaweed farming include nets, tarpaulins and plastic sacks. After the seaweed is detached from the longline, it needs to be dried. Farmers typically spread a net as a mat for this purpose. To protect the seaweed from rain or if it is later in the day, it is covered with tarpaulins. Once dried the seaweed is packed into sacks for sale or temporary storage. These plastic components are universally employed by farmers in managing their post-harvest seaweed.

The fate of the damaged plastic materials used in seaweed farming

According to information from interviews with farmers and other informants in this study, an estimated 30-300 bottles are needed monthly to replace those damaged (WM_RR_04, WM_RR_06, November_FN_RR). It's important to note that this quantity is not fixed and varies based on the number of operational longlines and the current farming season. The specific needs also differ among farmers, depending on their longline count. All interviewed farmers indicated no preference for the brand of plastic bottle, prioritising that it is leak-proof and no smaller than 500ml.

We have learned generally that damaged or leaking bottles are either burned or discarded into the ocean (WM_RR_03, WM_RR_06, WM_RR_07, WM_RR_08, WM_RR_09, WM_RR_12). Farmers residing along riverbanks often dispose of damaged bottles into the river, believing they will eventually be washed away. As one farmer said: "*We have the river, so the damaged bottles will just be thrown into it...and it flows directly into the sea.*" Another farmer opts to bury broken bottles to avoid the negative impact of burning plastic, having previously lost chickens allegedly due to toxic smoke from burnt plastic bottles (WM_RR_12).

Respondents also shared that once plastic materials such as ropes, tarpaulins and sacks are no longer useful, they are buried. This practice is intended to prevent these materials from entangling boat propellers if discarded into water bodies (WM_RR_11, WM_RR_12). Previously, used-bottle collectors from outside the village would exchange money or plastic household goods for unused bottles from farmers (WM_RR_03, WM_RR_05, WM_RR_08, WM_RR_09). However, this practice ceased about three years ago as collectors found it difficult to remove barnacles from the bottles, which damaged their plastic-chopping machines (WM_RR_03, WM_RR_12).

The prevalent practice of disposing unused plastic materials in water bodies and on land poses a significant risk of environmental pollution, both in terms of macroplastics and microplastics.

Immediate measures are required to manage these unused plastics to mitigate further environmental damage.

Waste management at the village level

Both local government and interviewed villagers acknowledge the absence of a specific waste management program. Despite recent aid to residents, it serves more as a charitable service rather than a solid waste solution which includes managing plastic waste from seaweed farming.

For example, years ago, a large garbage container was provided to the village (WM_RR_11, WM_RR_01) but the accompanying garbage collection service ceased within weeks, leading to garbage build-up and foul odours. After a year of disuse the container was returned to the district government (WM_RR_01).

More recently, iron drum trash bins were distributed to some residents along the village's main road (WM_RR_01, WM_RR_02, WM_RR_08, WM_RR_09, WM_RR_11, WM_RR_12). Despite a promise of regular collection for a monthly fee, the service was short-lived, leaving many bins rusted and damaged (WM_RR_09).

The Environmental Agency of Pangkep (DLH) cites financial constraints and a shortage of dump trucks as reasons for irregular garbage collection in many Pangkep villages, including Pitu Sunggu. The district government has asked each village to manage waste using government-provided Dana Desa development funds.

The village government plans to establish a temporary dump site, Tempat Penampungan Sementara (TPS), in Pitu Sunggu, but a specific timeline for this plan remains undecided and formal discussions slated for 2024. Despite the lack of a waste management system, farmers seem unaffected by plastic waste, though some wish for better community waste management.

The 2019 Seaweed Cultivation Guidelines by the Minister of Maritime Affairs and Fisheries mandate responsible disposal of cultivation materials without harming the environment and encourage using eco-friendly equipment. However, the 2019 Presidential Decree No. 33's National Seaweed Industry Development Roadmap (2018-2021) does not propose acquiring such eco-friendly facilities or equipment

Existing regulations on the national level

Pangkep Regency has developed the JAKSTRADA documents, underpinned by the Pangkajene and Islands Regent Regulation Number 35 of 2018. This regulation outlines regional policies and strategies for managing household and similar waste, aligning with the National Regulation "Presidential Regulation Number 97 of 2017 (PP. No. 97/2017)." This national regulation represents a significant step in Indonesia's waste management efforts.

The JAKSTRADA goal is to achieve 100 percent effective waste management by 2025. This includes reducing waste generation by 30 percent and improving waste handling by 70 percent within the same timeframe.

Included in Pangkep's JAKSTRADA are attachments that identify potential waste generation, compile waste management data, and provide a waste management balance sheet. The regulation sets forth policies, strategies, and specific targets for waste reduction and handling in the Pangkajene and Islands Regencies from 2018 to 2025. It proposes several measures to enhance waste reduction and promote improved management. These proposals include:

1. **Boosting community participation in waste management,** including sorting, collection, transportation, processing and final disposal, the following strategies are employed:
    a. Implementing communication, information and education (IEC) initiatives at the district and sub-district levels, both formally and informally. This involves carrying out waste handling activities and establishing Waste Bank Units (Bank Sampah Unit) within communities.
    b. Promoting a 3R-based Waste Disposal Area (TPS3R) and increasing residents' willingness to pay for waste management services.
    c. Providing capacity building through extracurricular learning, mobile libraries, curriculum subjects and educational parks.
    d. Strengthening the collaboration between central and regional governments is crucial. This includes developing landfill disposal sites (Tempat Pembuangan Akhir-TPA), revitalising programs at the regency level, constructing recycling centres (PDU) at the regency level, building compost houses and developing biodigesters.
2. **Strengthening commitment for budget allocation:** Both executive and legislative institutions at central and regional levels working to ensure dedicated budgets for handling household waste and waste similar to it.
3. **Enhancing law enforcement:** This involves conducting studies and establishing standard fees for waste handling services, including transportation, processing, and final processing. These efforts will be documented in official output documents.
4. **Implementing incentive and disincentive systems:** There is a focus on developing systems of incentives and disincentives to better manage household waste.

Reviewing the documents revealed a 2018 Regent Appeal (No. 660.1/18/DLH) and six 2020 announcements (No.6601/30-36/DLH) addressing waste management in Pangkep Regency. These directives target the Head of the Education Office, the Trade Office, Regional Apparatus Organisations (OPD), restaurant and retail shop owners. The key message is for all stakeholders to maintain cleanliness, equip themselves with trash cans or waste processing facilities and implement the 3R principles (Reduce, Reuse, and Recycle), along with composting.

A discussion with the Dinas Lingkungan Hidup (Environmental Agency) of Pangkep revealed that Bontokio village has set up a Centre of Waste Bank (Bank Sampah Induk/BSI). This bank collects and processes recycled and inorganic waste from various sources, including the community, institutions, offices and markets. The waste is then distributed to waste collectors or segregators for resale based on its economic value. BSI records transactions manually and reports its activities to the Ward Office regularly. They also coordinate with the Pangkep Environmental Office and other related Regional Work Units (SKPD). However, it’s noted that there is no BSI in Pitu Sunggu.

While the Pangkep government has made efforts at the regency level, including the JAKSTRADA document and various appeals and submissions to stakeholders, a comprehensive waste management scheme is still absent in 65 villages including Pitu Sunggu.

Image credit: Febrian Adi on Unsplash

4.0. FINDINGS AND RECOMMENDATIONS

Conclusion

The study found that microplastics are widespread in various forms across the coastal environment, including in the water, seaweed, epibiota and crabs. The highest concentration of microplastics was found near the estuaries and on organisms attached to the main ropes used in seaweed farming, including the seaweed and epibiota themselves. The abundance of microplastics ranged from 0.09 to 1.5 items per gram or per litre.

The microplastics found were classified into three types: line, fragment and foam, and displayed a range of colours, with blue, black, red and transparent being the most common. Their sizes varied, falling into four categories ranging from one to five millimetres.

The study identified 26 different types of synthetic and semi-synthetic polymers, with polyester, polystyrene (PS), polyethylene (PE), polypropylene (PP), HDPE, PET and nylon being the most common. FTIR test results showed a correlation between these polymers and materials found in plastic bottles and ropes used in seaweed farming. The study noted the influence of ocean currents on the distribution of microplastics, which varied in speed from slow to very fast at different cultivation locations.

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Qualitatively, plastic bottles used in Pitu Sunggu are obtained from informal sector waste collectors in Pangkep, Maros and Makassar. The number of bottles sold monthly correlates with the number of operational longlines and varies with seasonal conditions. Over time these bottles often degrade and become damaged and become unusable. Due to barnacle accumulation, farmers cannot resell the used bottles so they are often discarded into rivers or ocean, left on the land or buried.

Despite the Ministry of Marine and Fisheries Regulation Number 1/KEPMEN-KP/2019 providing waste management guidelines for seaweed farming activities, there is no specific regulation in Pitu Sunggu addressing plastic waste. At the district level, the Pangkep government has developed waste reduction and handling plans in the JAKSTRADA document. However, these regulations have not been effectively implemented at the village and sub-district levels in Pitu Sunggu. This lack of implementation contributes to the escalating plastic waste problem in the area.

Recommendations

Waste management at the household level is crucial in preventing plastic from entering the ocean through rivers. There is growing awareness and concern amongst Indonesian consumers about plastic pollution in marine food such as clams and crabs. This has resulted in stricter pre-consumption processing by washing the animals in clean water to remove pollutants. More research is needed to determine the impact of toxic pollutants, such as persistent organic pollutants (POPs), heavy metals, pesticides and other harmful compounds that accumulate in microplastics from the environment. The potential risks of higher-level health threats to humans also need to be assessed.

Based on these findings, the study proposes several recommendations.

1. **Implementing the Regional Strategy Policy for Waste Management:** it is recommended that local and regional authorities cooperate to implement the Regional Strategy Policy (No.35/2018). This implementation should specifically focus on establishing and maintaining comprehensive waste management facilities, including the Waste Management Site Reduce, Reuse, Recycle (TPS3R) within the village. These facilities should be equipped to handle the specific waste challenges posed by seaweed farming, including the disposal of plastic bottles. This initiative should include the provision of resources and training for local staff, ensuring the efficient operation of these facilities and facilitating easy access for community members to promote responsible waste disposal. Integrating advanced waste processing technologies that prioritise reducing, reusing and recycling plastics will be vital. To support this initiative, collaboration with local and regional authorities is necessary to secure funding and resources.
2. **Improving community waste management through education initiatives:** It is recommended to implement targeted education initiatives in local communities to significantly improve waste management practices. These initiatives should focus on raising awareness of the TPS3R - the Waste Management Site Reduce, Reuse, Recycle - and promoting environmental literacy with a particular emphasis on understanding and addressing the issue of microplastics. Education initiatives could include the development of education programs designed and introduced in schools, community organisations and through local media that emphasise the importance of waste reduction, reuse and recycling practices. Organise workshops and seminars that provide practical guidance on minimising waste and responsibly managing waste materials, including the proper disposal and recycling of plastics used in seaweed farming. Collaborate with environmentalists, scientists and waste management experts at universities and non-government organisations to provide accurate, evidence-based information and practical solutions to the community.
3. **Innovating sustainable seaweed farming practices:** Establish an effort among academia, government and industry to drive the research and development of sustainable materials for seaweed farming. This initiative should prioritise the creation of alternative materials used in floating devices, aiming to replace the less durable and environmentally harmful plastic bottles and nylon ropes currently in widespread use. The focus should be on developing solutions that are not only eco-friendly but also practical, cost-effective and suited to the diverse challenges faced by seaweed farmers, particularly during adverse weather conditions. This collaborative approach is essential for advancing sustainable seaweed farming practices, significantly reducing plastic pollution in marine ecosystems and promoting environmental stewardship within the community.

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5.0. REFERENCES

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5.0. STAKEHOLDERS

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Pangkep Environmental Office

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Pangkep Research and Development Planning Office

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Acknowledgements

The Australia-Indonesia Centre (AIC) acknowledges the Australian government for its generous support of the Partnership for Australia Indonesia Research (PAIR) through the Department of Foreign Affairs and Trade. The AIC also gratefully acknowledges the government of Indonesia's support for PAIR through its Ministry of Research and Technology.

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