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Analysis of microplastic contamination in the waters of Nunukan Regency and accumulation of contamination in *Kappaphycus alvarezii*

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ABSTRACT. Microplastics originate from community activities such as household waste, agriculture, aquaculture, capture fisheries, and other activities related to these sectors. Microplastics (MPs) are a problem in most waters, with the potential to indirectly impact ecosystems. The purpose of this study was to obtain information regarding the type, color, size, and abundance of microplastics and determine the relationship between microplastic abundance in seawater and *Kappaphycus alvarezii* seaweed. This study was conducted using a purposive sampling method in six regions with 30 water and seaweed sampling stations, Data were analyzed using Microsoft Excel and SPSS 25 software with Pearson's correlation and paired t-tests to determine the relationship between variables, expressed as the correlation coefficient (r). The results showed that the types of microplastics found in seawater and seaweed consisted of pellets. fibers. fragments. and films of various sizes. The fiber type was the largest because its elongated shape gives it greater overall dimensions than other microplastic types. The most dominant color of the microplastics was black-gray. followed by red-pink. green. yellow. purple. and transparent. The correlation test between the abundance of microplastics in seawater and seaweed showed a value of 0.119>0.05 indicates there is no correlation between MPs in seawater and seaweed. However. a statistically significant difference was found between the amount of microplastics with value 0.00<0.05. This result indicates that seaweed has the capacity to accumulate MPs pollution in seawater.

Keywords: *Kappaphycus alvarezii*; marine ecosystem; microplastic contamination; seawater pollution; seaweed

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INTRODUCTION

Plastic waste is currently a serious problem for the environment and humans(Putra *et al*., 2024). Plastic waste is malleable, lightweight, inexpensive, and highly durable, thus encouraging a culture of single-use and throwaway (Kameel *et al*., 2022). Seaweed cultivation contributes to plastic waste in marine environments. Indonesia, the second-largest seaweed producer, accounting for 29% of the world's total production after China (Kementerian Kelautan dan Perikanan, 2023) shows a significant contribution from seaweed farmers. According to a survey by the Badan Pusat Statistik (BPS) of 23 provinces in Indonesia, North Kalimantan is one of the five largest seaweed producers, with a production of 441,152 tons, the main producing area being Nunukan Regency (BPS, 2021).

The high level of aquaculture activity indirectly impacts the health of coastal and marine ecosystems. The use of plastic bottles as substitutes for buoys has increased drastically without proper waste management (Welellu *et al*., 2025). Plastics discarded into the environment experience mechanical and physicochemical damage and form plastic fragments known as microplastics (Zhang *et al*., 2021). Furthermore, ropes, anchor lines, packing sacks, and drying mats are generally made of plastic and degrade over time due to prolonged use and lack of maintenance, leading to the emergence of microplastic hazards in aquaculture environments (Wicaksono, 2022). The resulting microplastics ultimately impact aquatic ecosystems, including seaweed (Pamungkas *et al*., 2021). Contamination of seaweed commodities is unavoidable because they are cultivated using the longline method, which settles in the water column, allowing microplastics to be trapped (Werorilangi *et al*., 2023). The higher the microplastic content in seaweed, the lower the photochemical efficiency and chlorophyll a content (Gao *et al*., 2021).

Research related to microplastics has been widely conducted in waters, sediments, organisms and macroalgae such as in the Porong River, Sidoarjo Regency, East Java (Seftianingrum et al., 2023), Brondong coastal waters, Lamongan Regency (Labibah & Triajie, 2020), North Galesong sea waters (Humaerah & Rasyid, 2024), Wulan River Delta waters, Demak Regency (Wulandari *et al*., 2022), Indonesian sea waters (western Indonesia such as Java, Sumatra and eastern Indonesia such as Rote Ndao, Bali, Kendari, Kupang and Kutai Kartanegara) (Ambarsari & Anggiani, 2022), West Kalimantan mangrove coastal sediments (Febriyanti *et al*., 2024)), in shellfish fishery commodities (Lutfi *et al*., 2023), seaweed in Kupang Regency, East Nusa Tenggara (Serihollo *et al*., 2025), *Eucheuma cottonii* seaweed in Bomo Beach, East Java (Suryandari *et al*., 2022), and on the seaweed *Saccharina japonica* and *Pyropia yezoensis* in the form of microfibers <500 µm which are widely consumed by East Asian people (Gutow *et al*., 2015). Of the various related studies, there has been no research related to microplastics in Nunukan Regency or the relationship between the abundance of microplastics in the water and the accumulation of pollution in *Kappaphycus alvarezii.*

Based on this, research is needed on microplastic contamination in the waters of Nunukan Regency and the accumulation of contamination in *K. alvarezii*. This study aimed to determine the type, color, size, abundance, and accumulation of contamination in *K. alvarezii* to provide information and preventative measures for mitigating microplastics.

MATERIALS AND METHODS

Study area. This study was conducted in 6 (six) areas: Tanjung Harapan, Mansapa, Nunukan Selatan, Selisun, Liang Bunyu, and Binalawan (Fig. 1).

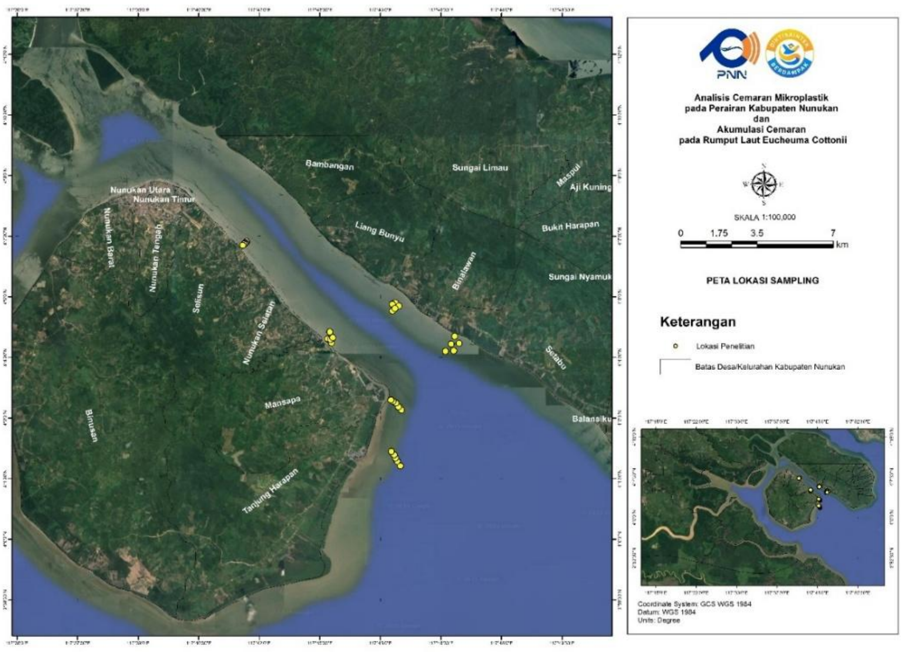


Fig. 1. The observation station in Nunukan District: Station I Tanjung Harapan; station II Mansapa; station III Nunukan Selatan; station IV Selisun; station V Liang Bunyu; station VI Binalawan

Sampling. The seawater collection process was carried out using a plankton net 30 cm in diameter by 1 m in length with a net mesh size of 50 µm (Campanale *et al*., 2020). The plankton net was deployed from the stern of the ship and towed for 5 min. The plankton net was then lifted and rinsed with seawater to allow all organic and inorganic materials to enter the sample bottle. Seaweed samples (500 g) were collected from the seawater collection location and placed in a sample bottle. The samples were then stored in a cool box and the preparation process was continued.

Time research. The research activities were carried out for 60 days from September to October at the Teknologi Hasil Perikanan Laboratory of Politeknik Negeri Nunukan, Kualitas Air Laboratory, and Sentral Ilmu Hayati Laboratory of Universitas Borneo Tarakan.

Laboratory analysis. The laboratory analysis was carried out in two steps preparation. First step, preparation seawater was prepared by filtering 100 ml of water and then oven-dried at 60 °C for 24 h. After oven drying, the sample was degraded with 30% H_2O_2 and separated using 30% NaCl (S. Safitri et al., 2022). The preparation was then filtered through 90 mm Whatman's grade 42 ashless cellulose paper with 2.5 µm pores. The second step was prepared the seaweed in three process (Serihollo *et al*., 2025). The first, 200 g of seaweed was washed with 100 ml of distilled water and the washing water was filtered. Second, the washed seaweed was added to 100 ml of distilled water, stirred at 150 rpm for 15 min, and filtered. Third, the seaweed was degisted using 6 M NaOH for 72 h at 60 °C. The sample was then added to 1:2 distilled water and filtered.

Identification. The filtered sample results were identified using a monocular microscope, followed by the MP identification process, which included the type, color, size, and abundance of MP. The type and color of the particles were calculated followed (Mahadika, 2022):

$$\textbf{Percentage}\ (\%) = \frac{\textbf{number of colour particle}}{\textbf{total number of colour particle}}$$

The abundance of microplastics in seawater was calculated using the following equation formula (Syacbudi, 2020):

$$C = \frac{n}{V}$$

Where:
C : microplastic abundance (particles/liter)
n : number of microplastic particle per sample
V : total water volume during sampling (20 liter)

The abundance of microplastics in seaweed is calculated using the following equation: (Pradiptaadi & Fallahian, 2022) :

$$C = \frac{n}{m}$$

Where :
C : microplastic abundance (particle/g)
n : number of microplastic per sample
m : sample weight (200 g)

Quality control. To ensure that there is no microplastic contamination during the testing process, quality control is implemented at every stage of the testing process. According to ITRC (2023), laboratory testing is performed using standard PPE, such as masks and brightly colored (cotton) laboratory gowns (ITRC, 2023). Samples were stored in glass containers, equipment was calibrated, washed with distilled water, and plastic containers were avoided to prevent contamination. Each sample was repeated five times for data validation (Deswati *et al*., 2021).

Data analysis. Data were analyzed using Microsoft Excel and SPSS 25 software with Pearson's correlation test and paired t-test with to determine the relationship between variables expressed as the correlation coefficient (r). The correlation coefficient (r) between variable X (MP in seawater) and variable Y (MP in seaweed) can be positive or negative. If the the p-value is <0.05, then relationship is statiscally significant; if the p.value is >0.05, then it is not significant (Jabnabillah & Margina, 2022).

RESULTS AND DISCUSSION

Microplastic types. The results of microplastic identification in seawater and seaweed in six areas of Nunukan Regency revealed four types of microplastics: pellets, fragments, fibers, and films (Fig. 2). Microplastic types can be influenced by seawater currents, which cause degradation, plastic dissolution, and acidic conditions that cause structural damage (Khanza *et al*., 2025). In addition, salinity and vegetation directly influence the spread of microplastics owing to seawater intrusion (Wang *et al*., 2025). Several other studies have also indicated that the same type of microplastic was found, such as in Pulau Tengah and Karimunjaya, where fragments were the most dominant type of microplastic, followed by fibers, pellets, and films (Salsabila *et al*., 2022).

At the Bedahan River estuary, Monokerto, Pekalongan Regency, fragments, films, pellets, foams, and fibers were found (Damanik *et al*., 2024), the Balandete estuary, Kolaka Regency, three types of microplastics were found, dominated by fragments, then fibers, and the least films (Cahayani *et al*., 2024), Mahitam Island, Lampung Bay, also found microplastics of film, fiber, fragments, and pellets with a total of 463 particles (Sari *et al*., 2023), the Wulan Demak River estuary found the most dominant type of microplastics were fragments (Pamungkas *et al*., 2022), Kupang Bay waters, in the tidal area, fiber, fragments, films, and foam types of microplastics were also found (Kapo *et al*., 2022).

Based on existing research results, the average microplastic is dominated by four types: microplastic fragments, fibers, pellets, and films. In this study, the microplastic fragments were suspected to originate from used bottles, food packaging, and household waste directly disposed of into rivers and the sea. This was evident at the sampling location, where a large amount of plastic bottles and household waste floated on the water's surface. According to (Al-Fatih, 2021), microplastic fragments originate from damaged plastic bottles, packaging, and other items. Microplastic fibers are suspected to originate from nylon seaweed ropes that have become brittle during the cultivation process and cleaning of the oyster ropes by rubbing them against wooden logs, causing the ropes to fall out. Furthermore, fibers can originate from waste from fishing boats and fishing gear, such as fishing lines and nets (Febriani *et al*., 2020). Microplastic films originate from plastic packaging, which has a low mass and is therefore easily degraded (Azizah *et al*., 2020). Pellets generally originate from the degradation of secondary plastic waste due to sunlight exposure (Mahendradatta *et al*., 2021).

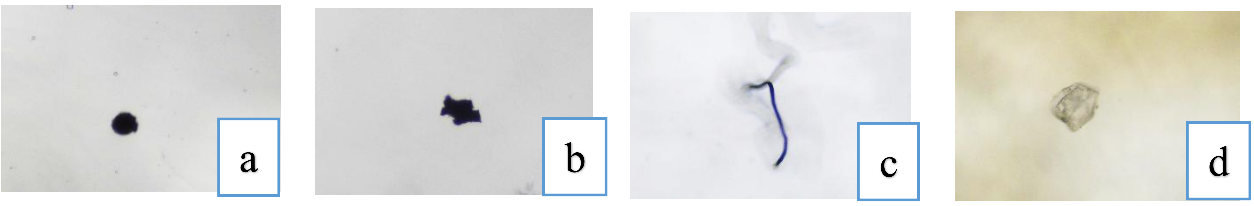


Fig. 2. Microplastic shape: a) pellet; b) fragment; c) fiber; d) film

In seawater, the highest microplastic contamination was found in fragments with 265 particles, followed by pellets with 254 particles, fibers with 213 particles, and the lowest was film with 58 particles. The highest microplastic contamination was found in the Mansapa area, followed by Nunukan Selatan, Tanjung Harapan, Binalawan, Selisun and Liang Bunyu (Fig. 3). Meanwhile, in seaweed, the highest number of microplastic contamination was also found in fragments with 845 particles, followed by pellets with 693 particles, fibers with 626 particles, and films with 143 particles (Fig. 4). The high microplastic contamination in seaweed in the Tanjung Harapan area compared to the microplastic contamination in water found in Mansapa is indicated by the large amount of seaweed planted in the Tanjung Harapan waters, which allows more microplastics to be trapped in the seaweed. The surface properties of seaweed can affect the absorption of microplastics, causing their accumulation in seaweed, which is a food chain pathway for marine organisms and humans (Harini *et al*., 2025)

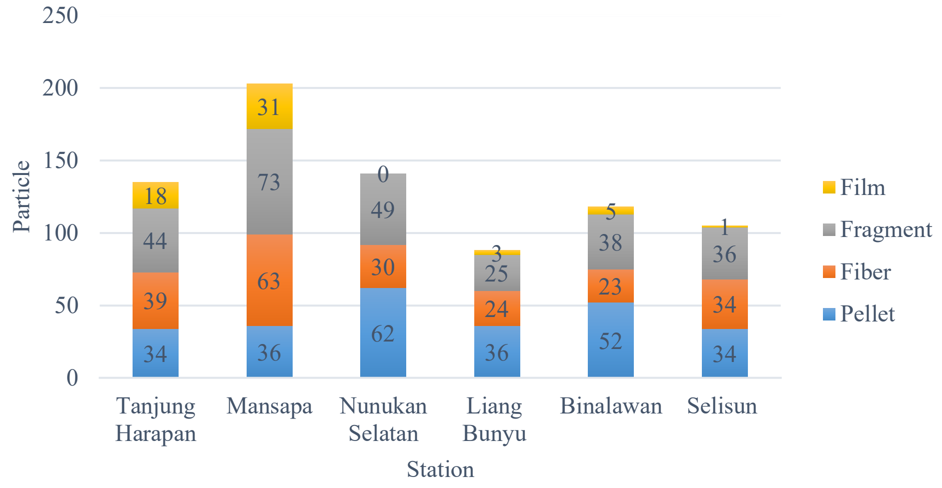


Fig. 3. Particle of microplastic in the seawater

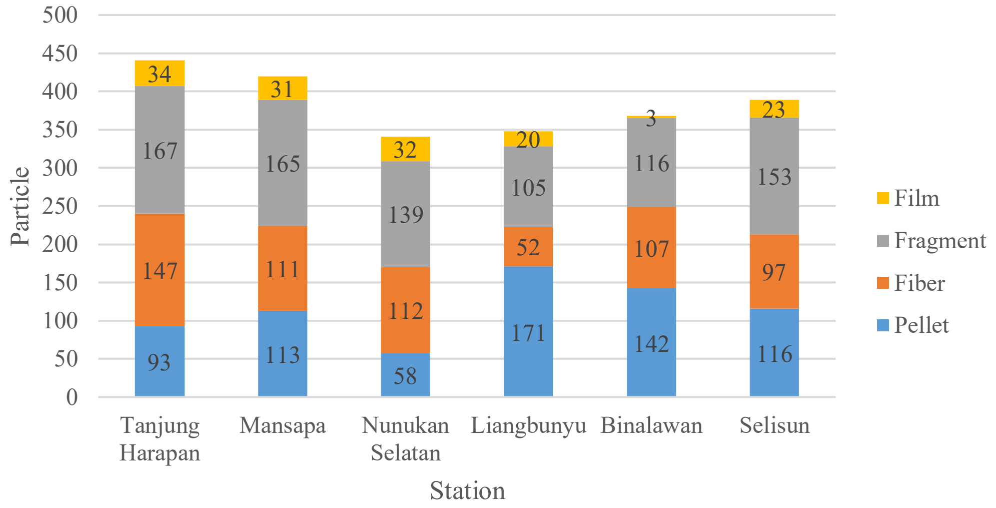
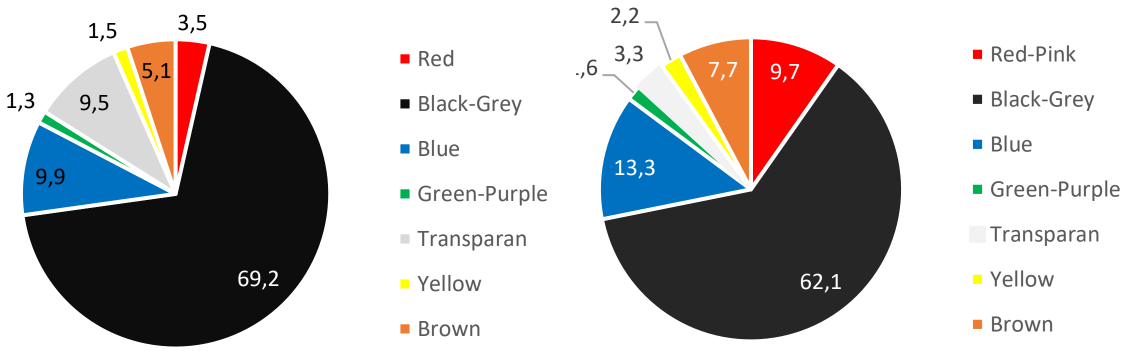


Fig. 4. Particle of microplastic in the seaweed

Microplastic color. The results of color identification on microplastics found nine colors, namely red, black-gray, blue, green-purple, transparent, yellow, and brown in seawater, while in seaweed, ten colors were found, namely red-pink, black-gray, blue, green-purple, transparent, yellow, and brown (Fig. 5). The most dominant color was black-gray, with a percentage of 69.2% in seawater and 62.1% in seaweed. The next color was blue, accounting for 13.3% in seaweed and 9.9% in seawater. The color red was more commonly found in seaweed than in seawater, while the color transparent was more commonly found in seawater (9.5%) than in seaweed (3.3%). The other colors were in the range of 1-5%. The color of microplastics is influenced by the coloring process of plastics, where black, white, and silver plastics do not experience significant changes because they can absorb and reflect UV radiation, and the presence of carbon and titanium dioxide dyes that protect HDPE polymers from photolytic degradation compared with blue, green, or red plastic pigments (Key *et al*., 2024). The blue color comes from synthetic dyes that can dissolve in water, and transparent MP is associated with transparent food packaging consisting of polyethylene and polypropylene (Wicaksono *et al*., 2021).

Microplastic size. The results of microplastic identification in seawater and seaweed (Table 1) revealed various sizes depending on the shape and type of microplastic. In the seawater and seaweed samples, the smallest type of microplastic was pellets measuring 15.34 µm respectively. The largest size was found in fibers, measuring 4925.97 µm in the seawater. The large size of the fibers is due to their elongated shape and the fact that they have undergone a filtration process (Marrone *et al*., 2021). Differences in the size of microplastics can be caused by UV rays, waves, seasons, and other abiotic factors (Sutanhaji *et al*., 2021).



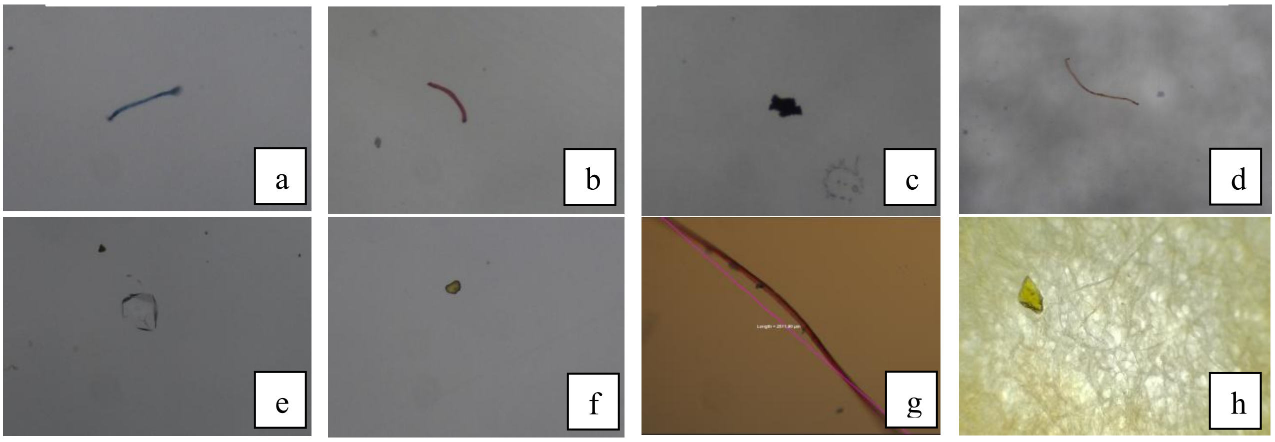


Fig. 6. Microplastic color: a) blue; b) pink; c) black; d) yellow; e) transparent; f) brown; g) red; h) green

Table 1. Microplastic size in seawater and seaweed

Sample	Microplastic type	Size range (µm)	Sample	Microplastic type	Size range (µm)
Seawater	Pellet	15.34 -109.95	Seaweed	Pellet	15.98 - 107.80
	Fragment	24.76 -341.2		Fragment	20.82 - 902.07
	Fiber	51.09 - 4925.97		Fiber	46.27 - 3136.18
	Film	47.02 - 452.86		Film	30.65 - 696.70

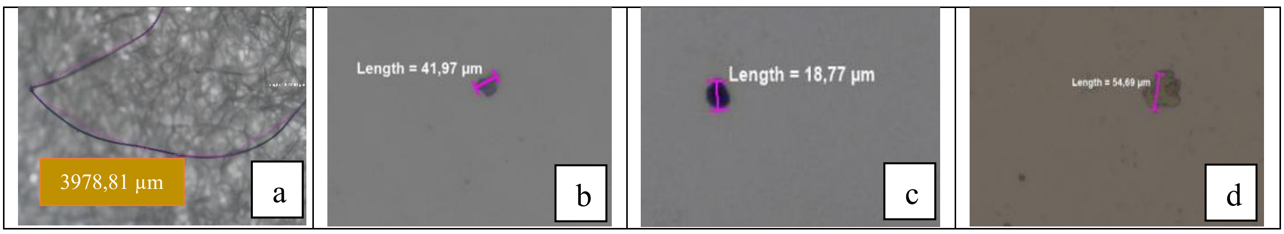


Fig. 7. Microplastic size: a) fiber; b) fragment, c) pellet dan d) film

Microplastic abundance. Based on the results of microplastic calculations in seawater, the highest abundance was in the Mansapa area with a value of 10.15 particles/L, followed by Nunukan Selatan with a value of 7.05 particles/L, Tanjung Harapan with an abundance of 6.75 particles/L, Binawalan Village at 5.90 particles/, Selisun 5.25 particles/L, and the lowest abundance in Liang Bunyu Village at 4.04 particles/L (Table 1). Meanwhile, the abundance of seaweed microplastics, Tanjung Harapan is the area that has the highest abundance level with a value of 22.05 particles/g, followed by Mansapa at 21.0 particles/g, Selisun with a value of 19.45 particles/g, Nunukan Selatan 7.05 particles/g, Binawalan 18.40 particles/g and Liang Bunyu Village at 17.40 particles/L. The microplastic with the lowest abundance in all samples was the film type.

Tabel 2. Microplastic abundance in seawater in 6 regions of Nunukan Regency

Station	Microplastic abundance (particle/L)				
	Pellet	Fiber	Fragment	Film	Σ
Tanjung Harapan	1.70	1.95	2.20	0.90	6.75
Mansapa	1.80	3.15	3.65	1.55	10.15
Nunukan Selatan	3.10	1.50	2.45	-	7.05
Liang Bunyu	1.80	1.20	1.25	0.15	4.40
Binalawan	2.60	1.15	1.90	0.25	5.90
Selisun	1.70	1.70	1.80	0.05	5.25
Total	**12.70**	**10.65**	**13.25**	**2.90**	**39.50**

Table 3. Microplastic abundance in seaweed in 6 regions of Nunukan Regency

Station	Microplastic abundance (particle/g)				
	Pellet	Fiber	Fragment	Film	Σ
Tanjung Harapan	4.65	7.35	8.35	1.70	22.05
Mansapa	5.65	5.55	8.25	1.55	21.00
Nunukan Selatan	2.90	5.60	6.95	1.60	17.05
Liangbunyu	8.55	2.60	5.25	1.00	17.40
Binalawan	7.10	5.35	5.80	0.15	18.40
Selisun	5.80	4.85	7.65	1.15	19.45
Total	**34.65**	**31.30**	**42.25**	**7.15**	**115.35**

The highest abundance of microplastics in seawater and seaweed was dominated by fragments, at 13.25 particles/L and 42.25 particles/g, respectively. Pellets were the most abundant at 12.75 particles/L and 31.3 particles/g, fibers were the most abundant at 10.65 particles/L and 31.30 particles/L, and films were the least abundant at 2.90 particles/L and 7.15 particles/g. In several regions in Indonesia, microplastic fragments were also found to be the most dominant type compared to other types of microplastics, such as in the waters of Central Sulawesi at 2.21 particles / 100 L (Safitri, 2023), the waters of Untung Jawa Island, Pulau Seribu, DKI Jakarta at 1324 particles (Hafitri *et al.*, 2022), the waters of the Kalimas River in Surabaya City at 197 particles(Wahyudi *et al.*, 2024), the waters of the Code River in D.I Yogyakarta at 203 particles (Syacbudi, 2020), and the waters of Banyu urip, Gresik, East Java at 22.89 × 102 particles m3 (Ayuningtyas et al., 2019). The types of microplastics in each region can vary depending on human activities that produce domestic waste (Ayuningtyas *et al.*, 2019; Rifandi & Ratnasari, 2022). Oceanographic factors such as currents, density, and monsoon winds also play a significant role in the distribution of microplastics in water (Sigit F A, 2019). Microplastics, such as microfibers, polyester, and polyamide, decompose under environmental influences, particularly UV light, which causes significant degradation (Sorensen *et al.*, 2021).

Corelation of microplastic. The results of the correlation test on the abundance of microplastics in seawater and seaweed, based on Table 3, showed a weak and non-significant relationship with a p-value > 0.05. This indicates that seawater pollution is not directly correlated with seaweed contamination. The scatterplot visualization shows a random distribution of points without a clear linear pattern between seawater and seaweed contamination (Fig. 8). The data points are scattered throughout the plot area without any visible trends. The non-linear relationship is suspected to be due to the ability of seaweed to act as a natural biofilter to absorb pollutants and serve as a habitat for other organisms (Kasanah *et al*., 2022). Therefore, the longer the cultivation process, the higher the absorbed contamination. Furthermore, microplastic particles tend to be distributed at the surface rather than at depth (Lestari *et al*., 2020). Sources of microplastic contamination in cultivation sites can be internal or external; therefore, it is necessary to address this by conducting regular maintenance and protecting the environment from sources of microplastic pollution (Wicaksono, 2022). The large number of microplastics found could also be due to current patterns that carry degraded waste to the sampling location and attach to seaweed (Serihollo *et al*., 2025). Other studies have also explained that the high microplastic content in seaweed is due to its sedentary and static lifestyle and its presence in the water column, making it more easily trapped (Werorilangi *et al*., 2023). Microplastics in seaweed can be influenced by interactions with the surface texture of the substrate, its chemical composition, and the presence of mucilage(Cham & Yasman, 2024). The presence of microplastics in seaweed is caused by the biofouling process, in which microplastics associate with microorganisms, making seaweed a potential substrate for biofilm formation (Aragao & Turan, 2022). Biofilm formation involves attachment, microcolony formation, maturation, and dispersion (Malik *et al*., 2020). The attachment of microplastics to seaweed is also influenced by environmental conditions, such as pH, temperature, and sunlight (Niu & Wu, 2024).

Table 4. Correlation test results of the relationship between microplastic contamination in seawater and *K, Alvarezii* seaweed

Particle types	R (Pearson correlation)	p- value	Interpretation
Total	-0.054	0.778	There is no significant linier correlation
Pellet	-0.206	0.276	Weak negative relationship, not significant
Fiber	0.094	0.620	Very weak positive relationship, not significant
Fragment	0.126	0.508	Weak positive relationship, not significant
Film	0.275	0.142	Moderate positive relationship, not significant

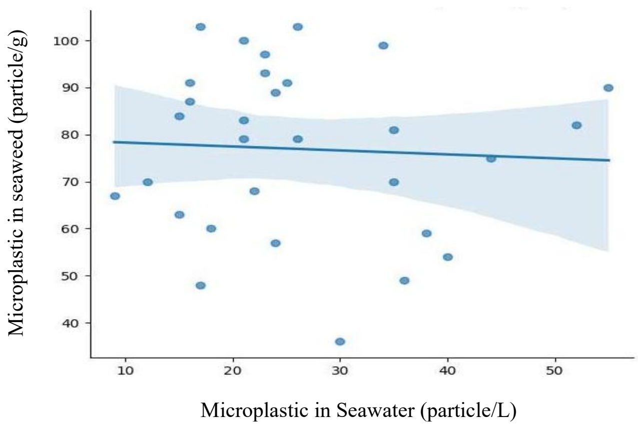


Fig. 8. Scatterplot distribution of microplastic pollution in seawater and seaweed

Table 5. Significant difference test result (Paired T-Test) microplastic in seawater and seaweed

Statistic	Value
t-statistic	-12.737
p-value	0.00000

A paired t-test conducted on the amount of microplastic contamination in seawater and seaweed showed a p-value of 0.00 <0.05, indicating a significant difference between the amount of contamination in seawater and seaweed. The average contamination in seaweed was higher than that in seawater. This indicates that seaweed can absorb or capture pollution particles in seawater. This is supported by other studies, namely the discovery of high microplastic content in two subtidal macroalgae species (*Padina* sp. and *Sargassum ilicifolium*) (Seng *et al*., 2020). The interaction of macroalgae with microplastics through adhesion mechanisms, such as attachment to the surface, sticking, embedding, trapping, and wrapping, reduces the process of photosynthesis, chlorophyll, and causes oxidative stress (Purayil *et al*., 2024). The accumulation of microplastics in *Chondrus* sp. macroalgae, which have a rough surface, at a concentration of 20,000 ng/L resulted in a decrease in growth and photosynthetic activity and an increase in reactive oxygen species (ROS) (Jung *et al*., 2023).

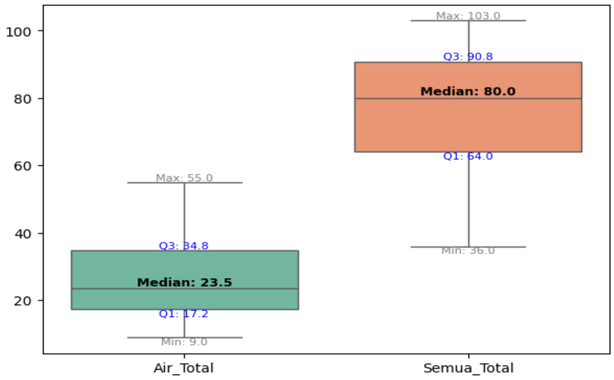


Fig. 9. Boxplot of the distribution of contamination values in both samples with different medians, quartiles, and ranges that strengthen the significant differences

CONCLUSION

Microplastic contamination in seawater and seaweed includes pellets, fibers, fragments, and films of varying sizes. The most dominant microplastic color is black-gray compared to other colors such as red-pink, green, yellow, purple, and transparent. The abundance of microplastics in seaweed is higher than that in seawater. The large amount of microplastic contamination in the environment causes problems for aquatic ecosystems and poses a food safety hazard to the human food chain through seaweed and other organisms that are sources of food for humans. The correlation test did not reveal a linear relationship between the abundance of microplastics in seawater and seaweed. However, a statistically significant difference was found between the amount of microplastics in seawater and seaweed, indicating that seaweed can accumulate contamination in water. The limitations of this study in detecting the significance of microplastic abundance may be caused by the mesh size used because smaller particles cannot be captured by the tool.

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