Anthropogenic Marine Debris (AMD) in Mangrove Forests of Pujada Bay, Davao Oriental, Philippines

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Publication Information:
Received 16 December 2019, Accepted 13 April 2020, Available online 29 June 2020
DOI: 10.21463/jmic.2020.09.1.03

Abstract

Anthropogenic marine debris (AMD) is a global threat to marine biodiversity and marine ecosystems. The main objectives of this study were to compare and characterize the AMD composition of mangrove stands that are located in a reserve area and mangrove stands that are influenced by nearby human settlement. Two study areas were chosen based on similar mangrove species composition and stand where transect quadrats (50 x 50m) were established in the area. The AMD were sampled during low tide in six subplots (5 x 5m) located in the transect quadrats in the mangrove forest of Dahican and Matiao, in Pujada bay, Davao Oriental. Various types of AMD were collected, cleaned and dried and then weighted and classified as belonging to plastics, cloths, rubber, glass, metals, wood or other items. Comparison of weight of AMD between the two study areas (Dahican and Matiao) showed no significant differences (P=0.119). In terms of comparison of different categories in the two study areas, only Matiao showed significant differences (P<0.001) with the category of cloth contributing highly at 39 g. There was no significant difference of the categories for the study area in Dahican (P=0.137). Further confirmatory studies on AMD and mangroves and its ability to trap AMDs are suggested including the impacts of AMD on marine fauna and flora.

Keywords

Anthropogenic marine debris (AMD), mangrove, marine litter, marine pollution, Mati City, plastics, Pujada bay

Introduction

Anthropogenic marine debris (AMD) can adversely affect the smallest organisms (e.g., zooplankton) and including the largest predators such as sharks, whales, and turtles (Desforges et al. 2015). Ecosystem engineers such as corals (Allen et al. 2017) and lugworms (Green et al. 2015b) are also reportedly affected by marine debris (Coleman and Williams 2002). Greater ecological impacts are expected as more studies show an ecosystem level effect and could impact the marine populations (Browne et al., 2015). Other studies have shown that fish and shellfish destined for human consumption can also ingest marine microplastics (Rochman et al. 2015). Evidence for possible trophic transfer and incorporation of toxic chemicals associated with marine debris in the biomass of marine organisms that ingest them are present (Farrell and Nelson 2013; Rochman et al. 2013). These findings can affect food security choices among consumers especially in food insecure developing countries dependent on marine fish resources (Macusi et al. 2011).

Anthropogenic marine debris is now recognized as a global threat to marine biodiversity (Hardesty and Wilcox 2017). In general, marine litter can be grouped into four main categories: (1) glass; (2) metal; (3) paper and; (4) plastics (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF, 2012). However, among the different types of marine litter, plastic is the most abundantly distributed marine litter. Previous studies have quantified its contribution from different countries which show that plastic composes greater than 80% of anthropogenic marine debris collected and counted from beach surveys (Thiel et al., 2013; Walker et al., 2006). Some reports even reported plastic making up 95% of beached litter (Lee et al., 2013). Further, plastic also makes up greater than 80% of floating marine litter, even recording as high as 96% in the Straits of Malacca (Ryan, 2013). Global estimates of plastics found floating from different oceans is estimated at 5.25 trillion pieces (Eriksen et al., 2014).

The identification of sources and sinks of AMD is an important aspect to further understand the marine litter problem. However, the sources and sinks of marine litter are poorly understood. Generally, marine litter input can be classified as land-based or ship-based. It is estimated that 80% of marine litter comes from land-based sources and the remaining 20% is from ocean-based sources (Faris and Hart 1994). However, in some areas (see Galgani et al., 2015) , litter from ocean-based sources can compose up to 95% of collected litter items.

Jambeck et al., (2015) identified 192 countries contributing as high as 12.7 million metric tons of marine plastic in 2010. Mismanaged waste, or inefficient solid waste management had been concluded as one of the main reasons for plastic entry to the marine environment (Macusi et al., 2019). According to Carson et al. (2011), a densely populated residential area can contribute higher number of marine litter. Therefore, it is not surprising that China, Indonesia, and the Philippines are the top three contributors of marine plastics globally (Jambeck et al, 2015). Direct disposal of household wastes into canals, low lying seabeds, and tourism areas in coastal sites contribute to marine litter (Orale and Fabillar, 2011; Wilson and Verlis, 2017). Also, sewerage, rivers and typhoons or storm can help carry litter from different sources farther inland and deposit it to the marine environment (Lebreton et al., 2017; Browne et al., 2011).

Ocean-based sources of litter include shipping, fisheries and offshore installations (Galgani et al., 2015). Wastes disposed from cargo, passenger and even luxury ships as well as discarded fishing materials (e.g fish nets, ropes and floaters or fish aggregating devices) from fishing boats contribute largely to ocean-based litter (Katsanevakis and Katsarou, 2004).

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Several factors affect the distribution of marine litter in different marine and coastal habitats. Distribution of lightweight and bouyant debris is greatly influenced by ocean current, tides, and also wind, can transport these materials over long distances or increase the vertical mixing of marine litter in the water column (Kukulka et al., 2012; Law et al., 2010). Other properties of marine litter, such as size and composition, as well as biofouling, also influences the distribution of litter (Kooi et al., 2017; Kooi et al., 2016; Fazey and Ryan 2016).

Marine debris are now ubiquitous, even found in the remotest islands and the deepest parts of the ocean (Chiba et al., 2018 ; Lavers and Bond 2017). Coastal environments, such as beaches and mangrove areas are considered as an important sinks of marine litter (Martin et al., 2019; Kusui and Noda 2003). Geophysical factors such as type of substrate and position of the beach (leeward or windward) have an influence in the stranding of marine litter in shores. For example, Schmuck et al., (2017) observed that leeward beaches accumulates more marine debris than windward ones and sandy beaches have more marine debris when compared to rocky beaches. Marine debris washed ashore can be buried in the sand allowing for the debris to be retained in this type of environment (Kusui and Noda 2003).

On the other hand, mangrove areas have been reported to act as traps of marine debris, accumulating high number of marine debris due to the pneumatophores acting as filters (Martin et al., 2019). Moreover, marine litter was higher in mangrove stands with more mangroves supporting the claim of Martin et al., (2019). The capacity of mangrove to retain marine litter was also demonstrated by the experiment of Ivar do sul et al., (2014). The potential impacts of marine litter to mangroves include smothering young saplings, covering and burying smaller mangrove seedlings, breaking young branches due to their weight and impact during waves and tidal forces. Floating marine litter can also clog or cover the pneumatophores of mangrove root systems, preventing it from taking oxygen from the air. With high volume of marine litter deposited in between its roots or its area, the litter can also prevent its propagules from landing properly on the water or on the soil beneath its canopy. Moreover, it can also displace various marine invertebrates that seek habitat on its roots and trunks including its nearby area due to the accumulated marine litter. This will have an impact on habitat suitability of the mangrove area affected by wastes as these young or smaller organisms are displaced by marine litter floating around or plastics wrapping itself on roots, trunks and even on leaves of the mangrove trees. Although further investigations are needed to asses the impacts of retained marine litter to mangroves and other organisms, the threat can be important one, especially for mangrove conservation.

In recognition of this threat, there has been an increase in the number of studies conducted on AMD, especially plastics and its impacts (Ryan 2015). However, the possible impacts of marine litter in the Philippines are far less studied (Abreo et al., 2018). In fact, there seems to be no available data even on the density, distribution and characterization of marine litter from the Philippines. According to Jambeck et al., (2015) and Lebreton et al., (2017), the country is a major contributor of anthropogenic marine debris globally and recent publications on the negative impacts of marine litter show the vulnerability of marine organisms in the country (Abreo et al. 2016a, 2016b; Obusan et al. 2016). Therefore, there is a need to address the lack of data in the country. This paper presents a study on anthropogenic marine debris found in mangrove areas, with the main aim that the result of this study provides information about AMD in mangrove areas. Specifically, this study aims to determine composition, density, weight, and rate of accumulation of AMD in selected mangrove forests of Pujada Bay, Davao Oriental, Philippines. We compared the weight of various categories of anthropogenic marine debris found in the two areas as well as evaluated the difference between the two study areas in terms of weight of the debris found. We predict that there will be no difference between the two study areas in terms of the weight of the AMD but there will be a difference in terms of the weight of the different categories of AMD.

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Methods

Description of study area

The study was conducted in Pujada Bay, Davao Oriental, Philippines (Fig. 1) which has an area of approximately 168 km^2 and was declared under National Integrated Protected Areas System (NIPAS) as Protected Landscape/Seascape under Proclamation No. 451 dated July 31, 1994 of the Philippine government. The fringing coastal areas of Pujada bay, are densely covered by mangrove forests in the past, but human settlements in the past 50 years have decreased the natural mangrove area. The current mangrove area planted in the study sites cover 400 ha which encompass both natural forests and rehabilitated or replanted mangrove sites. Because the area is protected and rehabilitated, some patches are thick and some are also open, including those that have human informal settlers and near the commercial center of Mati. Study area one is found in barangay Dahican, which is part of a mangrove protected area, and far from from human settlement but accessible to human visitors and gleaners. The natural and replanted mangrove area in Guang-guang has about 77 ha of mangrove area. For the mangrove forest of Guang-guang, there is no clear delineation of zones for local tourists, residential areas and fish and mangrove sanctuaries. The other study area is nearby to a human residential area, with a factory of coconut oil and other coconut byproducts. The mangrove stands found in the two study areas are generally representative of the mangrove population present in the embayment since the original mangrove forest stands are mostly gone.

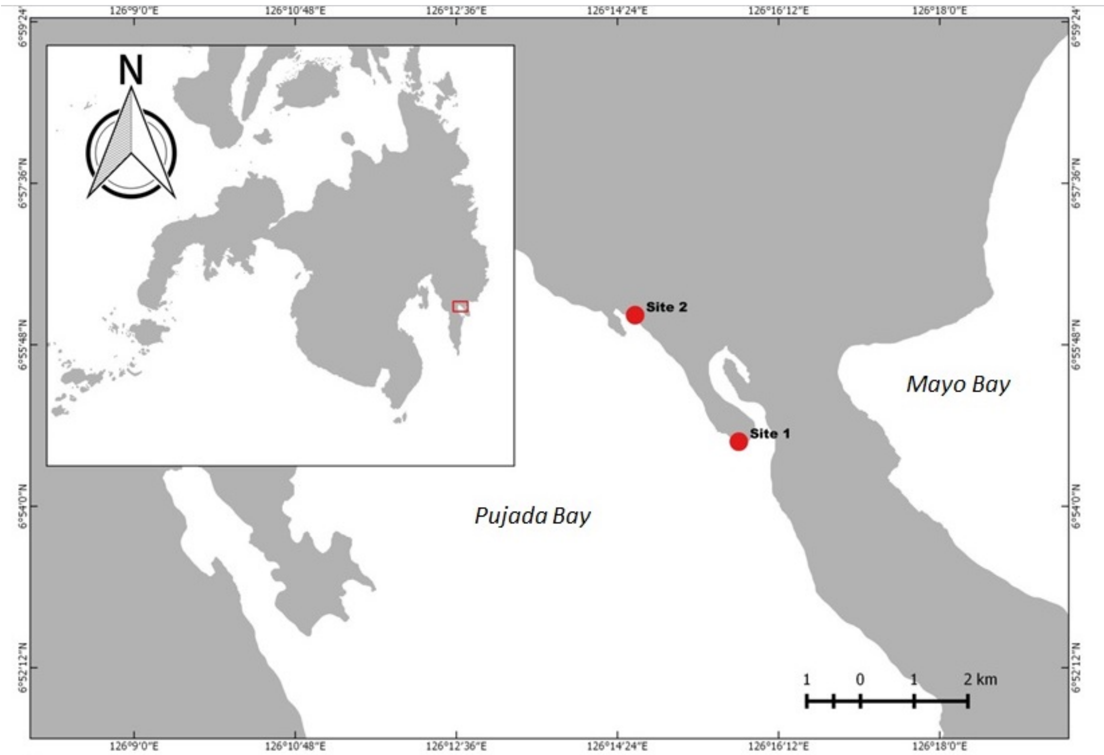

Fig 1. Map of the study sites where anthropogenic marine debris (AMD) were collected in Pujada Bay, Davao Oriental (area 1=Dahican, area 2=Matiao).

Mangrove sampling for composition and density

Before the AMD sampling was conducted, an inventory of mangrove species was done in the two study areas (barangay Dahican and Matiao). This basic mangrove assessment survey was conducted during low tide to be able to identify the different species found in the two study areas as well as quantify their density. As previously mentioned, mangrove density (how cramp or open the area is) can be influenced by the type of mangrove species found in the area as the root system can either prevent or trap the tidal flow of marine debris. While almost all mangrove root systems can act as a litter trap, some are more effective at this due to their projection from the surface of the ground and prop roots. We therefore assessed this to be able to eliminate this uncertainty in the comparison of the two areas, and control for the mangrove density while only looking at human settlement as factors mainly affecting the movement or deposition of AMD. There are no big river systems in the area and only small tributary which is both far from the two study areas.

The mangrove area is largely a composite of reforestation and interspersed with some old mangrove stands. The environmental setting of the mangroves are mainly tide dominated and allochtonous with no large river inputs found in the area except some creeks and tiny river tributaries. A 50 x 50m transect (English et al., 1997) was established in the two study areas (barangay Dahican, located at N 06^{o}55’53.1”, E 126^{o}15’09.1 barangay Matiao, located at N 06^{o}54’43.2”, E 126^{o}15’45.4”). Within the 50 x 50m transect quadrat, mangroves were counted and identified using Primavera’s (2009) Field Guide to Philippine Mangroves. Data were presented as the number of mangroves per unit area. During the fieldwork there was no effort taken to measure the diameter at breast height (DBH) or measure the crown canopy or root spread. This was because the study mainly assessed AMD found at the tidal level in the mangrove area. This was part of the limitation of the study.

Sampling of anthropogenic marine debris (AMD)

For the AMD sampling in each study area, six 5 x 5m subplots within the 50 x 50m (2500 m^2) transect was used for the AMD collection. Three subplots were established facing the landward side, and another three were established facing the seaward side. The subplots were 10 m away from each other making them not independent from each other (Fig. 2; the method was modifed from Ivar do sul et al., 2014). This method allows for quantification and comparison of the landward and seaward plots between two areas. Marine debris were collected in all the six subplots once per week for a total of one month for each study area in Dahican and in Matiao. Sampling was only conducted during low tide because of the difficulty of spotting, and picking up floating marine debris individually in the mangrove forest. By doing this during the low tide, a clear picking from the delineated six sublots would also be easier for quantification purposes. No effort was spent on collecting buried and microscopic AMD, only AMD readily visible to the naked eye were collected from each subplot. The collected samples were stored in a net bag and brought to the laboratory for cleaning, drying and processing.

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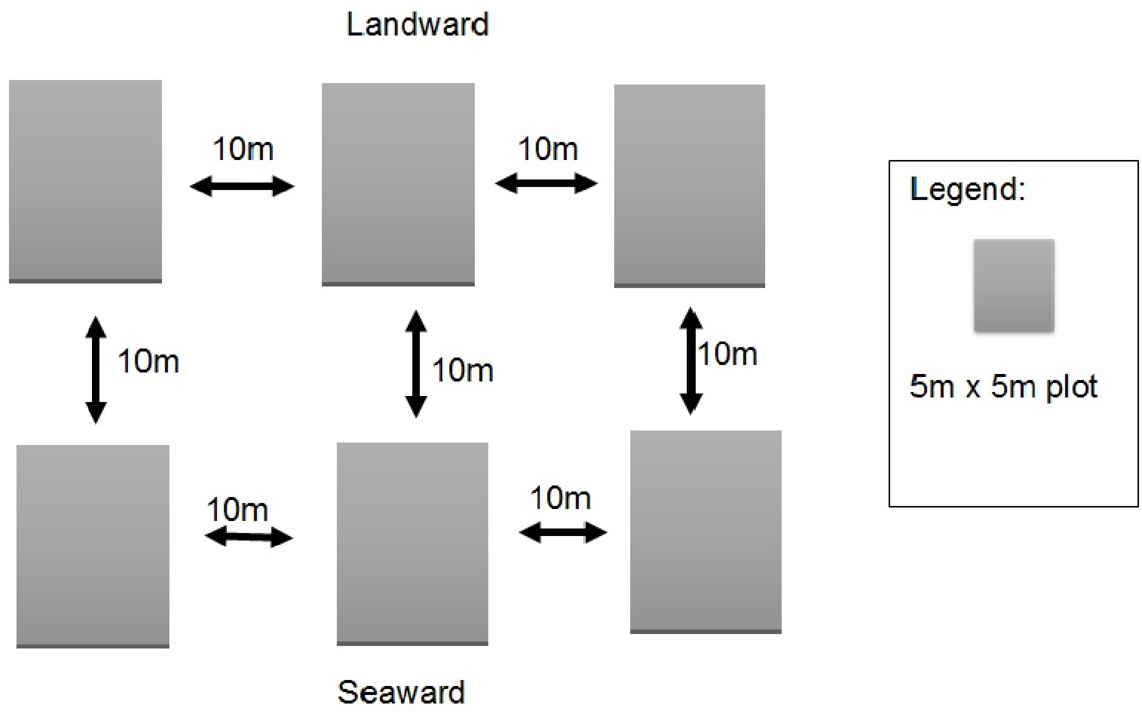

Fig 2. A schematic diagram of AMD sampling subplots in a 50 x 50m transect quadrat in the two study areas in the mangrove forests of Pujada bay, Davao Oriental, Philippines (landward=facing landward side, seaward=facing the seasward side).

The collected AMD were washed with tap water to remove dirt and sediments and then dried before actual weighting. Samples were counted and weighed using analytical balance for each litter. AMD was identified and categorized based on the classification by Cheshire et al. (2009) with some modifications of the categories as done in a previous study (Abreo et al., 2018). Briefly, each AMD were classified according to its major component and grouped into "plastic", "cloth", "glass", "metal", "rubber", "wood" and "others" for those that did not fit the categories such as diapers and ceramics. Further, the most abundant category, plastic, was segregated to single-used plastics and non-single-use. The diverse types of single used plastics required segregation to sub-groups. Single used plastics were grouped into "beverage packaging", "food packaging", "plastics bag", "Toiletries and cleaning agents packs" and "others" for items that did not fit in any of the previous categories.

Data analyses

Density and composition of anthropogenic marine debris

AMD density was calculated for both study areas using the data gathered in the initial collection. The initial collection shows the standing stock of AMD in the sampling area. Data was presented as the total number of items divided by the total area sampled (no. of items m^2) and total weight (g) divided by the total area sampled (g m^{-2}).

AMD composition was presented as percent composition (no. of items in a category ÷ total number of items in all categories × 100). The same calculation was performed using the weight of AMD collected. For subgroups under plastic, data were presented as percent compostion.

In determining the rate of accumulation of AMD, data from the first collection was not included in the calculations as these items were already present in the mangrove area before the study started (Eriksson et al. 2013). The daily rate of accumulation of AMD reported in this study was estimated from weekly collections for the whole two months of sampling. The study focused first in one study area followed by the second one considering the manpower and time available for the researchers. The estimate for the minimum and maximum daily accumulation rate of marine litter made use of weight and the number of items. This was done by getting the total weight of the weekly collections of different items of AMD in the different plots (landward and seaward plots) in each study area. The total weight was then divided by the area of the plot (25m^2) and this was then also divided by seven days to get the daily accumulation rate per plot. To get the accumulation rate for the whole area, the mean of all the plots for the study site was computed. A further analysis to extrapolate the result of the data was not done because of the limitations of the sampling.

Spatial distribution of anthropogenic marine debris

AMD data gathered from the field was first classified using the comprehensive UNEP classification scheme which is a guide for marine litter assessment in beaches and floating debris. This contains detailed types of marine litter many of which are not applicable or available to the area of study. Since the marine litter types found in the study areas are common and can be simplified to seven categories, we chose to put them under simpler and readily recognizable categeories. The seven categories chosen in this study were glass, wood, rubber, others, plastics, metal and cloth. Ceramics were classified under “others” as well as baby diapers. Most of the metals were tin cans while most of the bottles were beverages while the plastics were single-used food wrappers including styrofoam materials.

To analyse the weight data of the various categories, these were first checked for assumptions of normality and homogeneity of data using graphical ways [Probability Plots (PP plots) and box plots] and Ryan-Joiner tests. When data violated the assumptions of normality this was $\log_{10}$ transformed and then checked again for normality. In order to test whether there was significant difference between the two study areas in terms of weight of the AMD, a two-sample independent t-test was used because the means were not paired and sample sizes were different (Dahican, N=89; Matiao, N=79 or a total of N=168). Then to compare which categories of AMD were heavier in each site, a one-way ANOVA was used. Data on individual weights of various AMD was first tested for assumptions of homogeneity of data and All analyses were done using Minitab version 17 (Minitab Inc., State College, Pennsylvania, USA). The implications of the result were then discussed.

Results and Discussion

Mangrove species composition and density

As different types of mangrove species have different habit stands, root, trunk and canopy formations, some species can enhance litter trapping compared to others. For instance the arial roots of *Avicenia marina* can trap more plastic litter compared to a plain root or widely spaced stilt root system. But this can be dependent on the density of the plant stand also. A recent study finds that mangrove root system trap more plastic litter and larger sized marine litter compared to sandy beaches (Martin et al., 2019). Other species of mangroves, although they have big root systems, and large trunks, e.g. *Heritiera littoralis* these may not be able to retain plastic litter, because they lack stilt roots, and arial projections which can easily trap marine litter. In our study there were four species of mangroves found in study area 1 compared to the five species identified and found in study area 2 (see Table 1) with a density of 0.09 ind/m^2 compared to 0.08 ind/m^2 in study area 2. In terms of number of individuals, *Rhizophora mucronata* (locally known as bakhaw babae) dominated in both study areas. Both were observed to host similar species except for *Brugiera gymnorrhiza* (local name: Busain/Pototan) which was present only in study area 2. *Rhizophora* spp was abundant in the area mainly because it has been a pilot area of mangrove reforestation in the past while the presence of *Bruguiera gymnorrhiza* in the area showed that it was once part of an old growth forest located near the seaward side. The most common mangrove species in the Philippines are those that belong to family *Rhizophoraceae*.

Table 1. Species composition and number of mangroves in the two sampling sites (Area 1=Dahican; Area 2=Matiao)

Mangrove Species	No. of Individuals (Dahican)	No. of Individuals (Matiao)
Rhizophora mucronata	166	132
Rhizophora apiculata	37	30
Sonneratia alba	6	2
Avicennia marina	1	3
Bruguiera gymnorrhiza	0	62
TOTAL	**210**	**229**

Density, composition and rate of accumulation of anthropogenic marine debris

For the AMD composition, a total of 280 pieces AMD were collected in the two study areas with a total weight of 17,238 g. In terms of count, the AMD was dominated by plastics and the least was metal. Consequently, based on total weight of AMD, plastics compose 39% of the total weight, followed by glass and cloth making up 30% and 14% of AMD and followed by wood at 9% (Fig. 3).

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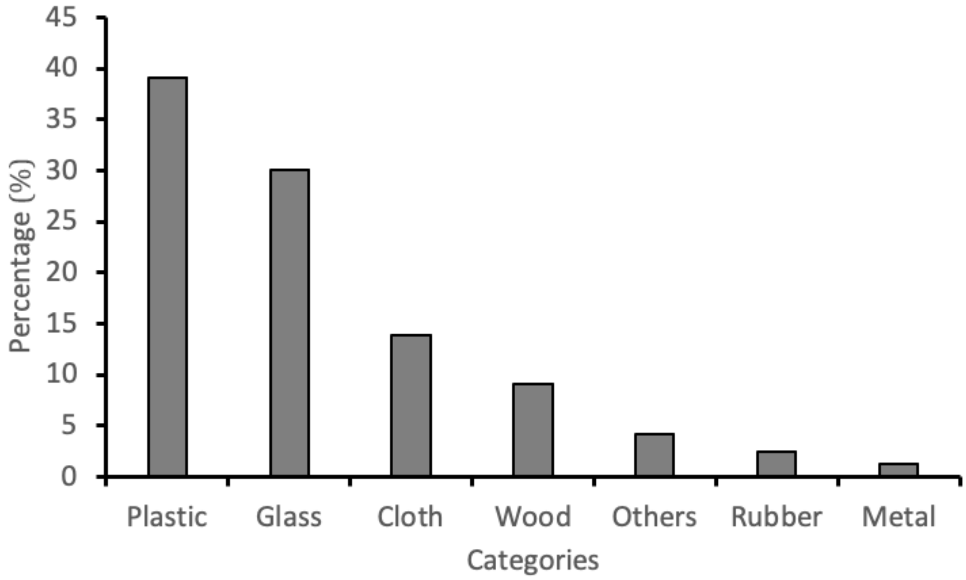

Fig 3. Total percent by weight of AMD collected from mangrove areas in Pujada Bay, Davao Oriental, Philippines (N=186)

Overall, single-used plastics make up 80% (based on counts) and 60% (based on weight) of plastic collected. Among these single-used plastics, are varied types of food packaging that were the most dominant in terms of count and weight (Table 2). The composition of AMD, on the other hand, showed similar trend with studies elsewhere. Majority of AMD collected in both areas were made up of plastic (66.79%). In other related studies, plastic has been found to compose at least 55.47% to as high as 95% (Katsanevakis and Katsarou 2004; Galgani et al. 2015). Moreover, plastics collected in the present study were dominated by single-used plastics (e.g. plastic bags, plastic bottle, shampoo sachet, chips packets, etc.). Plastic bags, for example, are common marine debris since these are carelessly discarded by consumers or disposed of together with other consumer products (Newman et al. 2015). Moreover, the reported household wastes were often disposed into the marine environment (Orale and Fabillar 2011). The presence of common household waste in the two areas of the present study (Fig. 5) supports the findings of Orale and Fabillar (2012).

Table 2. Percent composition of different single-used plastics collected from mangrove areas within Pujada Bay, Davao Oriental, Philippines.

Plastic categories	No. of pieces	Weight (g)
Beverage packaging	7.28	6.55
Food packaging	55.63	43.01
Plastic bags	19.21	6.76
Toiletries and cleaning agents	8.61	2.24
Others	9.27	41.45
TOTAL	**100**	**100**

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AMD density for the two areas ranges from 0.18 (±0.05) items m^{-2} to 1.39 (±1.37) items m^{-2} or 15.84 (±9.37) g m^{-2} to 62.09 (±24.10) g m^{-2}. When data from both areas were pooled, mean AMD density was 0.62 (±0.25) items m^{-2} or 1.24 (±0.74) g m^{-2}. Studies on the impacts of anthropogenic debris in the marine environment has been increasing in recent years (Ryan 2015). Relative to impacts on marine fauna, there seems to be paucity in published literature tackling the impacts, or distribution, of AMD in mangroves (Debrot et al. 2013). In the current study, debris in mangrove areas were lower compared to other studies on AMD in mangrove areas (e.g. Smith 2012; Debrot et al. 2013). Although this is the case, the highest recorded debris load in the present study was within the range recorded within mangrove areas in Papua New Guinea (Smith 2012) and was higher in a beach survey conducted in Australia (Smith and Markic 2013).

For study area 1, data from the six subplots resulted in a rate of accumulation of 0.03 items m^{-2} day^{-1} or 1.6 g m^{-2} day^{-1}AMD. Meanwhile, for study area 2, it has a rate of accumulation of 0.04 items m^{-2} day^{-1} or 3.8 g m^{-2} day^{-1} AMD. Available data on accumulation rates of AMD in beaches is reported as items km^{-1} day^{-1}. Lowest recorded accumulation rates of AMD in beaches were 0.05 items km^{-1} day^{-1}(Eriksson et al. 2013). Data on rates of AMD accumulation in mangrove area is lacking. Study area 2 had relatively higher rate of AMD accumulation. The proximity of study area 2 to household settlements could be the main reason for higher accumulation rate of AMD (Willis et al. 2017). Further studies are needed to confirm and quantify the input of AMD from coastal communities in the area.

Spatial distribution of anthropogenic marine debris

Various AMD found in the sampling area are shown below (Figs. 4, 5 and 6). The result of the analysis to test the hypothesis that there was no significant difference between the weight of AMD found in the seaward side of Dahican and Matiao showed that there was no significant difference (P=0.06) of the mean weight of AMDs between the two areas (Matiao, μ=14g ±7.5 g vs Dahican, μ=13 ±7.4 g). However in terms of investigating whether there was significant difference between the weight of the various categories of AMD found in Dahican (area 1) and Matiao (area 2), the result of the one-way ANOVA for Dahican showed no difference (P=0.137; see Table 3) but it showed highly significant differences for the various categories of AMDs found in Matiao (P<0.001; see Table 3). Post-hoc analysis for the various categories show that cloth was heaviest at 39.35 g followed by glass at 27.60 g, with metal and plastic having the least weight at 12.40 g and 13.60 g.

Table 3. Result of One-Way ANOVA on the weight of various AMD categories found in Dahican and Matiao

Study site	Dahican				Matiao			
Source	df	MS	*F*	*P*	df	MS	*F*	*P*
Categories	7	0.86	1.64	0.137	7	2.53	6.59	0.000
Error	81	0.52			71	0.38		
Total	88				78			

The results have shown that there was no significant differences between area 1 and area 2 for the count and weight data of AMD. Perhaps the main reason being that, first, marine debris are both circulated well in the two areas, second, access of local tourists in the first study area brought the same impact to the site and third, even though study area 1 is assumed to be far from settlements, the tidal current and distance from this source could have also brought the same accumulation of marine debris. Accumulation sites of AMD can be heavily influenced by wind and current patterns (Kukulka et al. 2012; Goldstein et al. 2013), proximity to urban centers (Smith et al., 2014) and local population density (Willis et al. 2017). Although these factors were not investigated in the present study, study area 2 which is near to human settlements could be the source of AMD in the area. This was corroborated by the presence of household wastes found in study area 2. According to (Willis et al. 2017), AMD deposition is close to its source. Conversely, some AMD have the ability to be transported to long distances due to its lightweight and persistence in the marine environment (Gregory 2009; Andrady 2015). This can explain the presence of AMD in study area 1 even if the site was far from human settlements. In addition, the presence of beach goers in the area suggests the possibility that local tourism could be a big source of AMD input. Moreover, the similar densities of mangroves found in the two study sites may have contributed to the retention of AMD in the sites as well as the lack of significant difference between the two sites. According to Ivar do Sul et al. (2014), mangrove density contributes to the retention of AMD, which may warrant further investigations to confirm these possibilities. Finally, in terms of the number and weight of AMD in sea- and landward plots, no significant difference wereobserved. These results reflect the ubiquity of AMD, especially plastics, in Pujada bay.

Fig 4. Different types of anthropogenic marine debris found in the study sites. (A) Plastics; (B) Cloth; (C) Glass; (D) Metal; (E) Rubber; (F) Ceramics; (G) Wood; and (H) others.

Fig 5. Different types of single used plastics collected from mangrove areas in Pujada bay, Davao Oriental, Philippines. (A) Food packaging; (B) Beverage packaging; (C and D) plastic bags; (E) Toiletries and Cleaning agents packs; and (F) others (e.g. foamed packaging).

Fig 6. Mangrove seedling entangled with plastic twine at a reforestation area in Pujada Bay, Davao Oriental, Philippines.

Summary

Pujada bay has 400 hectares of natural and reforested mangroves, of this, the area in Guang-guang has about 77 ha. The lack of difference between the AMD load of Matiao and Dahican can be explained in terms of wide ranging sources of AMD from human settlements, gleaners, visitors, and campers to wind and current forces. Although plastics are least in terms of weight, the study found them to be the most commonly distributed marine debris in the area. Plastics can be brought into the area by means of current flow, tides, rainfall, river source, drainage canals and the lack of garbage collection which would increase the chances of garbage ending up in a body of water. Moreover, the increasing number of settlers surrounding Pujada bay could point to this trajectory. A high input of AMD in Pujada bay will pose a serious risk for the mangrove seedlings and the rehabilitation effort that is on-going in the area (Fig. 6). It is vital that a larger spatial study on various beach forests and mangrove areas for AMD should be done considering its possible ecological impact on marine organisms in the area.

Acknowledgments

We are thankful to the anonymous reviewers of this manuscript for improving its contents and focus. We also thank Ricksterlie Verzosa of IALS at Davao Oriental State College of Science and Technology (DOSCST) for the many times we have discussed about AMD and did some computations together. This study would not have been possible without the permit granted by the Protected Area Management Board (PAMB) of Department of Environment and Natural Resources (DENR).

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