The effect of plastic debris attachment to the health of branching corals in Kelapa Dua Island, Thousand Islands

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Abstract. Plastic marine debris are a potential threat to the life of marine organisms such as corals. This study aimed to analyze the effect of different plastic waste attachments on the bleaching rate and the health of branching corals at Kelapa Dua Island. Branching coral colonies consisted of 15 fragments of *Porites cylindrica* at the water depth of 80-90 cm, then treated with plastic waste (control, clear plastic, sack plastic, packaging plastic, and black plastic) for four days. Determination of color changes in corals was determined using Adobe Photoshop CC 2019 and Image j software to obtain the area of the discoloration. The treatment with black plastic became most impactful, with a discoloration area of $5.33 \pm 0.48 \text{ cm}^2$ and a health percentage of $73.62 \pm 2.00\%$. Results of the linear regression between coral discoloration rate and light intensity showed a negative correlation, with $r = -0.77$ and $R^2 = 0.59$, then between the percentage of coral health and light intensity showed a positive correlation, with $r = 0.83$ and $R^2 = 0.69$. These results indicated that the decrease in light intensity due to the covered plastic debris affected the discoloration rate and the health percentage of branching coral.

1. Introduction
The use of plastic is a difficult problem to resolve until this time. This problem was inseparable from human needs who generally continue to use plastic, such as the use of plastic for packaging on many food products, household, office, and so on. The latest report stated that plastic production in the world increased by almost 350%, recorded from 99 million tons in 1989 to 359 million tons in 2018 [1]. Plastic debris wasn’t managed well eventually emptied into the marine environment [2]. Plastic debris was the largest contributor to the composition of marine debris [3,4].

Indonesia was the second highest after China in the order of countries that produced plastic waste and wasn’t also managed properly in 2010. Indonesia was known to produce 3.22 million tons/year of plastic waste that wasn’t managed properly, were 0.48-1.29 million tons / the year was a plastic waste that disembogued into the sea [2]. Jakarta Bay was the area with the largest potential pollutant recipient for the marine environment in Indonesia. This was inseparable from the function of Jakarta Bay as a center for port and shipping activities and was also an area that received input from 13 rivers directly [5,6].

Plastic debris in a marine environment is a threat because of its persistence, then it had the potential to have a negative effect on marine life [7]. The impact of plastic debris on marine life is mostly in the
form of disruption in the process of ingestion and attachment on the body [8,9]. Coral organisms are marine organisms that felt the negative effects of plastic debris. Research in the Florida sea reported about 57% of the debris attached to branching corals, 19% attached to solid corals, and 13% attached to soft corals [10]. Research in the Gulf of Thailand sea also showed the same thing, where 52% of the debris found in coral reef ecosystems was dominant in branching corals [11]. Attachment of plastic debris on coral has the potential effect on health degradation on corals. It was able to inhibit the light intensity and oxygen in corals, then it inflicted discoloration and bleaching on coral [12,13]. Other effects could reduce photosynthesis in zooxanthellae [14,15] and damage the coral physically such as tissue damage and fragmentation [11,16].

Differences in color in plastic debris allowed to obtain the different impacts on health in branching corals, then it was necessary to look specifically at the different impacts of each color. This study aimed to analyze the impact of differently colored plastic on the health of branching corals as indicated by discoloration in corals. The results of this study were expected to be a reference related to the detailed effects of degradation in coral polyps because of the attachment of plastic debris, especially the impact on the health of coral animals.

2. Methods
2.1 Study site
The study was located in Kelapa Dua Island, Kepulauan Seribu Regency, DKI Jakarta. The coordinate of the site study was at latitude 5˚39’ S and longitude 106˚33’ E (figure 1). Kelapa Dua Island is one of the islands in the Thousand Islands with accessibility to tourist activities. The study was conducted in October to November 2019.

![Figure 1. Kelapa Dua Island is the management area of the National Park Management Section (SPTN) Region I of the Kepulauan Seribu National Park. The black round mark is the point of conducting research at latitude 5˚39’ S and longitude 106˚33’ E. Rataan terumbu is the reef flat area and Lautan is the area of open seawater.](image)

2.2 Material
The materials used in the study included the basic diving equipment (masks, snorkels, and booties), cameras (G12, Canon, Japan), coral health chart (University of Queensland, Australia), light meter (LI-250A) with underwater quantum sensors (LI-192SA and LI-193SA), DO meter (DO-5510, Lutron, USA), pH meter (Pen Type PH-009-A), Refractometer (Master-S28M, Atago, Japan), and sample plastic. Branching coral colonies that consisted of Porites cylindrica were photographed and observed
using a coral health chart to determine the health status of coral. This method was the product of a research project conducted by the University of Queensland, Brisbane, Australia. Branching coral colonies sample consisted of 15 fragments at the depth 80-90 cm, then given the treatment with plastic debris.

2.3 Data sampling
Treatment of plastic debris attachment on branching coral samples. Plastic debris used as a treatment on branching coral colonies consisted of four types, specifically black plastic, packaging plastic, sack plastic, and clear plastic (figure 2). The plastics were attached and covered the chosen branching coral colonies, with three repetitions in different branching coral colonies for four days [15].

![Figure 2. The installation of plastic debris that was attached to branching coral colonies for four days. A (control), B (clear plastic), C (sack plastic), D (packaging plastic), and E (black plastic).](image)

2.4 Documentation of branching coral samples
The observation of the health in branching corals was based on the surface area that was discolored for four days on coral colonies [15]. Determination of discoloration of branching corals was determined using a coral health chart. The documentation was conducted using the Underwater Photo method [17].

2.5 Data analysis
Image files from documentation were analyzed with Adobe Photoshop CC 2019 and Image J software. Both were used to obtain the extent of bleaching or discoloration area that occurred on branching corals when attached by plastic debris [17,18,19]. Linear regression analysis was used to observe the correlation between oral health and light intensity due to the treatment of plastic attachment on corals with SPSS and Microsoft excel.

3. Results and discussion
3.1 Aquatic environmental conditions
Based on measurements, the aquatic environmental quality at the study site showed conditions that were still in normal quality for living coral animal organisms (table 1). Sea surface temperature parameters were in the average between 29.5 °C - 30.6 °C, then salinity was in the average between 31.6 °/oo - 32.4 °/oo, pH was in the range of 8, and dissolved oxygen was in the average between 6.3 mg/L - 8 mg/L for four days of observation. These water quality results weren’t much different from the water quality results in other studies that had been conducted in the tropical sea [20,21,22].
Table 1. Values of aquatic environmental parameters (mean ± SE), including sea surface temperature, salinity, pH, dissolved oxygen, and depth at the study site for four days of observation.

| Day | SST ± SE (°C) | Salinity ± SE (‰) | pH  | DO ± SE (mg/L) | Depth ± SE (cm) |
|-----|---------------|--------------------|-----|----------------|-----------------|
| 0   | 30.37 ± 0.13  | 31.67 ± 0.24       | 7.9 - 8.1 | 7.97 ± 0.52   | 82 ± 4.49       |
| 1   | 30.57 ± 0.37  | 32.44 ± 0.24       | 7.9 - 8.0 | 6.72 ± 0.41   | 82 ± 4.42       |
| 2   | 30.78 ± 0.35  | 31.78 ± 0.22       | 7.9 - 8.1 | 6.39 ± 0.26   | 80 ± 3.39       |
| 3   | 30.51 ± 0.26  | 31.89 ± 0.39       | 8.0 - 8.1 | 6.26 ± 0.17   | 87 ± 1.25       |
| 4   | 29.57 ± 0.09  | 32.33 ± 0.33       | 8.0 - 8.1 | 6.77 ± 0.22   | 83 ± 0.58       |

Generally, the weather on the measurement was sunny during the study time. Light intensity parameters showed varying results (table 2). Observations between morning, noon, and evening showed different values. Observations during the noon showed the highest light measurement results compared to morning and evening. It was because the sun was very high during the noon, while in the morning and evening the weather conditions were no longer as bright as the daytime measurements. The morning measurement on day 0 showed a different value compared to the trend of measurement in the other mornings. It was because the measurement on day 0 of data collection was carried out at 9 am. Specifically for the day 4 measurement, the light intensity measurement wasn’t longer carried out, because on the morning in day 4 the observations had ended.

Table 2. Average results of water light intensity (mean ± SE) at the study site for four days of observation.

| Day     | Water light intensity (µmol/m²det) ± SE |
|---------|----------------------------------------|
|         | Morning (08.00-08.30 AM)              |
| 0       | 962.17 ± 19.66                        |
| 1       | 545.33 ± 6.52                         |
| 2       | 527.00 ± 0.98                         |
| 3       | 476.63 ± 7.51                         |
| 4       | 497.13 ± 4.16                         |
|         | Noon (11.30 AM -12.30 PM)             |
| 0       | 1154.48 ± 56.33                       |
| 1       | 1222.13 ± 17.23                       |
| 2       | 1288.37 ± 22.26                       |
| 3       | 1053.53 ± 29.81                       |
| 4       | -                                      |
|         | Evening (15.00-16.00 PM)               |
| 0       | 392.07 ± 35.27                        |
| 1       | 403.70 ± 3.08                         |
| 2       | 475.57 ± 4.01                         |
| 3       | 467.80 ± 6.70                         |
| 4       | -                                      |

3.2 Decreasing of branching coral health
The average results of bleaching areas on branching coral colonies were diverse (table 3 and figure 3). The treatment with black plastic was the treatment with the largest bleaching area (average 5.33 ± 0.48 cm²), while the treatment with sack plastic was the treatment with the smallest bleaching area (2.54 ± 0.38 cm²) compared to other treatments. Especially for control treatment, the condition of branching corals did not change during the study. Related to the light intensity from each treatment, results showed that the existence of low light intensity tended to result in the deterioration of coral health, and vice versa. For example, the low light intensity resulted in the enlargement of the bleaching area in the treatments.

Table 3. Results of discoloration areas (mean ± SE) in each treatment for four days.

| Treatment         | Light Intensity (µmol/m²det) | Average of bleaching area on coral colonies (cm²) |
|-------------------|-------------------------------|-----------------------------------------------|
|                   | Day 0 | Day 1 | Day 2 | Day 3 | Day 4 | Ave  |
| Control           | 666.97 ± 103.92 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 | 0 ± 0 |
| Clear plastic     | 508.57 ± 72.99 | 0 ± 0 | 2.28 ± 0.70 | 3.21 ± 0.90 | 3.31 ± 0.89 | 4.62 ± 1.34 | 3.35 ± 0.48 |
| Sack plastic      | 353.69 ± 42.07 | 0 ± 0 | 1.60 ± 0.52 | 2.29 ± 0.67 | 2.94 ± 0.39 | 3.33 ± 0.57 | 2.54 ± 0.38 |
| Packaging plastic | 5.29 ± 1.09  | 0 ± 0 | 2.33 ± 1.16 | 3.26 ± 1.46 | 3.53 ± 1.18 | 4.77 ± 1.27 | 3.47 ± 0.50 |
| Black plastic     | 26.18 ± 13.60 | 0 ± 0 | 4.28 ± 1.25 | 5.00 ± 0.86 | 5.50 ± 1.16 | 6.55 ± 1.09 | 5.33 ± 0.48 |
There is no direct proof, but it is indicated by the opposing trends. The light intensity at the control was normal (ambient light conditions), the corals showed no signs of health deterioration during the experiment. It was in line with existing theories, where the reduced light intensity caused either the degradation or the impact on the degradation of oral health [23], even capable of causing bleaching to death on corals [12]. However, the packaging plastic treatment which had the lowest light intensity than others (5.29 µmol/m²-det) wasn’t the most significant effect on the degradation of coral health. This result needed to be considered whether the black color derived or other material made from black plastic caused more effects on coral animals. Other factors might be temperature or oxygen decrease under the plastic.

Figure 3. Results of digitizing the discolored surface area on branching coral. The red arrows focus on areas that have increased areas of color degradation on branching corals. B; clear plastic, K; sack plastic, Ke; packaging plastic, H; black plastic.

The average bleaching area for four treatments (clear plastic, packaging plastic, sack plastic, and black plastic) on branching coral colonies showed an upward trend over the four days of observation (figure 3). Apparently, the control status didn’t change during observation, from the beginning to the end of the observation. The treatment with black plastic became the treatment with the fastest increasing bleaching area trend. Furthermore, treating coral cover using clear plastic, sack plastic, and packaging plastic also showed a downward trend on coral health, but not so significant compared to the impact from black plastic. Coral colonies could develop from discoloration to bleaching if they were treated with continuous low light intensity [12,24]. The other interesting thing from the increase of the bleaching area and the decreasing percentage of coral health that occurred on the 2nd day of observation. It was
assumed from the sudden effect from light intensity changing of environmental waters when the treatment was conducted, then the corals affected drastically on the 2nd day of observation.

Table 4. Coral health percentage results (mean ± SE) in each treatment for four days.

| Treatment        | Light Intensity (µmol/m²-det) | Day 0     | Day 1     | Day 2     | Day 3     | Day 4     | Ave       |
|------------------|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Control          | 666.97 ± 103.92               | 100 ± 0   | 100 ± 0   | 100 ± 0   | 100 ± 0   | 100 ± 0   | 100 ± 0   |
| Clear plastic    | 508.57 ± 72.99                | 100 ± 0   | 90.41 ± 3.07 | 86.52 ± 4.02 | 86.11 ± 3.99 | 80.64 ± 5.92 | 85.92 ± 2.01 |
| Sack plastic     | 353.69 ± 42.07                | 100 ± 0   | 89.60 ± 4.53 | 86.20 ± 3.31 | 81.57 ± 3.28 | 79.27 ± 4.14 | 84.16 ± 2.32 |
| Packaging plastic| 5.29 ± 1.09                   | 100 ± 0   | 88.17 ± 7.28 | 83.82 ± 9.19 | 83.44 ± 6.94 | 78.25 ± 6.35 | 83.42 ± 2.03 |
| Black plastic    | 26.18 ± 13.60                 | 100 ± 0   | 78.16 ± 9.15 | 74.92 ± 8.03 | 72.80 ± 8.51 | 68.59 ± 6.77 | 73.62 ± 2.00 |

The percentage of coral health was calculated based on the partition between the total surface area of the coral colony with the surface area of the coral colony that was not degraded, then converted to a percentage value. The average percentage of coral health in branching coral colonies varied (Table 4). The treatment with black plastic became the lowest percentage of coral health (73.62 ± 2.00%) than other treatments for four days of observation. The treatment with clear plastic showed the highest percentage of coral health (85.92 ± 2.01%) among the four treatments for the coral colony attachment with plastic debris, then followed by sack plastic (84.16 ± 2.32%), and packaging plastic (83.42 ± 2.03%).

Figure 4. (A) Trend of average bleaching area in branching coral colonies for four days of observation. (B) The trend of the average percentage of coral health in branching coral colonies for four days of observation. Blue small round (control), orange rhombus (clear plastic), grey triangle (sack plastic), brown rectangular (packaging plastic), black large round (black plastic).

The trends of the percentage of coral health for all plastic debris treatments decreased over four days of observation (Figure 4). The treatment with black plastic had the most significant effect for decreasing the percentage of coral health, while the percentage of coral health from the other treatment with attachment plastic was not much different from another.

The relationship between bleaching extends, coral health status, and light intensity was investigated by linear regression analysis (table 5). The result of linear regression between the bleaching area and light intensity showed a significant relationship (Sig. Value = 0.00 < α value = 0.05) with a negative correlation value (r = -0.77) and the equation y = -0.005x + 4.613. It was concluded when there was a decrease in light intensity to be 1 µmol/m²-det due to the plastic debris attachment resulted in an increase of bleaching area by 4.57 cm² on branching corals with the percentage of 59% ($R^2 = 0.59$). Another linear regression result (Table 5) between the percentage of coral health and light intensity also showed a significant relationship (Sig. Value = 0.00 < α value = 0.05) with a positive correlation (r = 0.83) and the equation y = 0.026x + 77.024. It was concluded when there was a decrease in light intensity to be 1
µmol/m²det due to the plastic debris attachment resulted in a decreasing the percentage of coral health by 77.19% in branching coral with the percentage of 69% \( (R^2 = 0.69) \).

When coral health had decreased due to the decrease of light intensity, this also indicated the decrease in the density of zooxanthellae contained in coral tissue or gastrodermis [25,26]. It was inseparable from the endosymbiosis process that interacted between zooxanthellae and corals. Zooxanthellae are the provider of carbon needs and the results of photosynthesis were converted into nutrients and energy by corals, while coral animals became hosts for living zooxanthellae and transferred carbon for the process of photosynthesis of zooxanthellae. A decrease in zooxanthellae can also reflect coral disease. The Coral with the disease had less abundance of zooxanthellae than healthy coral [27]. Attachment of plastic debris on corals also leads to a decrease of zooxanthellae in coral gastrodermis. The low light intensity received by coral animals due to the attachment of plastic debris caused the lower abundance of zooxanthellae in coral [15].

### 4. Conclusion

The treatment of attachment of differently colored plastic debris on the branching coral colonies also had a different impact on the bleaching rate and the percentage of coral health. The treatment with black plastic debris had the most negative impact. The light intensity due to the attachment of plastic debris on branching coral was negatively correlated to the bleaching rate and positively correlated to the percentage of coral health in branching coral colonies over four days of observation. The results obtained in this study serve as a baseline to design a more comprehensive field experiment in the future by more quantities of coral colony samples and more observation time. Hopefully, the study with more samples and more time will able to do. Using coral colony samples from other coral lifeforms, such as massive, encrusting, foliose, laminar, columnar, or free-living can be the next innovation in generating new results related to the impact of attachment of plastic debris on coral animals.

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