Marine Macro Debris from Makassar Strait Beaches with Three Different Designations

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Abstract. Marine debris, especially plastic debris, is a global problem that requires intense monitoring and management since it affects humans, marine organisms, and the environment. This study aimed to examine and compare the abundance and composition of marine macro debris found on three beaches of South Sulawesi Province, Indonesia. All three sites were situated in the Makassar Strait, and similarly exposed to the Indonesian Through-Flow; however, each site had a different land-use designation: residential area (Labuange), recreational area (Lumpue), and restricted/private area (Bojo). From March to May 2018, marine macro debris was collected monthly on each beach, along a 2x25 m² transect (with three replicates/site). The samples were cleaned, sorted, counted, weighed, and analysed statistically. Plastic and rubber dominated marine macro debris in the study area (mean: 82-85%). The abundance of marine debris from Lumpue and Bojo beaches decreased drastically. However, marine debris from Labuange beach remained greater in each sampling period (4.67-7.62 items per m²), probably due to additional litter from the village. Beach morphology and wave direction pattern were also responsible for the high volume of marine debris washed up, especially on Labuange beach. Plastic and rubber, cloth/fabric, and processed lumber debris were the heaviest debris, with different orders in each site. Management efforts, including frequent local waste and marine debris collection, are required to minimize the impacts of marine debris on the environment.

1. Introduction

Anthropogenic litter is a problem encountered by many countries, including Indonesia. Anthropogenic litter can end up in the ocean through storm drains and sewers, rivers, etc. In addition, marine debris can come from beach visitors, boats, offshore platforms, and fisheries activities [1] intentionally, or unintentionally.

In most cases, plastic debris, which has strong and durable characteristics, dominates beach debris. With these properties, plastic debris has a broad negative impact, not only on aesthetic, human health [1, 2] and economic aspects [3, 4] but also on marine life [2, 5].

Indonesia is considered as the second greatest plastic debris contributor to the ocean, following China [6]. Community behaviour and improper management result not only in local environmental degradation but also global problems, since such litter can travel to other areas/region due to its light-weight properties. Therefore, Indonesian government efforts to manage marine debris should be supported, including by providing data and information on the type, amount, and weight of beach
debris in various areas, including in South Sulawesi. A few marine debris studies had previously been conducted in South Sulawesi, particularly on the south coast, e.g. in Takalar District [7]. This study was conducted on three beaches along the west coast of South Sulawesi facing the Makassar Strait. Each beach had a different designation, but was similarly exposed to the Indonesian Through-Flow. The study aimed to examine and compare the composition and abundance of marine macro debris found on the three beaches, as well to as identify their potential for harm to the environment. It is hoped that this study can help fill the gap in data and knowledge, and thus support efforts to achieve better marine debris management in South Sulawesi, across Indonesia, and in the Coral Triangle.

2. Methods

2.1. Study area and data collection
The study area comprised three beaches along the west coast of South Sulawesi facing the Makassar Strait, which is exposed to the Indonesian Through-Flow. The first site was Labuange beach, Barru District (119°36'32"E, 4°06'26"S). This is a residential area populated mostly by fishermen. The second site was Lumpue beach, Pare-Pare City (119°37'21"E, 4°03'30"S). Situated in a recreational area, the site had relatively low visitation intensity and was cleaned albeit at irregular times. The third site was Bojo beach, Barru District (119°36'47"E, 4°05'43"S), in a restricted/private area (Figure 1).

![Figure 1. Map of the study area showing the 3 study sites on the west coast of South Sulawesi](image)

From March to May 2018, marine macro debris (2.5–100 cm) was collected monthly on each beach, along a total of 150 m² permanent transects, which consisted of three continuous replicate transects. Each transect was set up approximately mid-way between the high and low tide lines (Figure 2). The samples were cleaned and sorted into the following categories: (1) plastic and rubber, which were put in the same category due to their similar composition (synthetic polymers); (2) metal; (3) glass; (4) processed lumber; (5) cloth/fabric; (6) other; (7) harmful materials. The samples were then counted and weighed.

The abundance (density) of marine debris each site was calculated monthly based on the debris type by dividing the number of items collected by the transect area. A similar calculation was also performed based on the weight of the marine debris. The proportions of each type of marine debris at each site were estimated monthly based on the abundance of marine debris items.
2.2. Data analysis
The study applied several statistical analyses, using Excel and SPSS 25. One-way ANOVA was performed to assess the between site differences in average abundance (quantity and weight) of each category of marine debris during each month. Prior to conducting the analysis, a normality test was performed, and data transformation was employed for non-normal variables. The transformation types depended on the type of skewness. Post-hoc tests were performed if the ANOVA result showed a significant difference (at the 95% confidence level) between sites.

3. Results

3.1. The abundance and composition of marine debris by quantity
During the sampling period, the total abundance of marine debris in the study area was 33.65 items per m² (Table 1). No harmful materials were found in the study area. The highest average abundant of marine debris was revealed in residential area of Labuange beach (6.03 ± 1.49 items per m²), followed by those in recreational area of Lumpue beach (4.13 ± 4.69 items per m²), and in restricted/private area of Bojo beach (0.42 ± 0.34 items per m²). Overall, there was a significant decreasing trend in the mean number of marine debris items per m² over the sampling period, except on Labuange beach.

| Period     | Total quantity of marine debris per m² (items/m²) | Labuange | Lumpue | Bojo |
|------------|--------------------------------------------------|----------|--------|------|
| March 2018 | 5.80                                             | 9.25     | 0.79   |
| April 2018 | 4.67                                             | 3.13     | 0.33   |
| May 2018   | 7.62                                             | 0.03     | 0.13   |
| Total      | 18.09                                            | 14.31    | 1.25   |
| Mean (± SD)| 6.03 ± 1.49                                      | 4.13 ± 4.69 | 0.42 ± 0.34 |

During all three sampling months and at all three sites in the study area, plastic and rubber predominated in the marine debris collected (Figures 3-5), ranging from 72 to 95% of all items collected (mean 82-85%). Thick plastic packages/bags were the most abundant item (by quantity) in the plastic and rubber category collected in all study sites during the sampling period. Labuange beach consistently had the highest number of thick plastic packages/bags (1.05-1.45 items per m²). Thin plastic bags were also very abundant on Labuange beach (0.26-1.52 items per m²). Nylon ropes, fishing line and equipment were also collected in relatively high numbers, particularly on Labuange beach (0.35-0.63 items per m²) and during the first sampling on Lumpue beach (0.91 items per m²).
Straws were collected in remarkably high numbers (1.60 items per m$^2$) during the first sampling of the Lumpue beach recreational area.

In March 2018 (Figure 3), plastic and rubber represented 72% of a total mean abundance of 0.79 items/m$^2$ in Bojo and 95% (of 9.25 items/m$^2$) at Lumpue beach, while the six other categories had less than 0.6 items per m$^2$. There was a significant difference in the abundance of plastic and rubber between Lumpue and Bojo beaches ($p < 0.05$).

In April (Figure 4), the findings were similar, with plastic and rubber representing around 84% of the total items found, followed by cloth/fabric at around 6-8%, and processed lumber 4-6%. The number of items was highest in the residential area of Labuange beach in all categories except glass, which was most abundant on Lumpue beach. The ANOVA indicated a significant difference in the abundance of plastic and rubber between Bojo and the two other beaches ($p < 0.05$). A significant
difference was also determined between the average abundance of metal debris in Labuange and Bojo (p < 0.05), although the abundance was low at both (< 0.01 items per m², less than 1%).

In May 2018 (Figure 5), plastic and rubber was once again the most abundant category of marine debris in the study area (75-89%), with the highest abundance on Labuange beach. Processed lumber, cloth, metal, glass and other material were also collected from Labuange beach, albeit in lesser numbers. Very low abundances of processed lumber and glass were observed in Lumpue and Bojo. There were significant differences (p < 0.05) in the average number of items/m² for the plastic and rubber, processed lumber, and cloth categories between Labuange and the other sites.

3.2. The abundance of marine debris by weight
By weight, the total abundance of marine debris in the study area was 1030.35 g per m². Corresponding with the total abundance by quantity, the greatest average weight of marine debris per m² was also found in residential area of Labuange beach (278.83 ± 154.91 g per m²), followed by the recreational area of Lumpue beach, and the restricted/private area of Bojo beach (34.52 ± 32.75 per m², and 30.76 ± 41.66 g per m², respectively) (Table 2). Plastic and rubber, cloth, and processed lumber were the heaviest debris in the study area, with different orders in each site.

Table 2. Total weight of marine debris per m² in the study area.

| Period   | Total weight of marine debris per m² (g/m²) |
|----------|-------------------------------------------|
|          | Labuange   | Lumpue     | Bojo      |
| March 2018 | 100.11     | 65.42      | 78.64     |
| April 2018 | 374.66     | 37.96      | 10.86     |
| May 2018  | 361.72     | 0.19       | 2.78      |
| Total     | 836.49     | 103.57     | 92.28     |
| Mean ± SD | 278.83 ± 154.91 | 34.52 ± 32.75 | 30.76 ± 41.66 |

The composition by weight of marine debris collected (Figures 6 to 8) showed greater temporal and between site variation than abundance in terms of the number of items. In March 2018, cloth/fabric was the heaviest debris collected in Labuange beach (59 g/m²), followed by plastic and rubber, and glass. On Lumpue beach, plastic and rubber was the heaviest debris category (46.49 g/m²), followed by processed lumber, glass, and cloth on Bojo beach, processed lumber was the heaviest debris (42.63 g/m²), followed by cloth, and plastic and rubber (6.89 g/m²) (Figure 5). There was a significant difference (p < 0.05) in the average weight of plastic and rubber per m² between Lumpue and Bojo beaches.

Figure 7 shows that in April 2018, plastic and rubber was the most abundant debris by weight on Labuange beach (162.26 g/m²) and Lumpue beach (17.43 g/m²). Meanwhile, on Bojo beach, cloth was the heaviest debris (6.40 g/m²). There were significant differences (p < 0.05) in the average weight of plastic and rubber between Bojo beach and the other two sites and in the average weight of metal between Labuange and Bojo beaches (p < 0.05).

In May 2018 (Figure 8), processed lumber was the heaviest debris found in Labuange beach (171.25 g/m²), followed by cloth/fabric (96.48 g/m²), and plastic and rubber (83.76 g/m²). The most abundant debris by weight in Lumpue was plastic and rubber while in Bojo beach it was processed lumber. There were significant differences (p < 0.05) in the average weight per m² of marine debris (i.e. plastic and rubber, metal, glass, processed lumber and cloth/fabric) between Lumpue beach and other two sites.
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Figure 6. The average abundance of marine debris by weight in the study area in March 2018.

Figure 7. The average abundance of marine debris by weight in the study area in April 2018.

Figure 8. The average abundance of marine debris by quantity in the study area in May 2018.

Nylon ropes, fishing line and equipment, and thick plastic packages/bags were the most abundant items by weight in the plastic and rubber category found at Labuange beach (2.47-56.85 and 4.85-82.41 g/m2, respectively). Clothing and fabric items (24.71-115.28 g/m2) and fabric pieces (up to 26.51 g/m2) were the heaviest items under the cloth/fabric category at Labuange beach. While lumber/building materials was the heaviest item per m² in the processed lumber category found in study area, with up to 156.79 g/m2 observed at Labuange beach, up to 11.15 g/m2 on Lumpue beach, and up to 42.62 g/m2 found on Bojo beach.

3.3. Detailed breakdown of marine debris
A detailed breakdown of the marine debris items collected by number of items is given in Table 3. A similar breakdown by weight is given in Table 4. Harmful materials were not found and are therefore not shown in these tables.
| No. | Category                                                                 | Labuange   | Lumpue   | Bojo   |
|-----|---------------------------------------------------------------------------|------------|----------|--------|
|     |                                                                           | Mar 2018  | April 2018 | May 2018 | Mar 2018  | April 2018 | May 2018  | Mar 2018  | April 2018 | May 2018  |
| 1   | Balls, tires, balloons, and their fragments                               | 0.05       | 0.00      | 0.00    | 0.04      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 2   | Plastic bottles                                                           | 0.11       | 0.22      | 0.21    | 0.13      | 0.09      | 0.00      | 0.09      | 0.01      | 0.03      |
| 3   | Plastic cups                                                              | 0.31       | 0.53      | 0.52    | 0.53      | 0.25      | 0.01      | 0.03      | 0.01      | 0.01      |
| 4   | Bottle/container caps                                                     | 0.49       | 0.15      | 0.16    | 0.82      | 0.13      | 0.00      | 0.02      | 0.03      | 0.01      |
| 5   | Cigarette lighters                                                        | 0.03       | 0.02      | 0.02    | 0.04      | 0.05      | 0.00      | 0.01      | 0.00      | 0.01      |
| 6   | Thin plastic bags                                                         | 1.07       | 0.26      | 1.52    | 0.23      | 0.05      | 0.00      | 0.01      | 0.00      | 0.00      |
| 7   | Thick plastic bags/wrappers                                               | 1.45       | 1.05      | 1.29    | 0.76      | 0.63      | 0.00      | 0.13      | 0.11      | 0.01      |
|     | Rubber bands, rubber                                                      | 0.12       | 0.01      | 0.05    | 0.07      | 0.08      | 0.00      | 0.04      | 0.01      | 0.00      |
| 8   | Tapes                                                                     | 0.05       | 0.01      | 0.01    | 0.01      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 9   | Pharmaceutical packaging                                                  | 0.03       | 0.03      | 0.01    | 0.01      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 10  | Straws                                                                    | 0.05       | 0.36      | 0.36    | 1.60      | 0.39      | 0.00      | 0.00      | 0.00      | 0.01      |
| 11  | Food container, plastic utensils, shoes, sandals, gloves, and their        | 0.06       | 0.05      | 0.07    | 0.15      | 0.04      | 0.00      | 0.02      | 0.01      | 0.00      |
|     | fragments                                                                 | 0.02       | 0.10      | 0.20    | 0.13      | 0.10      | 0.00      | 0.02      | 0.00      | 0.00      |
| 12  | Styrofoam                                                                 | 0.07       | 0.27      | 0.39    | 0.12      | 0.07      | 0.00      | 0.05      | 0.03      | 0.01      |
| 13  | Nylon ropes, fishing line and equipment                                    | 0.63       | 0.35      | 0.63    | 0.91      | 0.23      | 0.00      | 0.01      | 0.01      | 0.01      |
| 14  | Plastic ropes                                                             | 0.45       | 0.15      | 0.14    | 0.29      | 0.10      | 0.00      | 0.06      | 0.02      | 0.00      |
| 15  | PVCs, plastic hoses and sacks                                             | 0.01       | 0.03      | 0.01    | 0.01      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 16  | Plastic fragments                                                         | 0.81       | 0.28      | 0.41    | 2.72      | 0.37      | 0.01      | 0.09      | 0.04      | 0.00      |
| 17  | Personal care products                                                    | 0.05       | 0.06      | 0.01    | 0.20      | 0.05      | 0.00      | 0.00      | 0.01      | 0.01      |
| 18  | Metal                                                                     | 0.02       | 0.05      | 0.05    | 0.02      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 19  | Glass                                                                     | 0.01       | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 20  | Other metal items                                                         | 0.03       | 0.01      | 0.07    | 0.00      | 0.00      | 0.00      | 0.01      | 0.00      | 0.00      |
| 21  | Glass                                                                     | 0.00       | 0.03      | 0.02    | 0.02      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 22  | Glass fragments                                                           | 0.48       | 0.03      | 0.06    | 0.01      | 0.10      | 0.00      | 0.00      | 0.00      | 0.01      |
| 23  | Bulbs                                                                     | 0.00       | 0.01      | 0.01    | 0.03      | 0.01      | 0.00      | 0.01      | 0.00      | 0.00      |
| 24  | Other glass items                                                         | 0.05       | 0.01      | 0.00    | 0.05      | 0.00      | 0.00      | 0.00      | 0.01      | 0.00      |
| 25  | Processed lumber                                                          | 0.00       | 0.07      | 0.03    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 26  | Cardboard cartons                                                         | 0.00       | 0.04      | 0.09    | 0.00      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
| 27  | Cigarette package                                                         | 0.04       | 0.08      | 0.64    | 0.25      | 0.15      | 0.01      | 0.07      | 0.02      | 0.01      |
| 28  | Matchsticks                                                               | 0.00       | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 29  | Other/unclassified                                                        | 0.00       | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 30  | Clothing and fabric item                                                  | 0.24       | 0.29      | 0.20    | 0.03      | 0.12      | 0.00      | 0.03      | 0.01      | 0.00      |
| 31  | Diapers and sanitary napkins                                              | 0.04       | 0.06      | 0.27    | 0.02      | 0.07      | 0.00      | 0.01      | 0.01      | 0.00      |
| 32  | Food leftovers                                                            | 0.00       | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 33  | Animal carcass                                                            | 0.00       | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      | 0.00      |
| 34  | Other                                                                     | 0.00       | 0.01      | 0.07    | 0.02      | 0.01      | 0.00      | 0.00      | 0.00      | 0.00      |
Table 4. Average weight of marine debris per m² in study area

| No. | Category                                                                 | Average weight of marine debris per m² (g/m²) | Labuan | April 2018 | May 2018 | Lumpue | April 2018 | May 2018 | Bojo | April 2018 | May 2018 |
|-----|---------------------------------------------------------------------------|-----------------------------------------------|--------|-------------|----------|--------|-------------|----------|------|-------------|----------|
| 1   | Balls, tires, balloons, and their fragments                               | 0.48                                          | 0.00   | 0.00        | 1.58     | 0.00   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 2   | Plastic bottles                                                           | 1.41                                          | 3.79   | 4.69        | 0.45     | 1.09   | 0.00        | 2.11     | 0.01 | 0.42        | 0.00     |
| 3   | Plastic cups                                                              | 1.74                                          | 2.33   | 3.40        | 1.91     | 0.72   | 0.07        | 0.21     | 0.07 | 0.10        | 0.00     |
| 4   | Bottle/container caps                                                     | 1.11                                          | 0.25   | 0.51        | 1.81     | 0.26   | 0.00        | 0.09     | 0.05 | 0.03        | 0.00     |
| 5   | Cigarette lighters                                                        | 0.32                                          | 0.15   | 0.21        | 0.50     | 0.39   | 0.00        | 0.04     | 0.00 | 0.13        | 0.00     |
| 6   | Thin plastic bags                                                         | 7.39                                          | 2.21   | 5.83        | 0.93     | 1.49   | 0.00        | 1.73     | 0.00 | 0.00        | 0.00     |
| 7   | Thick plastic bags/wrappers                                               | 2.47                                          | 56.85  | 15.46       | 2.13     | 1.53   | 0.00        | 0.18     | 0.33 | 0.05        | 0.00     |
| 8   | Rubber bands, rubber fragments                                            | 2.59                                          | 0.17   | 0.40        | 13.18    | 0.55   | 0.00        | 0.39     | 0.01 | 0.00        | 0.00     |
| 9   | Tapes                                                                     | 0.13                                          | 0.01   | 0.13        | 0.01     | 0.01   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 10  | Pharmaceutical packaging                                                  | 0.04                                          | 0.13   | 0.02        | 0.03     | 0.01   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 11  | Straws                                                                    | 0.35                                          | 0.18   | 0.70        | 0.79     | 0.25   | 0.00        | 0.00     | 0.00 | 0.00        | 0.02     |
| 12  | Food container, plastic utensils, shoes, sandals, gloves, and their       | 0.25                                          | 0.25   | 0.38        | 0.33     | 0.13   | 0.00        | 0.92     | 0.01 | 0.00        | 0.00     |
|     | fragments                                                                 |                                               |        |             |          |        |             |          |      |             |          |
| 13  | Styrofoam                                                                 | 0.41                                          | 1.33   | 1.17        | 0.53     | 0.13   | 0.00        | 0.17     | 0.07 | 0.03        | 0.00     |
| 14  | Nylon ropes, fishing line and equipment                                   | 4.85                                          | 82.41  | 24.97       | 6.39     | 3.29   | 0.00        | 0.03     | 0.01 | 0.04        | 0.00     |
| 15  | Plastic ropes                                                             | 0.99                                          | 0.97   | 0.89        | 0.11     | 0.12   | 0.00        | 0.02     | 0.03 | 0.00        | 0.00     |
| 16  | PVCs, plastic hoses and sacks                                             | 9.35                                          | 2.20   | 0.45        | 0.07     | 0.05   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 17  | Plastic fragments                                                         | 2.91                                          | 1.55   | 12.94       | 5.48     | 0.67   | 0.10        | 0.25     | 0.04 | 0.00        | 0.00     |
| 18  | Personal care products                                                    | 0.68                                          | 0.57   | 0.14        | 2.07     | 0.56   | 0.00        | 0.00     | 0.03 | 0.14        | 0.00     |
| 19  | Cans                                                                      | 0.37                                          | 3.29   | 2.69        | 0.07     | 0.24   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 20  | Nails                                                                     | 0.13                                          | 0.00   | 0.00        | 0.00     | 0.00   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 21  | Other metal items                                                         | 0.18                                          | 0.09   | 0.55        | 0.00     | 0.00   | 0.00        | 0.00     | 0.03 | 0.00        | 0.00     |
| 22  | Glass                                                                     | 0.00                                          | 4.49   | 2.81        | 3.88     | 0.79   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 23  | Glass bottles                                                             | 4.25                                          | 0.43   | 0.82        | 0.15     | 0.41   | 0.00        | 0.00     | 0.00 | 0.00        | 0.02     |
| 24  | Glass fragments                                                           | 0.00                                          | 1.53   | 0.51        | 0.12     | 0.11   | 0.00        | 0.18     | 0.00 | 0.00        | 0.00     |
| 25  | Bulbs                                                                     | 0.86                                          | 0.03   | 0.00        | 0.24     | 0.00   | 0.00        | 0.00     | 1.54 | 0.00        | 0.00     |
| 26  | Other glass items                                                         |                                               |        |             |          |        |             |          |      |             |          |
| 27  | Processed lumber                                                          | 0.00                                          | 12.53  | 12.31       | 0.00     | 0.00   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 28  | Cardboard cartons                                                         | 0.00                                          | 0.58   | 1.57        | 0.00     | 0.16   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 29  | Cigarette package Lumber/building material                                | 1.63                                          | 59.63  | 156.8       | 11.15    | 4.45   | 0.02        | 42.62    | 2.25 | 1.80        | 0.00     |
| 30  | Matchsticks                                                               | 0.00                                          | 0.00   | 0.00        | 0.00     | 0.00   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
| 31  | Cigarette butts                                                           | 0.01                                          | 0.00   | 0.07        | 0.01     | 0.00   | 0.00        | 0.00     | 0.01 | 0.00        | 0.00     |
| 32  | Paper, newspaper, etc                                                     | 0.16                                          | 1.17   | 0.51        | 0.03     | 0.01   | 0.00        | 0.00     | 0.00 | 0.00        | 0.00     |
|     | Cloth/fabric Clothing and fabric                                          |                                               |        |             |          |        |             |          |      |             |          |
| 33  | items                                                                     | 26.84                                         | 115.3  | 24.71       | 0.26     | 7.12   | 0.00        | 25.31    | 1.37 | 0.00        | 0.00     |
4. Discussion

The study results confirm that the global problem on marine debris is also encountered in the study area on the west coast of South Sulawesi, Indonesia. The highest mean total abundance of marine debris was found in the residential area of Labuange beach (around 6 items/m²), followed by the Lumpue beach recreational area (around 4 items/m²), and the restricted/private area of Bojo beach (less than 0.5 items/m²). As the sampling was conducted on the neap tide of the east monsoon, where the distance between high and low tide is narrow, these values a probably considerably lower than if the debris had been collected during the west monsoon. In fact, huge mounds of debris above the recent high tide lines left over from the previous west monsoon can be considered for comparison. The mean abundances of marine debris per m² in study sites were far higher than those reported from sites in the South China Sea (0.032 items per m²) [8], the beaches of Bahia, northeastern Brazil (0.3 and 2 items per m²) [9], and the beaches of Takalar, Indonesia (0.48-0.80 items per m²) [7].

Similar to other findings elsewhere [7-11], plastic (in this study rubber was included in the same category) predominated the marine debris collected from the study area (72-95%). As a result, this category that has lightweight characteristics was include in the heaviest collected debris at some point during the study period in all study areas, rivalling or even surpassing in total weight the other significantly abundant categories with much higher weights per volume, such as cloth/fabric and processed lumber.

The average quantity of marine debris per m² decreased significantly at Lumpue and Bojo beaches after the first sampling collection which contained previously accumulated debris. Very low abundance of marine debris in the final sampling batch at the recreational area of Lumpue beach (decline from 8.77 items per m² in March 2018 to 0.02 items per m² in May 2018), was due to the implementation of a beach clean-up. The exception was Labuange beach, where the collected debris remained very high and even increased during the study period (4.82, 3.92, and 6.01 items per m² from March to May 2018), with values an order of magnitude larger (8 to 54 times greater) than in the private/restricted area of Bojo beach. The actual values in Labuange beach were probably even greater as the local community often push the beached debris toward the sea both to minimize the amount of debris on the beach, and to free a pathway for their boats.

Wave and current directional patterns and site morphology also played crucial roles in determining the amount and weight of marine debris in the study area. During the sampling period, the wave direction pattern around the study location changed between sampling times (Figure 9-11). In the first month of sampling, the typical wave direction pattern was predominantly from the Java Sea, with some input from the northern Makassar Strait. Since the marine debris collected from the first sampling period included the accumulation from previous months, some of the stranded debris might have come from previous wave directions as well.

| No. | Category                  | Average weight of marine debris per m² (g/m²) |
|-----|---------------------------|---------------------------------------------|
|     | Labuange  | Lumpue  | Bojo    |
|     | Mar 2018 | April 2018 | May 2018 | Mar 2018 | April 2018 | May 2018 | Mar 2018 | April 2018 | May 2018 |
| 34  | Diapers and sanitary     | 7.41  | 11.31  | 45.25 | 2.84  | 7.23  | 0.00  | 2.55  | 1.19  | 0.00  |
| 35  | napkins                  | 24.75 | 0.75   | 26.51 | 0.00  | 0.00  | 0.00  | 1.06  | 3.84  | 0.00  |
| 36  | Fabric pieces            | 0.00  | 0.00   | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 37  | Food leftovers           | 0.00  | 0.00   | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| 39  | Animal carcass           | 0.00  | 1.28   | 2.86  | 0.17  | 0.02  | 0.00  | 0.00  | 0.00  | 0.00  |
|     | Other/unclassified       | 0.00  | 0.00   | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
Figure 9. Typical wave direction patterns around the study location in March 2018

Figure 10. Typical wave direction patterns around the study location in April 2018

Figure 11. Typical wave direction patterns around the study location in May 2018
In April, the wave direction typically came from Flores Sea through Makassar City waters. While in May, the wave direction was predominantly from the Banda Sea through the Flores Sea and Makassar City waters. These different wave directions may have allowed significant contribution to the stranded marine debris from many sources. In addition, Labuange beach (Site 1) is more exposed to the open sea compared to the other sites, which may have contributed to the greater amount of marine debris stranded on Labuange beach. Lumpue beach is also a fairly exposed site, but there is a cape close to the site, which could act as a barrier to marine debris coming from the north side. Bojo beach is in a calm bay, therefore the amount marine debris entering the bay is likely to be much less, contributing to the lower amount collected compared to that from Labuange and Lumpue beaches.

The habits of beach users also played a significant role in the amount and weight of marine debris at the site. This was especially visible at Labuange beach, where the community throw their daily trash as well as boat ropes and other garbage onto the beach. This habit is likely to result in increasingly negative impacts on humans and marine organisms, as well as the marine environment.

Thick plastic packages/bags, the most abundant type of debris at all sites, together with other types of marine debris, significantly reduce the aesthetic value of the environment and could potentially harm marine life and the environment. Marine debris, mainly plastic, is often found in the digestive tracts of dead marine animals since they often mistake marine debris for food. This can then result in choking due to blockage of the throat or other parts of the digestive tract by debris items; alternatively, it may remain and accumulate in the digestive organs, thus making marine animals feel full until they die due to starvation [1, 2, 5]. Ropes and fishing gear that are released into the ocean can trap marine animals. Difficulty in breathing and moving due to entanglement in this type of waste is an often fatal threat encountered by marine organisms [1, 5]. Marine debris also a threat to coral reef ecosystems [12]. In addition, this durable plastic debris is also an attractive medium for some marine species to colonize; these organisms could then ride the currents to other regions, thereby increasing the opportunity for alien species to invade [2].

In Lumpue beach, littering from visitors also contributes to some degree to the beach debris, including straws that were found in high numbers, particularly during the first sampling period. However, the quantity of debris from visitor littering was not as great as that stranded from the waters of the Makassar Strait. In the private/restricted area of Bojo beach, there was only a small amount of debris, which probably mostly originated from the shore.

Unlike the other sites, where marine debris decreased during the study period, the consistently high abundance of marine debris (by quantity and weight) at Labuange beach, particularly plastic and rubber that have strong and durable characteristics, emphasizes the significant contribution of a residential area to marine debris. These results point to an urgent need for frequent local waste and marine debris collection to minimize the impacts of marine debris on the environment. These should be implemented in conjunction with other important efforts, including community education on marine debris problems and the handling of waste.

5. Conclusions
Plastic and rubber dominated marine macro debris in the study area during the study period, representing over 80% of all items. Plastic and rubber, cloth, and processed lumber were the heaviest debris in the study area, with different rankings in each site. The abundance of marine debris by quantity was consistently highest at Labuange Beach due to the regular input of extra litter from the village, while at the other two sites the density decreased once accumulated debris had been removed. Beach morphology and wave direction patterns also played significant roles, contributing to the greater quantity and volume of marine debris washed up on Labuange beach. Management efforts, including frequent local waste and marine debris collection, are urgently required to minimize the impacts of marine debris on the environment.
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