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Elucidating the surface macroplastic load, types and distribution in mangrove areas around Cebu Island, Philippines and its policy implications

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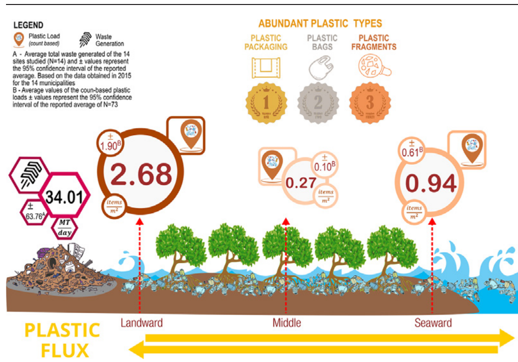
HIGHLIGHTS

- Mangroves in urban sites have more plastic density.
- Plastic load and types vary in the mangrove habitat with varying tidal height.
- Land-based activities produce more plastic waste.
- Sea-based activities can contribute to plastic loads in the mangrove seaward fringe.
- Count per unit area and mass per unit area are only moderately correlated.

GRAPHICAL ABSTRACT



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ABSTRACT

The Philippines is identified as one of the major marine plastic litter polluters in the world with a discharge of approximately 0.75 million tons of marine plastic debris per year. However, the extent of the plastic problem is yet to be defined systematically because of limited research. Thus, this study aims to quantify plastic litter occurrence in mangrove areas as they function as sinks for plastic litter due to their inherent nature of trapping plastics. To define the extent of marine plastic pollution on an island scale, mangrove areas in 14 municipalities around Cebu Island were sampled, with 3 to 9 transects in each site depending on the length of coastline covered by mangroves. Sampling and characterization of both plastics and the mangrove ecosystem was performed in three locations along the transect – landward, middle, and seaward. A total of 4501 plastic items were sampled throughout the study sites with an average of 1.29 ± 0.67 items/m^2 (18.07 ± 8.79 g/m^2). The average distribution of plastic loads were 2.68 ± 1.9 items/m^2 (38.52 ± 25.35 g/m^2), 0.27 ± 0.10 items/m^2 (6.65 ± 4.67 g/m^2), and 0.94 ± 0.61 items/m^2 (9.04 ± 4.28 g/m^2) for the landward, middle, and seaward locations, respectively. The most frequent plastic types found were i) packaging, ii) plastic bags and iii) plastic fragments. The plastic loads and types suggest that most plastic wastes trapped in mangroves come from the nearby communities. Fishing-related plastics originated from the sea and were transported across the mangrove breadth. The findings confirm that mangroves are major traps of plastic litter that might adversely affect the marine ecosystem. The study underscores the urgent need for waste mitigation measures, including education, community engagement, infrastructure, technological solutions and supporting policies.

1. Introduction

Plastics are generally fossil-fuel based materials that are used in all sectors of society leading to a production of 359 million tonnes (MT) in 2018

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(Plastics Europe, 2019). In fact, modern society's reliance on plastic is described by Reed (2015) as the age of the plasticine. The value of plastic is without question; yet, there is a problem with its fate after use. Geyer et al. (2017) estimated that, after use, 79% of plastic is disposed of in landfills and/or it leaks into the natural environment. According to Jambeck et al. (2015), 8 MT of plastic debris enters the marine ecosystem annually from coastal communities, while Meijer et al. (2021) suggests major rivers contribute around 1.7 MT. An additional 0.6 MT of plastic debris is derived from fishing gear (Boucher and Friot, 2017). Plastics have permeated all compartments of the marine environment. It is present in the water column, the seafloor, the sea surface and the coast, and so far its impact on 3726 species have been documented (Tekman et al., 2021). Yet despite the surge of studies, data is still skewed towards selected ecosystems and among the marine ecosystems mangroves are rarely studied for plastic occurrence, despite their ecological, societal and financial importance (Luo et al., 2021; Tekman et al., 2021).

Mangrove species are woody plants that thrive at the interface of land and sea. These plants host an assemblage of organisms such as bacteria, fungi, plants and animals, hence referred to as the mangrove forest community (Kandasamy and Bingham, 2001). Mangroves are distributed circumtropical with an estimated global cover of 18 million hectares, of which 41.4% is in Southeast Asia (Spaldinget al, 1997). Mangroves have a significant ecological value, providing ecosystem services valued at >US $ 1.6 billion y^{-1} (Costanza et al., 1998). Being at the crossing point of land and sea, mangroves have long been identified as well-adapted to deal with natural stressors such as temperature, salinity and anoxia. Yet being in a habitat where their tolerance limits are always tested, this ecosystem can be sensitive to disturbances, especially those created by humans (Kandasamy and Bingham, 2001).

Few studies have quantified plastics in mangroves (Garcés-Ordóñez et al., 2019; Kesavan et al., 2021; Suyadi and Manullang, 2020; Paulus et al., 2020; Rahim et al., 2020; Bijsterveldt et al., 2020); they suggest that this ecosystem serves as a trap for plastic waste from land (Suyadi and Manullang, 2020) and sea (Martin et al., 2019). The mechanism of trapping plastics may vary based on the morphology of the stand (Luo et al., 2021). For *Avicennia* spp. dominated sites, it may be the pneumatophores that trap plastics, while for other species, such as *Rhizophora* spp., it is the prop roots. There is paucity across global biogeographical mangrove regions in documenting such morphological determinants of plastic trapping. While the Philippines has a large mangrove cover at 256,185 ha (Long and Chandra, 2011) and very high annual plastic inputs to the marine environment (Jambeck et al., 2015; Meijer et al., 2021), the abundance and distribution of plastic pollution in Philippine mangroves is poorly documented (Abreo et al., 2020). Scarcity of observations means plastic policies in the country are not grounded on empirical data (Galarpe et al., 2021). Thus, it is the motivation of this study to facilitate data-driven policies.

The island of Cebu has a plastic waste problem and ample mangrove cover on all sides of the island (Long and Chandra, 2011). Economic growth and dense population are leading to increasing plastic waste generation (Cordier et al., 2021; Jambeck et al., 2015). All of its population lives within 35 km of the coast (Flieger and Cusi, 1998), and this zone is a major contribution to marine plastic pollution (Jambeck et al., 2015). Given these attributes, plastic occurrence in the mangroves of the island is expected to be high and fairly uniform across sites and mangrove intertidal zones.

This study aimed to characterize the plastic litter in mangrove habitats along the coasts of Cebu Island in terms of load, type and size. Plastic quantity was expressed as in units of mass per unit area as well as counts per unit area to address the existing limitation in many studies and to ascertain if one unit can be used to substitute the other.

2. Materials and methods

2.1. Study site

Cebu is a long (250 km) narrow (35 km) island in the Central Philippines surrounded by the country's largest marine protected area on the east, the Tañon Strait. On its north are the Visayan Sea and Camotes Sea and on the west is Cebu Sea (Flieger and Cusi, 1998) (Fig. 1). The island has a total area of 4467.5 km^2 and a total coastline of 522.04 km (Philippines Atlas, 2021). It is the 9th largest island in the Philippines, where it contributes 1.13% (2893.77 ha) of the national mangrove cover (Long and Chandra, 2011). The mangrove sites selected for this study were dominated by three genera, namely, *Rhizophora* sp., *Avicennia* sp. and *Sonneratia* sp. to represent both root structures the pneumatophores and prop roots.

Cebu has a population of 5.1 million people, with the population density among the highest in the country (Philippine Statistics Office, 2021). It is also among the most economically progressive provinces in the country, relying on industry and services (Yu, 2016). Yet, along with the rest of the country, the province has problems with waste management, in which the majority of the waste is improperly disposed of, including a portion of the 34.0 MT average daily waste of the 14 municipalities sampled in this study (Cebu Provincial Waste Management Board (CPWMB), 2017) (Fig. 1).

2.2. Sampling and plastic litter characterization

The study was conducted in the first quarter of 2021. During this period, the tide in Cebu ranged from −0.4–1.7 m (Tides4Fishing Website). Sampling was conducted during low tide, when the plastics on the forest floor were easily distinguished. Transects were established perpendicular to the coast, from the landward edge of the mangroves to the seaward edge. A total of 14 locations (=sites) were sampled, each by 3–9 transects, depending on the length of the coastline covered by mangroves. A total of 79 transects were established. Along each transect, three plots were set up: one at the landward side (Q1), one in the middle of the transect (Q2) and one at the seaward fringe (Q3) (Martin et al., 2019; Suyadi and Manullang, 2020). The transect length varied (100 to 600 m) due to the variation in the mangrove forest depth. Plastics were quantified within 10 × 10 m forest plots. The proportion of plot area sampled for plastics varied according to the following: Each site was first categorized into one of three types, according to the relative plastic abundance: 'low' sites had <35% of the forest floor covered in plastic, 'medium' sites had 35–75% covered and 'high' sites had >75% covered. For the plot with low plastic load, the entire 10 × 10 m plot was sampled. For medium and high plastic load plots, one 5 × 5 m or 2 × 2 m subplots, respectively, were sampled within the 10 × 10 m plot. Sub-plot was placed in areas within the plot that most closely represented the average plastic abundance within the plot. This study was able to sample a total of 220 plots covering an area of 18,978 m^2.

All visible (either fully on the surface or partially buried) surface plastic litter (>1 cm) within the sampled plot were collected by hand, placed in a plastic sack and brought to the laboratory. In the laboratory all samples were washed, air dried (by hanging the plastics on a wire) for 48 h, sized, weighed and characterized based on the UNEP/IOC guidelines litter typology (Cheshire et al., 2009). The area per plastic item was calculated as the product of the longest width and length axis. For labeled plastics, the brand was recorded. Brands that were manufactured by local enterprises were classified as local brands. Brands that were manufactured by multinational companies were classified as international brands.

2.3. Quality control

The sacks used for waste collection were new and checked to ensure that there were no tears and fragments to prevent contamination of the sample. To further ensure sack fragments were not included in samples, during cleaning all collected samples were checked for resemblance with the sack material and photographed for later cross checking by another researcher.

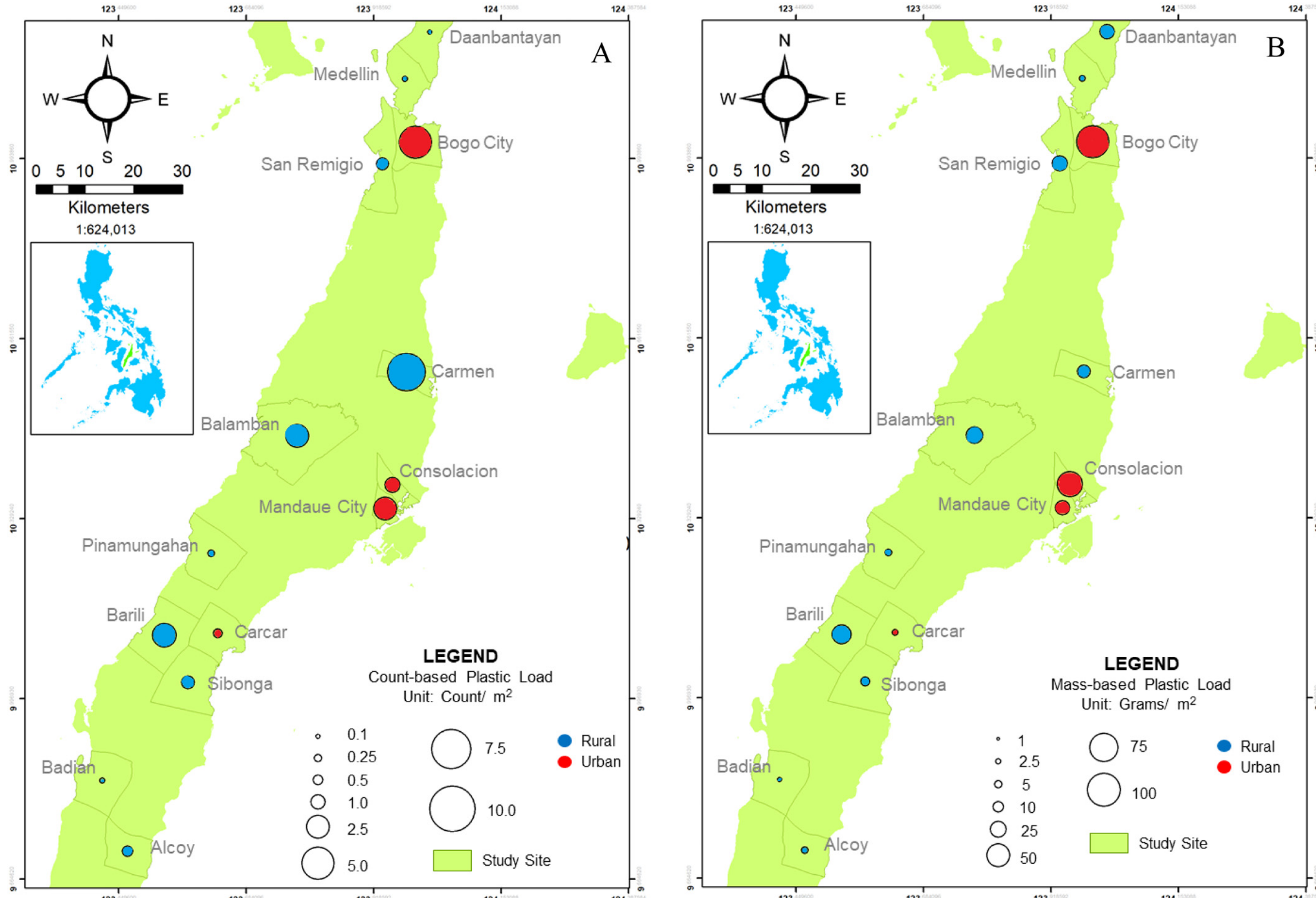

Fig. 1. Average plastic count (items/m^2) (A) and mass (g/m^2) (B) per unit area in the mangroves sites across the island of Cebu.

2.4. Data analysis

Data on plastic count and mass per unit area were not normally distributed even after data transformation; thus Kruskal Wallis Test was used to determine the difference among sites and mangrove zones (landward, middle and seaward). Similar tests were conducted to determine the difference in the mean abundance and mean mass of plastic within plots. Mann U Whitney Test was also used to analyze plastic occurrence (plastic count and mass per unit area) between rural and urban sites. Pearson's correlation was used to determine the relationship between the count and mass per unit area.

3. Results

Plots contained a total of 4501 items and an average plastic litter load ($\pm$ 95% confidence interval) of 1.29 $\pm$ 0. 67 items/m^2. This is equivalent to an average of 18.07 $\pm$ 8.79 g/m^2 (Fig. 1). If extrapolated to the total mangrove cover of Cebu Island, this means the mangroves in Cebu contain 245 to 791 tons of plastic waste, which is equivalent to 102 g per Cebu inhabitant.

The Philippine Republic Act No. 9009 identified areas of high population, economic activity and large land area as component cities, thus are classified as urban centers. So mangrove sites were grouped as either urban (Bogo, Carcar, Consolacion and Mandaue City) or rural (Alcoy, Badian, Balamban, Barili, Carmen, Daan Bantayan, Medellin, San Remigio, Sibonga and Pinamungajan). Urban sites had significantly higher plastic waste count and mass per unit area than rural sites (Supplementary Material Fig. 1). Fig. 1 shows that Bogo and Carmen had significantly higher plastic mass and counts than all other sites. Plastic litter was not observed in a total of 14 plots across Badian, Balamban, Daan Bantayan, Medellin, Pinamungajan, San Remigio and Sibonga (Fig. 2).

This study differentiated plastic load across three tidal heights (landward, middle, seaward) within the mangrove habitat. Overall, the data shows that plastic load was highest at the landward side (Fig. 2), although, landward plastic items were generally smaller items.

For the sampled sites in this study, there was moderate correlation between the count and the mass of the plastic litter ($R = 0.61$, $p < 0.05$) (Fig. 3). This was because plastic counts were only moderately predictive of plastic mass. For instance, Carmen had higher counts (55.75 items/m^2; 53.20 g/m^2) than Bogo, since many of the plastics at Carmen were fragmented and small; yet, Bogo had greater mass (706.50 g/m^2; 31.75 items/m^2), since litter there were generally intact and thus larger and heavier. Ranking sites according to plastic abundance would suggest Carmen to be most polluted, while plastic mass would make Bogo most polluted.

There are 11–25 categories of plastics observed per site (Supplementary Material Fig. 2) but majority are single use plastics. The top three plastic waste recorded in the mangroves are plastic bags, packaging and plastic fragments. These three items comprised 70.2% of the observed litter in terms of count (Fig. 4). This study categorized plastics packaging as packets of fast consumer goods (food, toiletries). This description is classified under “Others” according to the UN Litter Classification Code but being the most abundant, this study opted to categorize this separately. Meanwhile, following the description of the UN Litter Classification Code, plastics that are

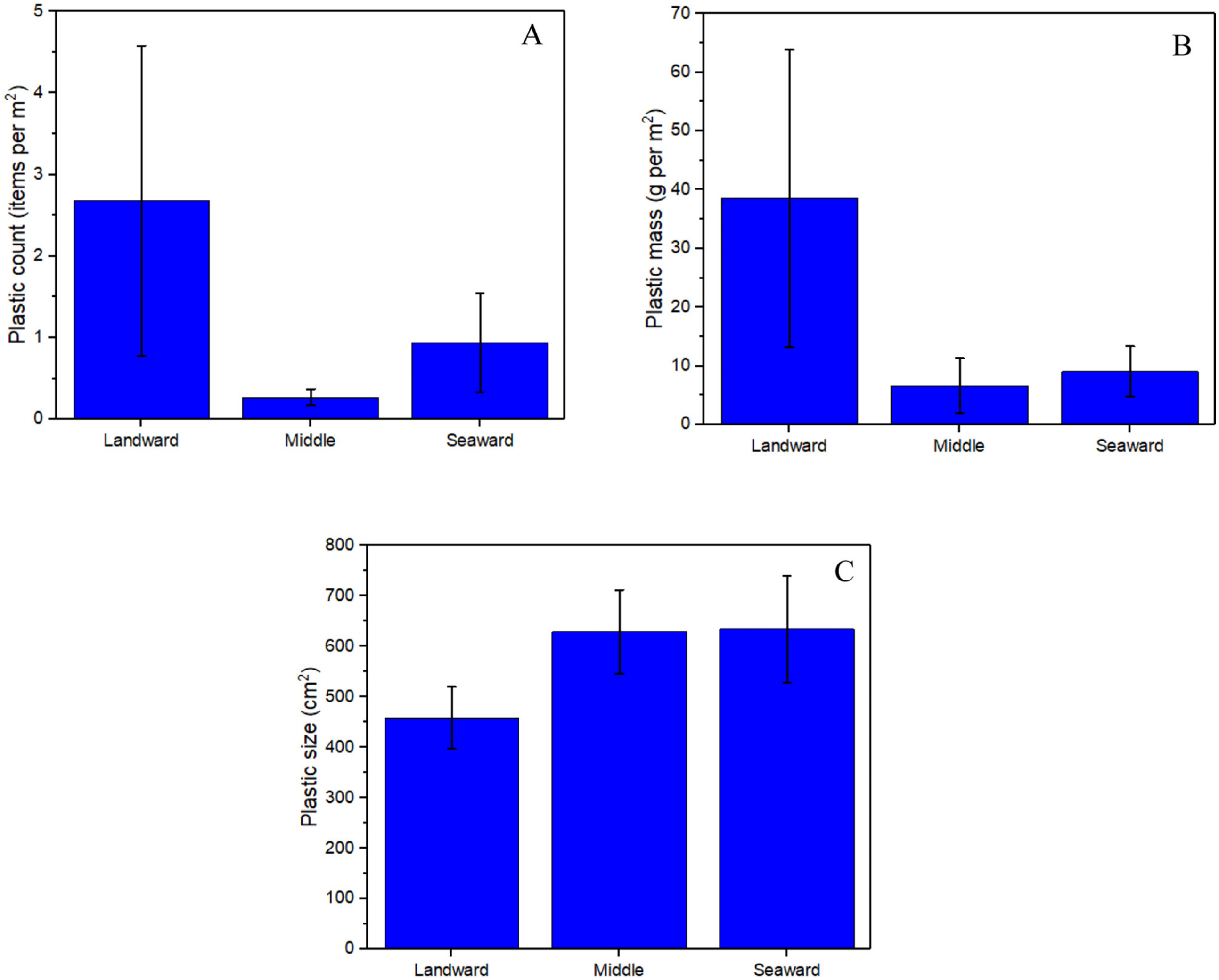

Fig. 2. Plastic (A) count, (B) mass and (C) size of plastic samples in the landward, middle and seaward plot of the mangroves in Cebu Island.

either opaque or clear are plastic bags. Plastic fragments on the other hand are portions of plastics of which the initial purpose could no longer be determined.

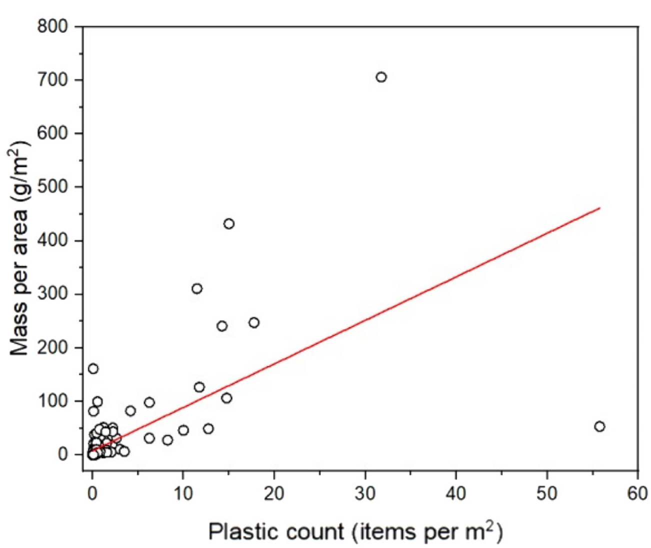

Fig. 3. Relationship between count and mass of plastic per unit area for all plots (n = 220) sampled in the mangroves of Cebu Island.

Three distinct patterns are observed in plastic waste types found in the mangroves (Fig. 5). Packaging, fragments, clothing and PET bottles are abundant in the landward plot but decreases in number at the seaward plot. While, bags, sack, tarpaulins and sanitary items are equally distributed across plots. In contrast, fishing-related litter such as buoys, fishing gears and nets that only comprise a small portion of the total litter observed, were mostly recorded (54%) in the seaward plot with much less found in the other plots.

Brand audit is helpful to trace the origin of the item. For this study, only 1457 items of the 4501 plastics had labels and were included in the brand audit. Of these, 55.73% and 35.34% were local and international, respectively. The remaining 8.93% are untraceable. Untraceable items had labels that were already difficult to decipher being faded or fragmented or for some, having a brand description which is not publicly known and not traceable.

4. Discussion

4.1. Plastics load and distribution

The average plastic litter count in this study appear higher in comparison to studies conducted in the Middle East and Caribbean (Garcés-Ordóñez et al., 2019; Martin et al., 2019) but similar to some studies in Indonesia and India (Kesavan et al., 2021; Paulus et al., 2020) (Table 1). In contrast, lower plastic counts were reported in Southern Philippines (Abreo et al., 2020) with an average of 0.18 ± 0.05 items/m^2 of litter

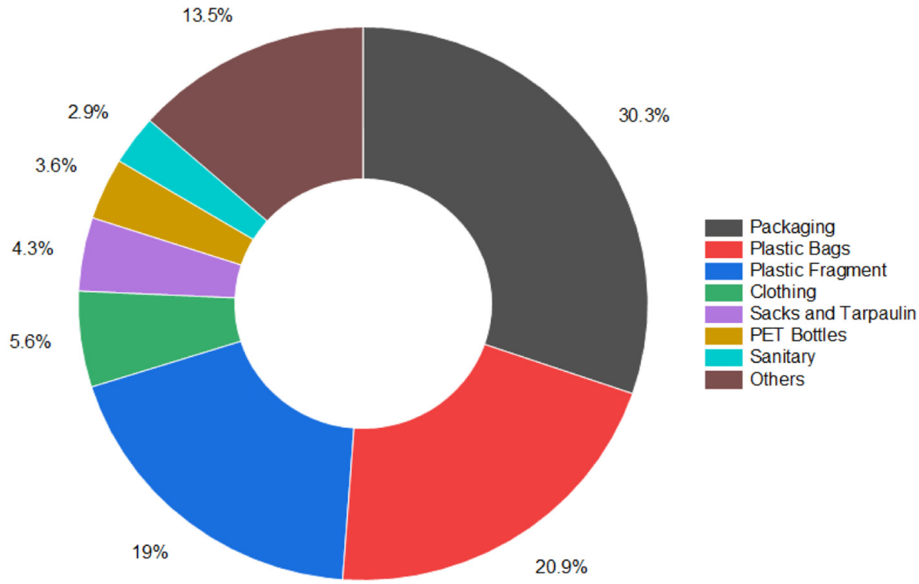

Fig. 4. Proportion of each plastic category in terms of count ($n = 4501$) as observed in the mangroves of Cebu Island.

even after accounting for non-plastic items such as metals and glass. This can be explained, however, because the area sampled by Abreo et al. (2020) is a rural area. As shown in this study, urban sites have more waste littered in the mangroves primarily because it has higher population density and more economic activities (Cordier et al., 2021; Jambeck et al., 2015).

Aside from the social factors, differences in mangrove structure are likely to determine the inherent trapping potential of the ecosystem (Luo et al., 2021) and may explain why some sites have more plastics than others. Dense mangroves are reported to trap more plastics (Martin et al., 2019). Furthermore, according to Green and Webber (1996) prop roots may allow debris to pass through them, while the presence of debris is positively correlated with the pneumatophores. However in this study, both mangrove root types were able to trap plastics (Fig. 6).

Furthermore, the reported density of plastic litter may also be influenced by how the transects were established. Martin et al. (2019) set up transects parallel to the coast particularly at the seaward fringe while other studies used transects perpendicular to the coast with landward, middle and seaward plots (Garcés-Ordóñez et al., 2019; Suyadi and Manullang, 2020; Bijsterveldt et al., 2020). This study shows that plastic load is highest

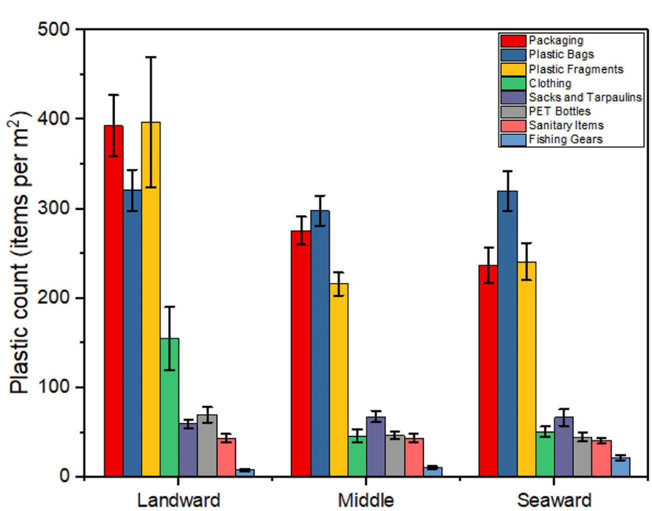

Fig. 5. Distribution of the different plastic categories ($n = 4501$) across the three plots of the mangroves in Cebu Island.

in the landward side due to its proximity to human settlements or markets and is consistent with other studies (Garcés-Ordóñez et al., 2019; Suyadi and Manullang, 2020). The load distribution in this study clearly establishes the idea that mangroves trap plastics from both land and sea. Overall, all sites were polluted with plastic waste, supporting the notion that mangrove forests serve as traps for plastic litter (Martin et al., 2019).

4.2. Relationship between plastic count and mass

A significant positive correlation between counts and mass of plastic litter trapped in the mangroves of Cebu is found, indicating the total mass increases as the number of plastic waste items found rises. The correlation is only moderate due to variations in the weight of individual items of litter, with fragmenting plastic bag generating a lot of very light items contrasting with single heavy items such as shoes or fishing buoys. Moreover, plastic densities largely and commonly range from 0.9 to 2.1 g/cm^3 (Wypych, 2016) and once it is made into a product, additives increase the complexity of its physical property such as density (Boucher and Billard, 2019). Thus, counts of plastic litter alone are not an accurate measurement of plastic pollution. Plastic waste may fragment over time but this does not necessarily mean more pollution than one whole large piece; although certainly the impacts on the fauna and flora may be very different according to the size (Thushari and Senevirathna, 2020). According to LITTERBASE, marine litter is reported in either items/km^2, items/km or items/m^2; although other units are also reported (Tekman et al., n.d.). More recent studies report both mass and counts (Kesavan et al., 2021), while some studies still only report count (Martin et al., 2019; Suyadi and Manullang, 2020). Having to report both units will provide a clearer picture of the degree of plastic pollution in the area and allows the comparability of data. Hence, this study suggests that both units need to be reported to give an accurate idea of the scale of plastic pollution in a given area. As stated by Boucher and Billard (2019), we can manage only what we can measure and for a multifaceted material such as plastics, efficient metrics accounting for plastic pollution are needed in order to guide sound eco-design and waste management strategies.

4.3. Plastic litter types

Plastics are a transboundary problem but the brand audit clearly suggests that a large portion of the plastic wastes are locally-generated waste. This is conjectured from the notion that these local brands are not used

Table 1
Summary of plastic litter studies in mangroves.

Location	Dominant mangroves	Items per m^2 (ave.)	Items per m^2 (range)	References
Cebu, Philippines	*Rhizophora* sp., *Avicenia* sp. and *Soneratia* sp	1.29 ± 0.67 items/m^2 (18.07 ± 8.79 g/m^2)	0–31.75 items/m^2	This study
Cienaga Grande de Santa Martine, Columbian Caribbean	*A. marina*	0.0394 ± 0.01 items/m^2 0.0030 ± 0.0022 items/m^2	0.0015–0.0728 items/m^2	Garcés-Ordóñez et al., 2019
Red Sea	*A. marina*	0.66 ± 0.18 items/m^2	0.02–0.01 items/m^2 3.7–1.8 items/m^2	Martin et al., 2019
Arabian Gulf		1.21 ± 0.53 items/m^2	0.22–0.06 items/m^2 3.0–2.0 items/m^2	Martin et al., 2019
Kupang, Indonesia	*R. mucronata, R. stylosa, A. marina, A. alba, Osbornia octodanta, Ceriops tagal*	1.92 items/m^2	0.864–2.418 items/m^2	Paulus et al., 2020
Kendari Bay, Indonesia	Not stated	252.75 items/m^2	220–378 items/m^2	Rahim et al., 2020
Arbon, Indonesia	Dominant species not mentioned but study site has 15 species	92 ± 28 items/m^2	10–230 items/m^2	Suyadi and Manullang, 2020
Central Java, Indonesia	*Avicennia* spp.	27 items/m^2	0–236 items/m^2	Bijsterveldt et al., 2020
Mumbai, India	*A. marina Acanthus ilicifolius, C. tagal, Bruguiera cylindrical*	5.51 ± 2.33 items/m^2 (396.25 ± 144.71 g/m^2)		Kesavan et al., 2021

and marketed elsewhere. However, it should be noted that the origin of international brands are difficult to trace since they can be sold everywhere. It can be that these were manufactured in the country and used by locals as well.

The high diversity of plastic categories recorded suggests not only the widened range of applications of plastic but also the inefficiency of plastic waste collection and the very low recycling of all plastic types. The most abundant plastic waste is packaging of fast consumer manufacturing goods and plastic bags, which suggest that the sources of these materials originated from land-based activities. This data supports the observation reported in many other studies where plastic packaging in the form of multi-layered sachets, normally made of a thin film of plastic and aluminum in a sandwich-laminate form, is an ubiquitous marine litter in the Philippines (Posadas, 2014; Kalnasa et al., 2019; Paler et al., 2019). This is because of a huge demand of flexible plastic packaging such as sachets, pouches, and bags, for various commodity products often sold in small quantities in developing economies like the Philippines and the majority of the ASEAN Region ([GIZ] Deutsche Gesellschaft für Internationale Zusammenarbeit, 2018). Single-use packaging is necessary to retain food quality, sanitation, and longevity or shelf life; but it can also be out of economic necessity and convenience (Nielsen et al., 2019). Uniquely for Filipinos and many Asian communities, it is because of the affordability of products in smaller packaging such as sachet that makes this widely preferred (Singh et al., 2009). Meanwhile, these two ubiquitous plastic wastes may be fragmented easily; thus, there is the abundance of plastic fragments in the open or marine environment. Further, clothing, sacks and tarpaulins, PET bottles are wastes that have the potential to be recycled if only these are collected properly and efficiently. Currently, there is no established institutional mechanism to collect and recycle clothing, sacks, and tarpaulins which are still reusable and may have a resale value; nevertheless, the current direction for these wastes is for disposal. Meanwhile, PET bottles are purchased by the informal sector referred to as" junk shops" channeled locally or abroad for recycling ([GIZ] Deutsche Gesellschaft für Internationale Zusammenarbeit, 2018). Yet these are among the top plastic waste litter items, which suggest that the economic incentive associated with these material is not lucrative. Diaper and sanitary napkins are also abundant in the sampled sites. Diaper usage is low in the Philippines with only close to two diapers per day for infants' ages 0–24 months (Thaman and Eichenfield, 2014). However, almost 5% of the 5.1 million individuals in the island belong to this age range (Philippine Statistics Office, 2021), resulting in an almost 500,000 diapers disposed daily; thus, contributing to a massive amount of improperly disposed diaper waste. Meanwhile, fishing-related items are most likely accidentally or expediently discharged to the sea, referred to as ghost nets, a common practice in the Philippines (Macfyden et al., 2009).

The varying patterns of plastic distribution in the mangrove (Fig. 5) suggest that plastic litter can originate from land or sea and may be transported across the mangrove breadth. The possibility of litter being transported

Fig. 6. Plastics trapped in the mangrove (A) prop roots and in between (B) pneumatophores.

from land towards the seaward fringe is the most likely occurrence. According to Fazey and Ryan (2016), transport and sedimentation is affected by buoyancy of the items and fouling. As corroborated in this study, items with larger surface areas (plastic bags, sacks and tarpaulins), fishing buoys and air filled items such as PET bottles are buoyant; and, thus were transported further by current or wind (Fazey and Ryan, 2016; Schwarz et al., 2019). Meanwhile, smaller macroplastics tend to sink faster than the larger ones as they are more susceptible to biofouling due to their increasing surface area-to-mass ratio (Fazey and Ryan, 2016). This explains why plastics in the landward were on average smaller than those in the middle and seaward side as shown in Fig. 2.

4.4. The I=PAT model

The case of Cebu Island is a classic example of the I=PAT model (Chertow, 2001) where plastic pollution is a function of the dense population, consumption pattern, and the lack of technology to manage the plastic wastes. Technology herein can be referred to as process or product. Evidence shows that the plastic per capita appears only in grams but the consolidated volume is massive, similar to the case of the diaper waste. Meanwhile, the common preference of Filipinos to buy products in sachet packaging contributes to a large proportion of the total plastic waste. Littering is widespread in Cebu as observed in many areas all over the island not just in the mangroves, a similar situation occurs all over the world (Pucino et al., 2020). According to Schultz et al. (2013), the presence of existing litter tempts others to litter as well and the visibility of trash receptacles reduces littering behavior. The latter results from the lack of infrastructure for proper disposal and is the case for Cebu. Indeed, the plastic value chain in the country often ends in improper disposal whether waste is in bulk or singly. This is a manifestation of ineffective if not absent institutional and technological mechanisms for proper and efficient segregation of waste, collection, transport, storage, treatment and disposal. This observation conforms with the findings of Pucino et al. (2020) where South East Asian countries, such as Thailand and Vietnam, have high plastic consumption yet poor waste management practices.

4.5. Impacts to mangrove ecosystems

Plastic occurrence in some areas in Cebu Island is alarmingly high such that it may pose a threat to the mangroves. In a study by Bijsterveldt et al. (2020), the researchers concluded that mangroves are resilient if 50 % of their pnuematophores are covered with plastics, but the mangrove trees will eventually deteriorate if plastics continue to accumulate completely covering the pneumatophores. It was further observed that immediate responses to suffocation of mangroves are manifested by pneumatophore growth and leaf loss; although canopy cover was still maintained for trees with 50 % of their pneumatophores covered with plastic waste. The portion of pneumatophores covered by plastics was not accounted for in this study but observation show that none of the sites had 100 % of the pneumatophore covered by plastic. In fact the typical observation was that plastics were in between pneumatophores (Fig. 6). Although a separate study showed that there is a negative correlation between plastic debris load and tree density, seedling density, mean tree diameter and mean tree height, leading the researchers to conclude that plastic can significantly reduce mangrove health quality (Suyadi and Manullang, 2020). Given that plastics were found between pneumatophores or trees, indeed this may affect seedling establishment and eventually density. Nevertheless, with these few studies on the impact of plastic to mangroves, it is difficult to deduce the accurate impacts. In fact, this just further indicates the need for more impact assessment studies especially in potentially vulnerable mangrove sites so that mitigating measures can be implemented immediately to prevent the deterioration of these mangrove forest.

4.6. Policy implication

Borja and Elliot (2019) emphasized that plastic research should not only focus on how much and what plastic is there but what can be done about the plastics as well. In fact, there is a need to ensure that policies are tailored from sound science (Borja et al., 2017); something that is absent in the Philippines (Galarpe et al., 2021).

4.6.1. Implications to mangrove preservation and sustainable development

According to the National Integrated Coastal Management (NICM) Program of the Philippines as mandated by the Executive Order 533, there should be proper management of the mangrove forests and a sound disposal of agricultural, industrial, household or domestic wastes, in order to reduce their adverse impacts on the coastal zone and downstream communities. However, it is apparent that this is not enforced and thus immediate action should be taken to remedy the situation. In fact, the removal of plastic litter should be a priority activity in rehabilitation projects after reforestation (Melana et al., 2000; Garcia et al., 2014).

4.6.2. Implications to solid waste management

The findings of this study clearly show the lack of proper waste management in the household, community, barangay, and local government unit levels in Cebu Island, which can be extended to the whole Philippines both on land and sea. The Philippines has enacted Republic Act 9003, also known as the Ecological Solid Waste Management Act of 2000, which is a comprehensive policy that ensures the protection of public health and the environment through the proper segregation of waste, collection, transport, storage, treatment and disposal. However aside from littering, waste collection is not widely implemented across the island; focused only in urban centers and in communities near coastal areas (Cebu Provincial Waste Management Board (CPWMB), 2017); hence, waste may leak into the environment (Cebu Provincial Waste Management Board (CPWMB), 2017). This is also a problem observed in other Southeast Asian countries (Pucino et al., 2020). The so called “sachet economy” is a cultural and economic phenomenon where industries and companies use sachet marketing to position a product in the market by capitalizing on affordability and accessibility. To be successful, brands should be ubiquitous, popular and be sold in a price range with the coinage system in the market (Sy-Changco et al., 2011). This goes to show that companies collectively can be game changers in strategizing this demand to reduce plastic waste; and they can take part in actively promoting the Extended Producer Responsibility (EPR) and Plastic Neutrality in managing plastic wastes. Further, the packaging industry may implement take-back refilling schemes, down-gauging and use of biopolymers as substitute to reduce their plastic footprint (Hopewell et al., 2009; Nielsen et al., 2019). However, this call should be paired with the political pressure to bring about this change. The currently poor recycling rate has to be improved considering that for the entire island, there are only two local government units that have an institutionalized residual recycling program where sachets are made into products or added into cement blocks (Cebu Provincial Waste Management Board (CPWMB), 2017). Clearly, recycling capacity is not enough to process the total waste volume. This is an aspect that has to be improved not just in Cebu but in the region (Pucino et al., 2020). If technological advancement is introduced to increase capacity, it should be noted that the desire to recycle is associated with culture too. Cultural experience, education and engagement in socio-civic activities may increase the propensity of stakeholders for recycling (Crociata et al., 2015).

The current practice is that difficult-to-recycle items such as diapers and sanitary napkins are landfilled (Cebu Provincial Waste Management Board (CPWMB), 2017) but with the massive volume of this type of wastes produced daily, the pressure it puts on landfill is very high. Other sound options must be pursued. Currently, open-fire burning, which is sometimes misunderstood as incineration, is prohibited in the Philippine Clean Air Act; but good technologies for incineration and co-processing are already adapted and practiced especially in most developed countries for energy recovery (Hopewell et al., 2009).

The International Convention for the Prevention of Pollution from Ships (MARPOL) of which the Philippines is a signatory prohibits the discharge of garbage, fishing gear included, from ships (Food and Agriculture Organization of the United Nations, 2021). Accidental loss or discharge must in fact be reported. Therefore, the country's level of commitment to this convention must be reinforced. Coastal cleanups are common in beaches and waterways (www.oceanconservancy.org), but this is not enough to be sustainable; further, it is suggested this should also include cleanups of mangrove ecosystems.

It is clear that Cebu needs to conduct a massive clean-up of its mangrove areas but it has to be sustained with concerted commitment and programs from the citizens, industry and the government. Particularly if Cebu's population continues to increase at its current rate, it is imperative that it has to be curbed. Single use plastics preference and littering has to be discontinued, industry has to take accountability of their plastic footprint and the government has to implement institutional and technological mechanisms to properly manage the plastic waste stream. Overall, this study supports the call that marine plastic pollution, although often viewed as an ecological problem, must be addressed by all stakeholders of the society, because the sound solutions lie within societal change.

5. Conclusion

Plastic litter currency should be in terms of count and mass to establish a more accurate measurement of plastic pollution and make comparison between sites more objectively.

Plastic waste is improperly disposed in both land and sea and the mangrove ecosystems serve as dump sites of these improperly disposed waste. Land-based activities produce more wastes but sea-based activities can significantly contribute to plastic loads especially in the mangrove seaward fringe. These findings suggest that enforcement of solid waste management should be implemented both at land and sea to mitigate the imminent negative impacts of plastic pollution especially affecting the mangroves ecosystems.

Population, high plastic consumption rate and poor waste management especially in urban centers are attributes related to voluminous waste in the mangroves. These inferences can be further tested by models, to further our understanding of the drivers of plastic waste.

To effectively manage plastics wastes, private and public partnerships have to be implemented, employing strategies on education, community engagement, infrastructure and technological solutions, and policies. This situation in Cebu can also be true in all other islands in the Philippines and beyond, especially those without proper solid waste management practices. Hence, these findings can be used to enhance the national framework on plastic waste management to bring about societal change in calling for responsible custody of the environment.

CRediT authorship contribution statement

Maria Kristina O. Paler: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft. **Ian Dominic F. Tabañag:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – review & editing. **Francis Dave C. Siacor:** Conceptualization, Investigation, Methodology, Project administration, Visualization. **Paul John L. Geraldino:** Conceptualization, Methodology, Project administration. **Mark Edward M. Walton:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Christian Dunn:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Martin W. Skov:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Jan G. Hiddink:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing. **Evelyn B. Taboada:** Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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References

[GIZ] Deutsche Gesellschaft für Internationale Zusammenarbeit, 2018]. Managing packaging waste in the ASEAN Region: from linear to circular packaging value chains. Accessed from: https://www.giz.de/de/downloads/giz2018_ASEAN-Packaging-Waste_web.pdf Accessed 2021 June 21.
Abreo, N.A.S., Siblos, S.K.V., Macusi, E.D., 2020. Anthropogenic marine debris (AMD) in mangrove forests of Pujada Bay, Davao Oriental, Philippines. J.Mar.Island Cult. 9 (1), 3.
Bijsterveldt, C., Van Wesenbeeck, B., Ramadhani, S., Raven, O., Van Gool, F., Pribadi, R., Bouma, T., 2020. Does plastic waste kill mangroves? A field experiment to assess the impact of macro plastics on mangrove growth, stress response and survival. Sci. Total Environ. 756, 143826. https://doi.org/10.1016/j.scitotenv.2020.143826.
Borja, A., Elliot, M., 2019. So when will we have enough papers on microplastics and ocean litter? Mar. Pollut. Bull. 14, 312–316.
Borja, A., Elliot, M., Uyarra, M.C., Carstensen, M.C., Mea, M., 2017. Bridging the Gap Between Policy and Science in Assessing the Health Status of Marine Ecosystems. 2nd edition. Frontiers Media, Lausanne (2017).
Boucher, J., Billard, G., 2019. The challenges of measuring plastic pollution. Field Actions Sci. Rep. 19, 68–75.
Boucher, J., Friot, D., 2017. Primary Microplastics in the Oceans: A Global Evaluation of Sources. IUCN, Gland, Switzerland 43pp.
Cebu Provincial Waste Management Board (CPWMB), 2017. Cebu Provincial Solid Waste Management Framework Plan 2017-2027.
Chertow, M., 2001. The IPAT equation and its variants changing views of technology and environmental impact. J. Ind. Ecol. 4 (4), 13–29.
Cheshire, A.C., Adler, E., Barbière, J., Cohen, Y., Evans, S., Jarayabhand, S., Jeftic, L., Jung, R.T., Kinsey, S., Kusui, E.T., Lavine, I., Manyara, P., Oosterbaan, L., Pereira, M.A., Sheavly, S., Tkalin, A., Varadarajan, S., Wenneker, B., Westphalen, G., 2009. UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter. UNEP Regional Seas Reports and Studies, No. 186 IOC Technical Series No. 83: xii + 120 pp.
Cordier, M., Uehara, T., Baztan, J., Jorgensen, B., Yan, H., 2021. Plastic pollution and economic growth: the influence of corruption and lack of education. Ecol. Econ. 182, 106930. https://doi.org/10.1016/j.ecolecon.2020.106930.
Costanza, R., d'Agre, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P., van den Belt, M., 1998. Forum of valuation of ecosystem services. Ecol. Econ. 25, 67–72.
Crociata, A., Agovino, M., Sacco, P.L., 2015. Recycling waste: does culture matter? journal of behavioral and experimentalEconomics 55, 40–47.
Fazey, F., Ryan, P., 2016. Biofouling on buoyant marine plastics: an experimental study into the effect of size on surface longevity. Environ. Pollut. 210, 354–360.
Flieger, W., Cusi, D.R., 1998. The Mountains of Cebu and Their Inhabitants: Measurements & Estimates. Program on Population, East-West Center and Office of Population Studies, University of San Carlos, Honolulu, Hawaii and Cebu City, Philippines.
Food and Agriculture Organization of the United Nations, 2021. Abandonment of fishing gear. Available at https://www.fao.org/fishery/topic/14887/en.
Galarpe, V.R.K.R., Jaraula, C.M.B., Paler, M.K.O., 2021. The nexus of macroplastic and microplastic research and plastic regulation policies in the Philippines marine coastal environments. Mar. Pollut. Bull. 167, 112343.
Garcés-Ordóñez, O., Olaya, V.C., Granados, A., Blandón-Garcia, L.M., Espinosa, L.F., 2019. Marine litter and microplastic pollution on mangrove soils of the 'Ciénaga grande de Santa Marta, Colombian Caribbean. Mar. Pollut. Bull. 145, 455–462.
Garcia, K., Gevaña, D., Malabrigo, P., 2014. In: Faridah-Hanum, I., Latiff, A., Hakeem, K., Ozturk, M. (Eds.), Philippines' Mangrove Ecosystem: Status, Threats, and Conservation in Mangrove Ecosystems of Asia: Status, Challenges and Management Strategies.

Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3 (7), e1700782.

Green, S., Webber, M., 1996. A survey of the solid waste pollution in Kingston harbour mangroves, near Port Royal,Jamaica. Caribb. Mar. Stud. 5, 14–22.

Hopewell, J., Dvorak, R., Kosior, E., 2009. Plastics recycling: challenges and opportunities. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 364 (1526), 2115–2126. https://doi.org/10.1098/rstb.2008.0311.

Jambeck, J., Geyer, R., Wilcox, C., Siegler, T., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 137 (6223), 768–771.

Kalnasa, M.L., Lantaca, S.M.O., Boter, L.C., Flores, G.J.T., Galarpe, V.R.K.R., 2019. Occurrence of surface sand microplastic and litter in Macajalar Bay,Philippines. Mar. Pollut. Bull. 149, 110521.

Kandasamy, K., Bingham, B., 2001. Biology of mangroves and mangrove ecosystems. Adv. Mar. Biol. 40, 81–251. https://doi.org/10.1016/S0065-2881(01)40003-4.

Kesavan, S., Xavier, K.A.M., Deshmukhe, G., Jaiswar, A.K., Bhusan, S., Shukla, S.P., 2021v. Anthropogenic pressure on mangrove ecosystems: quantification and source identification of surficial and trapped debris. Sci. Total Environ. 10 (794), 148677. https://doi.org/10.1016/j.scitotenv.2021.148677 Epub 2021 Jun 28. PMID: 34218150.

Long, J., Chandra, G., 2011. Mapping the Philippines'mangrove forests using Landsat imagery. Sensors 11, 2972–2981. https://doi.org/10.3390/s110302972.

Luo, Y., Not, C., Cannicci, S., 2021. Mangroves as unique but understudied traps for anthropogenic marine debris: a review of present information and the way forward. Environ. Pollut. 271, 116291.

Macfyden, G., Huntington, T., Cappell, R., 2009. Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No. 523. UNEP/FAO, Rome 115p.

Martin, C., Almahasheer, H., Duarte, C., 2019. Mangrove forests as traps for marine litter. Environ. Pollut. 247, 499–508.

Meijer, L.J.J., van Emmerick, T., van der Ent, R., Schmidt, C., Lebreton, L., 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Sci. Adv. 7, 18.

Melana, D.M., Atchue III, J., Yao III, C.E., Edwards III, R., Melana III, E.E., Gonzales III, H.I., 2000. Mangrove Management Handbook. Department of Environment and Natural Resources, Manila, Philippines through the Coastal Resource Management Project, Cebu City, Philippines 96 p.

Nielsen, T., Hasselbalch, J., Holmberg, K., Stripple, J., 2019. Politics and the plastic crisis: a review throughout the plastic life cycle. Wiley Interdiscip.Rev.Energy Environ. 9. https://doi.org/10.1002/wene.360.

Paler, M.K.O., Malenab, C.T., Maralit, J.R., Nacorda, H.M., 2019. Plastic waste occurrence on a beach off southeastern Luzon, Philippines. Mar. Pollut. Bull. 141, 416–419.

Paulus, C., Soewarlan, L., Ayubi, A., 2020. Distribution of marine debris in mangrove ecotourism area in Kupang, East Nusa Tenggara,Indonesia. AACL Bioflux 13, 2897–2909.

Philippine Statistics Office, 2021. Highlights of the Region VII (Central Visayas) Population - 2020 Census of Population and Housing (2020 CPH). Available at http://rsso07.psa.gov.ph/.

Philippines Atlas, 2021. Cebu. Available at https://www.philatlas.com/physical/islands/cebu.html.

Plastics Europe, 2019. Plastics-The Facts 2019. An Analysis of European Production, Demand and Waste Data.

Posadas, D., 2014. Sachets Help Low-income Communities But Are a Waste Nightmare. The Guardian.

Pucino, M., Boucher, J., Bouchet, A., Paruta, P., Zgola, M., 2020. Plastic Pollution Hotspotting and Shaping Action: Regional Results From Eastern and Southern Africa, the Mediterranean, and Southeast Asia. IUCN, Switzerland viii + 78 pp.

Rahim, S., Widayati, W., Analuddin, K., Saleh, F., Alfirman, Sahar, S., 2020. Spatial distribution of marine debris pollution in mangrove-estuaries ecosystem of Kendari Bay. IOP Conf. Ser. Earth Environ. Sci. 412 (1), 0–8. https://doi.org/10.1088/1755-1315/412/1/012006.

Reed, C., 2015. Dawn of the plasticene age. New Sci. 225. https://doi.org/10.1016/S0262-4079(15)60215-9.

Schultz, P.W., Bator, R.J., Large, L.B., Bruni, C.M., Tabanico, J.J., 2013. Littering in context: personal and environmental predictors of littering behavior. Environ. Behav. 45 (1), 35–59. https://doi.org/10.1177/0013916511412179.

Singh, R., Ang, R.P., Sy-Changco, J.A., 2009. Buying less, more often: an evaluation of sachet marketing strategy in an emerging market. Mark. Rev. 9 (1), 3–17.

Spaldinget al., n.d. M. Spalding F. Blasco C. Field International Society for Mangrove Ecosystems, WCMC, National Council for Scientific Research, Paris.

Suyadi, Manullang, C.Y., 2020. Distribution of plastic debris pollution and its implications on mangrove vegetation. NovMar. Pollut. Bull. 160, 111642. https://doi.org/10.1016/j.marpolbul.2020.111642 Epub 2020 Sep 11. PMID: 32920254.

Schwarz, A.E., Ligthart, T.N., Boukris, E., van Harmelen, T., 2019. Sources, transport, and accumulation of different types of plastic litter in aquatic environments: A review study. Mar. Pollut. Bull. 143, 92–100.

Sy-Changco, J., Pornpitakpan, C., Singh, R., Bonilla, C., 2011. Managerial insights into sachet marketing strategies and popularity in the Philippines. Asia Pac. J. Mark. Logist. 23, 755–772.

Tekman, M.B., Gutow, L., Macario, A., Haas, A., Walter, A., Bergmann, M., .. Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung. Litterbase.Available in https://litterbase.awi.de/ Accessed on July 2021.

Thaman, L., Eichenfield, L., 2014. Diapering habits: a global perspective. Pediatr. Dermatol. 31 (1), 15–18.

Thushari, G.G.N., Senevirathna, J.D.M., 2020. Plastic pollution in the marine environment. Heliyon 6 (8), e04709.

Wypych, G., 2016. Handbook of Polymers. 2nd ed. ChemTec Publishing 714pp.

Yu, J.M., 2016. Cebu Economic Factbook 2016. Cebu Economic and Business Unit (C.E.B.U.) 32pp.