Macroplastic Transport and Deposition in the Environs of Pulauan River, Dapitan City, Philippines

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Plastic pollution is an emerging threat in the riverine ecosystem that affects the marine ecosystem. The Philippines, being an archipelago, is heavily dependent on its marine ecosystem. It is also considered the largest emitter of plastic via rivers. Despite this, limited field studies have been conducted to validate this finding, which is mainly based on numerical models. In this study, we determined the prevalence of macroplastics in Pulauan River, Dapitan City by observing the plastic flux and further comparing the morning and afternoon flux. Macroplastic collection was also performed to compare the plastic densities of three stream areas: upstream, midstream, and downstream. Results show that macroplastic flux in the morning (304 items/h) was significantly higher than in the afternoon (91 items/h). The correlation of macroplastic flux and flow velocity was determined to be positive – suggesting that as macroplastic flow velocity increases, plastic flux tends to increase. Macroplastic collection results showed that upstream density (0.074 items/m$^2$) is significantly lower than midstream (0.559 items/m$^2$) and downstream (0.473 items/m$^2$) densities. This shows that the nearer the area is to the river mouth, the more susceptible it is to plastic litter deposition. The composition of the macroplastic litters observed and collected was attributed to the influences of human activities (aquaculture, fishing, and residential) – where food packaging, plastic bags, and plastic fragments are the top three most abundant. Due to the limitations of this study, there is a need to investigate further the different factors on the transportation and deposition of macroplastic litters in Pulauan River that can help to avoid threats in the aquaculture sector, for which the river is known.

Keywords: macroplastic, Philippines, plastic flux, stream density, river

INTRODUCTION

Plastic pollution is a prevalent and emerging problem in the world, especially in the Philippines. According to Jambeck et al. (2015), the country was ranked as the 3rd plastic polluter in the world out of 192 countries, which contributed 0.28–0.75 million metric tons per year of generated plastic debris. The disposal of these plastics is mostly on land, but they always find a way to enter bodies of water and accumulate, which in turn cause heavy pollution (Horton et al. 2017). Because they can pose a threat to human health, wildlife, and the environment, their presence in the aquatic environment has received much attention. These plastics often called macroplastics are known to be harmful to aquatic animals in a way that they can be mistaken as their food and other animals can be entangled and die by discarded fishing nets and other plastic materials (Aden 2018). These macroplastics are defined as plastics with greater than 5 mm in size (van
Emmerik and Schwarz 2019). Although most studies on plastic litter focused on marine-based environments, there is an emerging interest in studies on the riverine system knowing that rivers are pathways for plastics to the ocean (Verster and Bouwman 2020).

Plastic litters released by river sources tend to accumulate on coastlines (Cruz and Shimozono 2021) and can be everywhere; therefore, the exposure to different marine organisms is high (Abreo et al. 2016a, b) where it can cause harm. There are already studies in the Philippines that show plastic litter interfering with the eating habits of marine life (Abreo et al. 2016a, b; Aloy et al. 2011).

It is said that rivers contribute 0.4–2.75 million tons of plastics to oceans annually (Lebreton et al. 2017; Schmidt et al. 2017). The top 20 of those polluting rivers are located in Asia (Lebreton et al. 2017). The Philippines contributes to plastic pollution mostly via rivers and streams from land-based sources (Jambeck et al. 2015; Lebreton et al. 2017). There are 4,820 rivers in the Philippines that emit 356,371 MT/year of plastic waste, as estimated by the model in the study of Meijer et al. (2021), making it the largest contributing country from riverine sources. An example of this is the Pasig River; before it was rehabilitated, solid waste contributed 10% of the pollution, and these solid waste blocks the penetration of sunlight and sinks in the riverbed, causing the existing aquatic life to suffocate (Helmer et al. 1998). The river is said to release 32–64 thousand tons of plastic each year (Lebreton et al. 2017). The reduction of aquatic fish and plant species was also observed and affected the fishing sector in the river (Helmer et al. 1998).

Despite being the largest contributor of riverine plastics and the third biggest polluter of plastics in the marine environment, only a limited number of studies have been conducted in the Philippines—such as those in mangroves (Abreo et al. 2019), beaches (Paler et al. 2019; Esquinas et al. 2020; Sajorne et al. 2021; Galarpe et al. 2021), and biota (Abreo et al. 2016a, b; Espiritu et al. 2019; Obanan et al. 2020). There is only one study conducted on riverine plastics in the Philippines focusing on Tullahan, Meycauayan, and Pasig Rivers (van Emmerik et al. 2020). Despite being considered major contributors to riverine plastics, there is no such study conducted on the rivers in Visayas and Mindanao, also major sources of riverine plastic pollution based on numerical models.

The Pulauan River located in Dapitan City, Zamboanga del Norte has constituents that depend on aquaculture as a source of living. Surrounding the rivers are fishponds and fish pens that yield different aquaculture products of different varieties of fish, crustaceans, and shells. Aside from those, residential houses are also along the river that can potentially be sources of plastic pollution. The presence of mangrove species is also attributed to the plastic litter abundance in the river because the litter can get stuck in its pneumatophores, roots, and branches.

The mismanaged waste disposal from different sectors like residential and aquaculture that finds its way to rivers and streams make plastic pollution in freshwater ecosystems important for marine plastic pollution (Superio and Abreo 2020). Despite the ecological importance of Pulauan River and its contribution to the economy of the area, the emerging threats due to plastic litter have not been evaluated. There is no systematic study to assess the extent of plastic pollution in the area and the number of plastics transported through the river.

To address these knowledge gaps, this study was conducted to determine the flux of macroplastics transported through the Pulauan River. It also aims to assess the prevalence of plastics along the river banks and the types of plastics deposited in the area.

MATERIALS AND METHODS

Locale of the Study
The study was conducted in Pulauan River located in Dapitan City, Zamboanga del Norte, which is in the northern part of the Zamboanga Peninsula. Its approximate geographical coordinates are 8°50’ north latitude and 123°30’ east longitude, and it has a total area of 39,053.1267 hectares (Figure 1). It has an approximate width of 60 m and an approximate depth of 6 m. It is bounded on the north by the Sulu Sea and on the south by the Municipalities of Mutia and La Libertad, on the east by the Municipalities of Sibutad and Rizal, and on the west by Dipolog City and the Municipalities of Polanco and Piñan—all in the Province of Zamboanga del Norte. It traverses through Barangay Antipolo, Barangay San Pedro, and a portion of Barangay Polo, which is going in the northwest direction spilling at Pulauan Bridge in San Pedro towards Dapitan Bay. The river is surrounded by marshland that is converted into an aquaculture area. It produces different kinds of cultured fish, crustaceans, and shells (CLUP 2015–2024). Due to its importance in the food industry and its susceptibility to different kind of pollutants, the river, and its organisms warrants investigation.

Macroplastic Flux Observation
Plastic flux was determined based on the study of González-Fernández and Hanke (2017), as adopted by van Emmerik et al. (2018) with modifications. Observations were done in Pulauan Bridge for 10 consecutive days from 02–11 Jul 2021. Pulauan Bridge is approximately 300 m from the river mouth with an approximate width of 60 m
and is the only area where macroplastic flux observation can be conducted. Macroplastic litter floating was counted and identified for 1 h, which was conducted twice a day: morning (8–9 AM) and afternoon (4–5 PM). Each floating and superficially submerged macroplastic item that was visible was counted, independent of its size. It was then categorized per plastic classification. The flow velocity was also determined in order to assess if it affects the macroplastic flux.

**Surface Flow Velocity**

In order to get the flow velocity of the Pulauan River, the method of “Pooh-sticks” based on Bull and Lawler (1991) was adopted and modified. A table tennis ball was tracked...
and timed over a predetermined distance of 10 m. The ball was timed using a stopwatch from the predetermined starting point up to the predetermined endpoint. The flow velocity (m/s) was calculated by dividing the transect length by the travel time of the tracked item.

This method was done three times to determine the average flow velocity.

**Macroplastic Collection on Riverbank**

Macroplastics were collected on the riverbank following the method of Rech et al. (2014) with modifications. The area was divided into three sections: the downstream, midstream, and upstream (Table 1). The sampling sites were heterogeneous depending on their accessibility. Each section had three quadrats (5 m x 5 m) with a 15-m distance in between quadrats. Macroplastics found in the quadrats were collected and placed in a container. The macroplastics were then weighed and characterized. Collection of macroplastics from the same site was done twice a week for 3 wk from 17 Jul–04 Aug 2021.

**Plastic Litter Categorization**

The collected macroplastic litter was classified based on its uses such as food packaging, toiletries, plastic bag, plastic bottle, disposable cups, plastic caps, medical waste, cigarette butts, plastic fragments, cigarette cartons, diaper/sanitary pads, ropes, and others. It was categorized further into polymer types: PET (polyethylene terephthalate), HDPE (high-density polyethylene), PVC (polyvinyl chloride), LDPE (low-density polyethylene), PP (polypropylene), PS (polystyrene), multilayer, and others for other polymer combinations (Martins and Sobral 2011).

**Data Analysis**

The density (PLD) and composition (PLC) of the collected macroplastics were determined using the computations based on the study of Abreo et al. (2019):

\[
PLD = \frac{\text{Number of items}}{\text{Total area sampled} (L \times W) (m^2)} = \text{Item/m}^2
\]

\[
PLC = \frac{\text{Number of items per category}}{\text{Total number of items in all category}} \times 100
\]

**Statistical Analysis**

The PAST (Paleontological Statistics Software) version 4 (Hammer et al. 2001) statistical tool was used in analyzing the data. A normality test was first done to determine if the data was parametric or non-parametric. To determine the significance between the macroplastic flux in the morning and afternoon, the t-test was used, whereas Mann-Whitney was used for macroplastic flux and flow velocity. In comparing the stream densities of marine debris in the riverbank, the one-way analysis of variance was used.

**RESULTS**

**Macroplastic Litter Flux**

A total of 1,636 macroplastics items were identified from the Pulauan Bridge for 10 d of observation (Figure 2). There were 1,280 items observed in the morning, which was higher than the total items observed in the afternoon, which was 356 items. The highest macroplastic flux observed was 304 items/h – the highest for this parameter – in the upstream direction and 271 items/h in the downstream direction. The observation done at the river mouth of Pulauan River shows that macroplastic flux varies in the time of the day, as well as the flow direction. The macroplastic flux in the morning is significantly higher than in the afternoon (\(p = 0.0077\)).

It was also observed that during sampling days, bad weather was evident. Heavy rainfall occurred the night before and high tide happened during sampling days 4–8. Rain and slight drizzle with a strong wind were also happening at different times of the day.

Figure 3 shows that the flow velocity is related to macroplastic flux. The afternoon macroplastic flux and flow velocity have a significant correlation (\(p = 0.047\)), whereas those in the morning do not (\(p = 0.217\)). Considering this result, there is still a weak positive correlation between the morning and afternoon macroplastic flux and flow velocity (morning: \(r = 0.428\);

<table>
<thead>
<tr>
<th>Area</th>
<th>Coordinates</th>
<th>Area type</th>
<th>Litter count</th>
<th>Density (items/m²) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>8°36′55″N, 123°24′9″E</td>
<td>Mangrove</td>
<td>67</td>
<td>0.074 ± 0.024 b</td>
</tr>
<tr>
<td>Midstream</td>
<td>8°36′51″N, 123°23′52″E</td>
<td>Mangrove</td>
<td>503</td>
<td>0.559 ± 0.191 a</td>
</tr>
<tr>
<td>Downstream</td>
<td>8°37′25″N, 123°23′37″E</td>
<td>Residential</td>
<td>426</td>
<td>0.473 ± 0.164 a</td>
</tr>
</tbody>
</table>
afternoon: $r = 0.638$). This shows that, generally, as the flow velocity increases, the macroplastic flux also increases.

Mostly, residential waste was observed during the sampling (Figure 4). The most abundant plastic classification was food packaging (33%) – followed by plastic bags (24%), plastic fragments (14%), toilets (8%), others (6%), plastic bottles (3%), medical waste (3%), disposable cups, plastic caps, cigarette butts, cigarette boxes, diaper/sanitary pads, ropes, straws, rubber, cans, and sacks. Food packaging includes food wrappers for junk foods, candies, and biscuits plus sachets for food condiments like soy sauce, vinegar, and seasoning. Plastic bags were second because the area is an aquaculture farm that depends on *sari-sari* store-bought ice for the cooling of harvested livestock, which resulted in a lot of ice wrappers. Trash bags were also observed because it is where fingerlings were contained before transferring them to the fish pens or fish ponds.

**Macroplastics in Riverbank**

There was a total of 996 items collected in the three streams. The upstream had predominantly mangrove species on both sides of the river, whereas the midstream had a residential area on one side and mangrove species on the other side. The downstream area had mangrove species on both sides, but residential houses occupied most of the riverbanks on both sides. The lowest litter count of 67 items was collected upstream, whereas the midstream had the highest litter count of 503 items. The midstream location yielded the highest mean density of 0.559 items/m$^2$, followed by downstream with 0.473 items/m$^2$ and upstream with 0.074 items/m$^2$ (Table 1). The density of macroplastics fluctuates with time, showing no clear decreasing trend (Figure 5). Statistically, there is a highly significant difference between the densities of the three sites ($p = 5.748 \times 10^6$). To specifically determine which stream was significant, Tukey’s pairwise test was used. It showed that upstream density was significantly lower than midstream and downstream densities ($p < 0.0001$). Midstream and downstream densities are not significantly different from each other. The areas in midstream and downstream are considered to be residential; therefore, it was expected to have a higher number of macroplastic wastes with the addition of drifters during upstream flow direction that can get stuck in the mangrove trees in the area. Accordingly, there is no significant difference
between the macroplastic debris densities collected on weekends and weekdays.

The most abundant plastic classification in the riverbanks was food packaging (34.2%) – followed by plastic bags (18.7%), plastic fragments (15%), others (7.8%), toiletries (7.2%), plastic bottles (3.9%), ropes (3.1%), textiles (1.1%), plastic caps (1.2%), sacks (1.4%), medical wastes (1.3%), metals (1.0%), cigarette cartons, glass, disposable cups, diaper/sanitary pads, rubber, nets, drinking straws, and cigarette butts (Table 2).

Most of the polymer types (Figure 6) identified is LDPE (55%), which comes from food packaging and plastic

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**Table 2.** Summary of the plastic classification, composition, and weight of the collected samples from the riverbank of Pulauan River.

<table>
<thead>
<tr>
<th>Classification</th>
<th>No. of items</th>
<th>Percentage (%)</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food packaging</td>
<td>341</td>
<td>34.2</td>
<td>679</td>
</tr>
<tr>
<td>Plastic bags</td>
<td>186</td>
<td>18.7</td>
<td>713.5</td>
</tr>
<tr>
<td>Fragments</td>
<td>149</td>
<td>15.0</td>
<td>104.6</td>
</tr>
<tr>
<td>Toiletries</td>
<td>72</td>
<td>7.2</td>
<td>220.9</td>
</tr>
<tr>
<td>Plastic bottles</td>
<td>39</td>
<td>3.9</td>
<td>1,272.1</td>
</tr>
<tr>
<td>Ropes</td>
<td>31</td>
<td>3.1</td>
<td>695.7</td>
</tr>
<tr>
<td>Textiles</td>
<td>11</td>
<td>1.1</td>
<td>1,121.8</td>
</tr>
<tr>
<td>Plastic caps</td>
<td>12</td>
<td>1.2</td>
<td>22.2</td>
</tr>
<tr>
<td>Sacks</td>
<td>14</td>
<td>1.4</td>
<td>500.1</td>
</tr>
<tr>
<td>Medical</td>
<td>13</td>
<td>1.3</td>
<td>38.1</td>
</tr>
<tr>
<td>Nets</td>
<td>4</td>
<td>0.4</td>
<td>236.8</td>
</tr>
<tr>
<td>Cigarette cartons</td>
<td>9</td>
<td>0.9</td>
<td>113.9</td>
</tr>
<tr>
<td>Disposable cups</td>
<td>7</td>
<td>0.7</td>
<td>18.6</td>
</tr>
<tr>
<td>Diaper/ sanitary pads</td>
<td>5</td>
<td>0.5</td>
<td>185.2</td>
</tr>
<tr>
<td>Drinking straws</td>
<td>1</td>
<td>0.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Cigarette butts</td>
<td>1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Rubber</td>
<td>4</td>
<td>0.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Cans/ metals</td>
<td>10</td>
<td>1.0</td>
<td>456.3</td>
</tr>
<tr>
<td>Glass</td>
<td>9</td>
<td>0.9</td>
<td>3,049.4</td>
</tr>
<tr>
<td>Others</td>
<td>78</td>
<td>7.8</td>
<td>1,707.3</td>
</tr>
</tbody>
</table>
Macroplastic debris drifters and human intervention are also factors considering that the area is residential. The river has mangrove trees, oyster farms, and fish pens, where macroplastic debris can be deposited. The deposited macroplastics may be disturbed by waves from the change of tides plus increased flow velocity and water level (van Emmerik et al. 2019) or from traversing fishing boats, especially in the morning when fishing is done. Studies on the river plastics in the Philippines (van Emmerik et al. 2020) did not account for the contribution of these factors to the amount of plastics transported in the river.

In the study of Lebreton et al. (2016), they assume that artificial barriers act as sinks for plastic litter, which in this study can be in the form of fish cages, fish pens, and oyster rafts that disrupts the rivers flow, added by the mangrove trees in the riverbanks. The abundance of macroplastic flux can also be because of the abundance of plastic litter on the riverbank area.

As the result of the riverbank collection shows, the abundant collection of macroplastic litters is attributed to the area having mangrove trees. According to the study by Martin et al. (2019), plastic litter – especially those larger in size – is more likely to be trapped in the mangrove root systems than on sandy beaches. The midstream and downstream areas have the most collected macroplastic litters. It was expected that these areas would have a higher quantity because the macroplastic debris during upstream flow gets deposited in the downstream area first then in the midstream area – leaving it stuck in mangrove trees, which is the reason why the quantity of macroplastic litter in the upstream area was the lowest. Also, according to Rech et al. (2014), the further the distance is to the river mouth, the plastic litter decreases. Another factor to be considered is that both midstream and downstream areas are residential.

The sources of plastic litter deposited are close to where they come from (Willis et al. 2017); therefore, residential macroplastic litters are highly observed to be abundant during samplings. They are mostly single-use plastics. Plastic food packaging is the most abundant. It was observed to be mostly junk food wrappers, condiments sachets, and other food storage and is present in both macroplastic flux and riverbank collection sampling. It was expected to be the most prevalent plastic litter due to it being locally available and able to be purchased in smaller
quantities, which makes them more affordable (Paler et al. 2019). Plastic bags are the second most abundant litter, and aquaculture activities are suspected to be one of the reasons. Out of all plastic bags, ice wrappers have more quantity during macroplastic flux sampling. It is assumed to be because sari-sari store-bought ice is used for cooling during the harvesting of fish livestock.

For the riverbank collection, grocery bags have higher quantities. The abundance of sari-sari stores beside or near the river has a great influence on its quantity. Based on observation, the practice of buying in sari-sari stores and putting items, may it be few or many, in grocery bags or plastic bags adds to the plastic debris in the river. It is easier for grocery bags to be deposited or stuck in the riverbank due to it having handles that can be caught in the branches, roots, or pneumatophores of mangrove trees.

The third most abundant plastic litter in both samplings is the fragments. According to the United States National Oceanic and Atmospheric Administration, plastic fragments are those bigger than 2.5 cm in diameter that have sustained their hard structure due to weathering or applied force. It is either undetectable or constitutes less than half of the original structure. These plastic fragments will, through time, become microplastics that can be ingested by aquatic animals, which will pose a problem to the aquaculture industry in Pulauan River.

The most abundant polymer type is LDPE, which is mostly from plastic bags and other food packaging. The second most abundant polymer type is multilayer. These multilayer plastics are mostly used in food packaging in order to prolong shelf life (Mulakkal et al. 2021). Compared to other polymer types, multilayer plastics are difficult to recycle, especially those that are laminated; the method to delaminate it is either physical, chemical, or mechanical (Kaiser et al. 2017). This, in turn, will become an added problem in our waste management.

The findings of this study can serve as baseline information for the LGU (Local Government Unit), DENR (Department of Environment and Natural Resources), BFAR (Bureau of Fisheries and Aquatic Resources), and other concerned agencies for intensive and consequent monitoring of the condition of Pulauan River. This study provides background information for other related research studies to be conducted in the Pulauan River and other river systems.

ACKNOWLEDGMENTS
The researcher wishes to express her sincere gratitude and deep appreciation to the following institutions and individuals: the Department of Science and Technology–Science Education Institute through the ASTHRDP (Accelerated Science and Technology Human Resource Development Program) scholarship program that funded this study; Jessa Cabugnason, Jerome Cabugnason, and Jerry Elumbaring as research assistants during the conduct of samplings; and Shiela Mae Gaboy, Sherley Ann Inocente, and Christine Joy Pacilan for the support throughout the conduct and writing of this study.

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CONCLUSION
Overall, we unraveled the macroplastic pollution in Pulauan River stream and riverbank. Pulauan River, although small, still showed a significant abundance of plastic litter with 1, 636 items for macroplastic flux sampling and 996 items for riverbank collection sampling. Macroplastic flux was higher in the morning than in the afternoon, which is influenced by flow velocity, flow direction, weather conditions, and other factors.

Macroplastic litter is most abundant in midstream and downstream areas and is believed where the macroplastic flux mostly is from. These results show that the deposition of macroplastic litters in the river system will continue if the intervention of the different affecting factors is not properly taken. It is alarming to think that, through time, more plastic debris can be transported by the river and can cause a massive problem in our freshwater and marine ecosystems.

Although waste management strategies are introduced through policies and laws in the Philippines, the abundance of plastic litter in our waterways system is still due to human activities, and only humans can also control it. Studies on the contributions of slope area, vegetation cover, seasons, and other factors to the amount of plastics in the river warrant further investigation.


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