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Characterization of mangrove composition and anthropogenic marine debris accumulation in mangrove ecosystems of Mactan Island, Philippines

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Abstract. *Cortes ST, Retubado ZAZ, Colita LB, Caballero JE, Lorca AS, Rosales RC. 2024. Characterization of mangrove composition and study of anthropogenic marine debris accumulation in Mactan Island, The Philippines mangrove ecosystems. Biodiversitas 25: 3521-3530.* Mangrove forests are recognized for their economic and socio-ecological importance. However, their unique morphological structures lead them to become efficient traps of waste sourced from various anthropogenic activities. The continuous accumulation of these Anthropogenic Marine Debris (AMD) could cover the forest floors, resulting in the oppression of their pneumatophores and knee roots. In the long run, this phenomenon could lead to tree death. In this regard, the study assessed the mangrove forest composition and AMD occurrence in the highly urbanized Island of Mactan as a basis for planning its conservation. Fifteen (15) quadrats in each sampling station measuring 10×10 m were established in two sites, Punta Engaño (S1) and Catarman (S2). In two sampling sites, five quadrats were established in each zone (i.e., seaward, midward, and landward). The study recorded 17 mangrove species in two sampling sites, of which all 17 species are present in S1 and four in S2. Of the 17 species, 16 are valid mangrove species belonging to seven (7) families and ten (10) genera. The presence of *Pemphis acidula* J.R.Forst. & G.Forst. in S1 is a significant finding of the study, as it is categorized as one of the endangered species in the Philippines. This study also confirmed the occurrence of AMD in the forest floors of the mangrove areas. A total of 5192 debris items were identified, and they weighed 213.61 kgs for both sites, covering 3,000 m^2 of the island. The majority of this debris is made of single-use plastics used for packaging. These findings underscore the urgent need for local government action focused on effective waste management policies and strategies, information education campaigns, and community extension projects for the long-term survival of the mangrove forests.

Keywords: Coastal, mangrove, marine litter, Philippines, plastic contamination

INTRODUCTION

Mangroves are woody plants which are uniquely positioned at the dynamic interface between land and sea, specifically along coasts and estuaries in tropical and subtropical latitudes (Adams and Rajkaran 2020; UNEP 2014). These areas where they exist are characterized by high and changing levels of salinity, extreme tides, strong winds, high temperatures and low relative air humidity, and anaerobic muddy soil of which only a few species can adapt (Kandasamy and Bingham 2001; Srikanth et al. 2016). In other words, mangroves exhibit highly developed adaptations to extreme conditions, both physiological and morphological. One of the morphological adaptations allowing them to overcome the threats of soft and anaerobic sediments of intertidal zones is its aerial and profuse lateral roots that provides the trees anchorage to the substrate and resistance against currents and storms (Srikanth et al. 2016; Carugati et al. 2018). This anatomical adaptation also allows gas exchange by supplying oxygen to underground roots to aerate them and enable the mangroves to survive in an oxygen-poor substrate (Nguyen et al. 2023).

However, the complex structural network of the trees and aboveground root systems, although considered a morphological adaptation, may also be considered a disadvantage as it results in less dynamic and more efficient traps and accumulators of Anthropogenic Marine Debris (AMD) (Yin et al. 2020; Vorsatz et al. 2023). As defined by UNEP (2009), AMD is “any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment.” These are introduced in the marine environments, particularly in mangrove ecosystems, through sea-borne wastes, improper management of anthropogenic waste produced by urban and industrial areas, accidental loss, and natural disasters (Li et al. 2021; Vorsatz et al. 2023). Their entrapment in the spatial complexity, particularly the plastic wastes, can result in faster fragmentation due to mechanical abrasion and microbial activity, thus resulting in a hotspot for microplastic production (Luo et al. 2021). This phenomenon exposes humans to microplastics, as seafood is part of our diet (Cortes and Otadoy 2020). Moreover, other non-biodegradable debris like metals, glass, ceramics, and others will contribute to exacerbating landscape degradation because their accumulation in the areas becomes an eyesore and aesthetically unpleasant, leading to decreased tourism activities and income loss (Agamuthu et al. 2019).

While previous research within mangroves has mainly focused on microplastics (e.g., Valsan et al. 2024; Aguirre-

Sanchez et al. 2024; Chaisanguansuk et al. 2023; Navarro et al. 2022), only a few have been recorded on the abundance and occurrence of macro debris in mangrove areas (Vorsatz et al. 2023). Hence, there is a need to examine further the drivers and accumulation of AMD in mangrove ecosystems, particularly in urban areas where high levels of anthropogenic activities occur. The Mactan Island in Cebu, Philippines, is one of the highly urbanized settlements in the country. It is a limestone Island of about 62 km^2 located on the east coast of Cebu Island and is sandwiched by two provinces, Leyte and Bohol. Tourism, manufacturing industries, and fishing are a few activities where its population sourced their livelihood (Wong 1999; Tsuji 2020). The mismanaged waste from these activities on the Island may be deposited in its mangrove areas. To date, no study has been recorded assessing the abundance and occurrence of wastes accumulating in the mangrove ecosystems of Mactan. This study is essential considering that the Island is adjacent to the left of the Olango Island Group (Figure 1), the first to be declared the Ramsar Wetland Site in the Philippines in 1994. The AMD accumulating in the mangroves of Mactan may eventually spread to it, affecting a vast congregation of its migratory waders, shorebirds, fish, and other marine resources. In this study, we initially characterized the species of mangroves in two sampling sites of mangrove forests on the Island of Mactan. Eventually, we conducted an anthropogenic survey trapped in the mangrove forests' landward, midward, and seaward zones. The debris was characterized according to material composition and form.

MATERIALS AND METHODS

Study area and sampling

The study was conducted in Mactan, an island in the east of mainland Cebu which is divided into the City of Lapu-Lapu and Municipality of Cordova. Its land area covers 50.49 km^2 and is identified as the most populated island in the Philippines. There were two sampling stations established and distributed along the northern and southern coasts of the island on April 2024. Other than the presence of mangrove ecosystems, these stations were identified and selected because of having high level of anthropogenic disturbances caused by the presence of fishing and recreational activities, resorts, residential, and industrial areas. The stations were in Punta Engaño, Lapu-Lapu City designated as S1 and Catarman, Cordova designated as S2 (Figure 1).

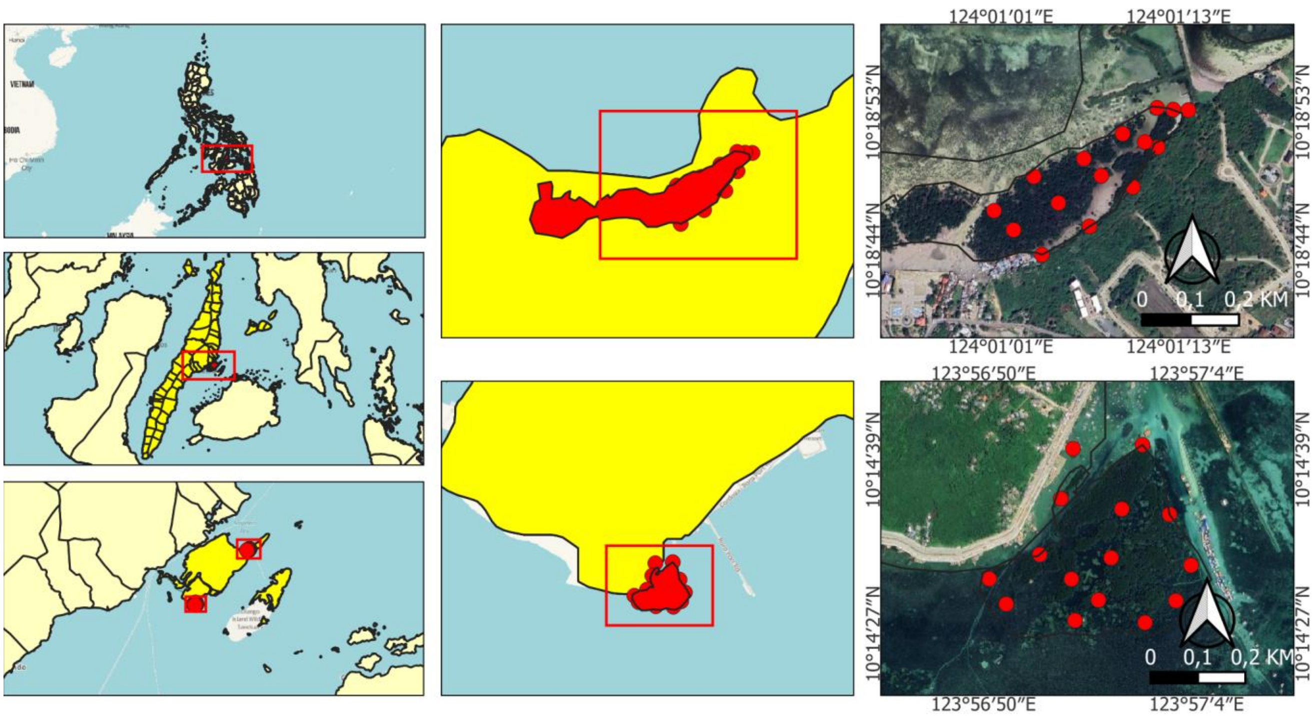

Figure 1. Mactan Island in the Cebu Map, the sampling sites (Punta Engaño, Lapu-Lapu City and Catarman, Cordova) in the map of Mactan, and plot locations

Table 1. AMD by material composition and form

AMD classification	Category
Material composition	Plastic, foamed plastics, cloth, glass and ceramic, metal, paper and cardboard, rubber, wood, others
Material form	Containers, fishing and boating, food and beverage, packaging, sanitary, smoking, others

Data collection

Five transects perpendicular to the shore were established in each sampling station. There were fifteen (15) quadrats, measuring 10×10 m, were established in each sampling site (Figure 1). Each transect has three quadrats established as representative sample of seaward, midward, and landward zones resulting to a total of 15 quadrats per sampling site. The distances between quadrats were not fixed because the mangrove forests are patchy or discontinuous. Each quadrat was delineated with ropes attached to corner pegs. Those in red dots in Figure 1 are the established quadrats in the sampling sites. A total of 30 quadrats were established in this study, covering 3,000 m^2 or 0.3 ha of the Island for both sampling sites. The vegetation within each quadrat was initially examined and characterized based on the mangrove species present. These species were characterized using Primavera's 2009 Field Guide to Philippine Mangroves. The sampling was conducted during low tide and dry season in April 2024 at the two sampling stations' landward, midward, and seaward zones. Surveying low tides makes spotting and picking the AMD less complicated. Following the procedures suggested by Seeruttun et al. 2021, AMD (>5 mm) observed on sediments and tree canopies within each quadrat were photographed before being collected, identified, counted, and weighed. Those wood debris of anthropogenic origin were weighed in situ using a digital portable balance and left in the quadrats. The collected AMD per quadrat was stored in a clean and new net bag separately and transported to the laboratory for cleaning to remove any mud, algal growth, or biofouling organisms present. These were allowed to air dry for at least two days by hanging them on a wire before sorting and weighing in the analytical balance. The AMD classification follows the recommended system of Cheshire et al. 2009, comprising a two-level hierarchy. Firstly, the items are identified by material composition and then by form (Table 1). This classification system contains a list of nine (9) different AMD classes according to material composition, 77 discrete types of litter, and seven (7) different AMD classes according to form. Those buried debris and microscopic AMD within the quadrats and AMDs outside the quadrats but within the sampling stations were collected a week after the survey as part of the clean-up drive. All AMD were disposed of following Cebu City's segregation procedures.

Data analysis

All data collected were recorded and saved in microsoft excel before these were transferred to a statistical and graphing software. No data treatment was performed for the mangrove species composition but the conservation status of each mangrove species based on Department of Environment and Natural Resources Administrative Order No. 2017-11 (DAO 2017-11) and International Union for Conservation of Nature (IUCN) were identified along with its classification whether true mangrove or mangrove associate was recorded. True mangroves are plant species uniquely adapted to survive in saline, waterlogged conditions typical of coastal mangrove ecosystems, exhibiting specialized traits like salt filtration, aerial roots, and viviparous seeds. In contrast, "mangrove" is a broader term that may refer to the entire mangrove ecosystem, which includes both true mangroves and mangrove associates, the latter lacking such specialized adaptations. The data on count of AMD per composition, form, and zonation were treated using two-way ANOVA. Two-way ANOVA is used when you want to examine the effects of two independent variables on a dependent variable, as well as their interaction. In this case, this statistical technique was performed to examine the effects of material composition and zonation on AMD count, and the effects of material form and zonation on AMD count. Principal components analyses were also performed using OriginPro 2024 to examine the association between count of AMD composition and zonation as well as count of AMD form and zonation. Finally, data on weight of AMD per composition and form were treated using descriptive statistics reported as mean±SE.

RESULTS AND DISCUSSION

Mangrove species composition

Table 2 reflects the list of mangrove species present in the studied areas of Mactan Island. There are 17 mangrove species recorded in the two sampling sites of which all seventeen (17) species are present in S1 while four (4) in S2. Of the 17 species, 16 are true mangrove species belonging to seven (7) families and ten (10) genera. It is equivalent to 30% of the 39 known true mangroves in the Philippines. This number of species reveals that Mactan Island has higher number of true mangrove species compared to other places in the Philippines such as in Imelda, Dinagat Island with 10 species belonging to six families (Cañizares and Seronay 2016) and Mabini, Davao de Oro with eight species belonging to six genera of five families (Manual et al. 2022). However, this number of true mangroves is less than that of Camotes Island with 31 species belonging to 17 genera of 13 families (Lillo et al. 2022), Sibonga, Cebu with 20 species belonging to 14 genera of 11 families (Lillo et al. 2024), and Puerto Princesa Bay, Palawan Island with 27 species belonging to 15 genera of 14 families (Dangan-Galon et al. 2016).

Table 2. List of species recorded in the studied area in Punta Engaño, Lapu-Lapu City (S1) and Catarman, Cordova (S2)

Family name	Species name	Common name	Conservation status		Sampling site		Mangrove classification	
			DAO 2017-11	IUCN 2.3	S1	S2	True mangrove	Assoc. species
Lythraceae	*Sonneratia alba* Sm.	Pagatpat	Not yet assessed	Least concern	*	*	x	
Acanthaceae	*Avicennia marina* (Forssk.) Vierh.	Miapi	Not yet assessed	Least concern	*	*	x	
Rhizophoraceae	*Bruguiera cylindrica* (L.) Blume	Pototan	Not yet assessed	Least concern	*		x	
Rhizophoraceae	*Rhizophora apiculata* Blume	Bakhaw Lalaki	Not yet assessed	Least concern	*	*	x	
Rhizophoraceae	*Rhizophora mucronata* Lam.	Bakhaw Babae	Not yet assessed	Least concern	*	*	x	
Rhizophoraceae	*Rhizophora stylosa* Griffith	Bakhaw Bato	Not yet assessed	Least concern	*		x	
Rhizophoraceae	*Rhizophora ×lamarckii* Montrouz.	Bakhaw Hybrid	Not yet assessed	Not evaluated	*		x	
Rhizophoraceae	*Bruguiera gymnorhiza* (L.) Lam.	Busain	Not yet assessed	Least concern	*		x	
Lythraceae	*Pemphis acidula* J.R.Forst. & G.Forst	Bantigi	Endangered	Least concern	*		x	
Meliaceae	*Xylocarpus granatum* J.Koenig	Tabigi	Not yet assessed	Least concern	*		x	
Meliaceae	*Xylocarpus moluccensis* (Lam.) M.Roem.	Lagutlot	Not yet assessed	Least concern	*		x	
Rubiaceae	*Scyphiphora hydrophylacea* C.F.Gaertn.	Nilad	Not yet assessed	Least concern	*		x	
Euphorbiaceae	*Excoecaria agallocha* L.	Buta-buta	Not yet assessed	Least concern	*		x	
Rhizophoraceae	*Ceriops zippeliana* Blume	Lapis-lapis	Not yet assessed	Least concern	*		x	
Rhizophoraceae	*Ceriops tagal* (Perr.) C.B.Rob.	Tungog	Not yet assessed	Least concern	*		x	
Arecaceae	*Nypa fruticans* Wurmb	Nipa	Not yet assessed	Least concern	*		x	
Pteridaceae	*Acrostichum speciosum* Willd.	Palaypay	Not yet assessed	Least concern	*			x
Total					17	4	16	1

Of the seven families, *Rhizophoraceae* is the most represented (n=8), and *Rhizophora* is the most dominant genera (n=4) of mangroves. The species present in both sampling sites are *Rhizophora apiculata* Blume, *Rhizophora mucronata* Lam., *Sonneratia alba* Sm., and *Avicennia marina* (Forssk.) Vierh. While the first two species belong to the family *Rhizophoraceae*, the other two species belong to Lythraceae and *Acanthaceae*, respectively. The dominant presence of these four species confirms the findings of previous studies in the country where these mangroves were also recorded such as those conducted in Carcar City and Municipality of Sibonga in Southern Cebu Island (Lillo et al. 2024), Camotes Island (Lillo et al. 2022), and Manamoc Island (Martinez and Buot Jr 2018). Their presence in both sampling sites is a consequence of their biological traits, ecological roles, and adaptation to the environmental conditions of the coastal areas. For example, *Rhizophora* species and *A. marina* has specialized root systems which are stilt roots and pneumatophores, respectively. These help them anchor and survive in a waterlogged, anoxic environment, characteristic of coastal areas (Carugati et al. 2018). In addition, these root systems help them become resilient and survive environmental stressors which include but are not limited to typhoons and fluctuating tidal flow, thus, contributing to their dominance. In the long run, the dominance of these mangrove species stabilizes shorelines, reduces coastal erosion, and provides habitat, making them ecologically valuable. These mangrove species also prefer medium to hypersaline levels, a characteristic of coastal areas (Raganas and Magcale-Macandog 2020). Under this condition, these four mangrove species become more competitive and outgrow other species, thus, explaining their dominance in the sampling sites. Other explanation of their dominance rests on being pioner species of *S. alba* and *A. marina* (Thirumurugan et al. 2022) and viviparous reproduction of the two *Rhizophora* species (Robert et al. 2015).

The presence of *Pemphis acidula* J.R.Forst. & G.Forst in S1 is a significant study finding. Although the IUCN Red List tagged this as a minor concern, its population trend is decreasing (Ellison et al. 2010) because of habitat loss and the collection for use in the bonsai trade (Ellison et al. 2010). Moreover, the Philippine Department of Environment and Natural Resources (DENR-DAO2017-11) categorized it as endangered. The presence of this endangered mangrove species in the area underscores the need for targeted efforts to take legal and policy actions, research and monitoring, and community extension services aimed toward conserving and propagating it. Its presence also serves as an ecological (i.e., biodiversity indicator and keystone species), environmental (i.e., protecting the coastal areas and helping improve water quality), and socio-economic importance in the mangrove ecosystem. It is also essential to recognize that it supports the life of infaunal and epifaunal species in the area.

AMD count and weight by material composition in S1 and S2

Various AMD were found in the two sampling sites. A total of 5192 debris items were identified and weighed 213.61 kgs. It covers 3,000 m^2 of the island (Figure 2 for photographs of AMD trapped in mangrove forests). At the site level (Figure 3), S1 established in Punta Engaño, northeast of Mactan, had 2.68 items m^{-2} and weighed an average of 0.069 kg. Meanwhile, S2, established in Catarman, southwest of Mactan, had 0.78 items m^{-2} and weighed an average of 0.074 kg. While S1 had a higher count of AMD m^{-2}, S2 had heavier debris trapped in its mangrove forest m^{-2}. The presence of these debris in the sampling sites confirms available literature that mangroves are vulnerable to accumulation and retention of potentially harmful debris, thereby acting as significant traps (e.g., Yin et al. 2020; Li et al. 2021; Jayapala et al. 2024). Although the number of items m^{-2} is significantly lower than those reported in Pantai Indah Kapuk, Jakarta, Indonesia with 533 items m^{-2} (Hastuti et al. 2014), Penang Island, Malaysia with 73.12 items m^{-2} (Yin et al. 2020), and Mutupore Island, Papua New Guinea with 78.3 items m^{-2} (Smith 2012), this is higher than those recorded in Pujada Bay, Davao Oriental. It is the single survey of AMD abundance in a mangrove forest in the same country, in which abundance is reported to range between 0.18 to 1.39 items m^{-2} in two sampling sites. It indicates that the proximity of mangrove forests to highly urbanized areas with a high level of anthropogenic activities influences the abundance or load of waste in them.

Eventually, a two-way ANOVA was performed to examine the effects of material composition and zonation on AMD count in both sampling sites which results are shown in Table 3. First, there was a significant effect of material composition on debris count in Punta Engaño, $F(8, 108)=3.61$, $p<.05$. As evidence, Figure 4.A reveals that when the count or number of items in three zones in each category of AMD material composition are added and the average is obtained, plastics (238.60 items±129.65) have highest average count found in the sampling site accounting 89.00% of all debris and on average weighed 2.27 kg±0.83 (Figure 4.E). Meanwhile, the trace average number of items with their corresponding weight average are only recorded in the site except for papers and cardboards with no presence at all knowing their rapid degradation. These are other unclassified debris (8.13 items±12.58; 0.91 kg±0.37), foamed plastics (6.47 items±2.19; 0.12 kg±0.03), woods (5.27 items±9.29; 0.81 kg±0.26), clothes (3.73 items±5.85; 1.56 kg±0.95), rubbers (3.27 items±3.85; 0.42 kg±0.20), glasses and ceramics (2.00 items±2.88; 0.71 kg±0.27), and metals (0.60 items±1.18; 0.05 kg±0.01). Figure 4.E explicitly presents the average weight of each AMD per material composition and per zone in S1 (Punta Engaño). Similarly, there was a significant main effect of material composition on debris count in S2 (Cordova), $F(8, 108)=30.27$, $p<.05$. Figure 4.B shows that plastics (56.73 items±10.77; 1.94 kg±0.33) remain highest in terms of average debris count in three zones which is consistent with the results in Punta Engaño. Traces of glasses and ceramics (5.13 items±1.61; 2.49 kg±0.77), foamed plastics (4.40 items±2.06; 0.19 kg±0.07), other unclassified debris (3.53 items±4.26; 0.90 kg±0.35), woods (3.40 items±1.20; 1.19 kg±0.39), clothes (1.80 items±0.53; 0.46 kg±0.15), rubbers (1.80 items±0.63; 0.126 kg±0.05), metals (0.67 items±0.36; 0.042 kg±0.03), and paper and cardboards (0.60 items±0.36; 0.043 kg±0.03) were found in the sampling site. Figure 4.F explicitly presents the average weight of each AMD per material composition and per zone. Consistent with previous studies in Mutupore Island, Papua New Guinea (Smith 2012), Mahebourg and Ferney, Mauritius (Seeruttun et al. 2021) which reported plastics to account by far majority of the debris at 89.7, 42.92, and 43.66%, respectively, plastic also leads the most percentage of litters in the sampling sites.

Figure 2. Anthropogenic debris in the sampling sites

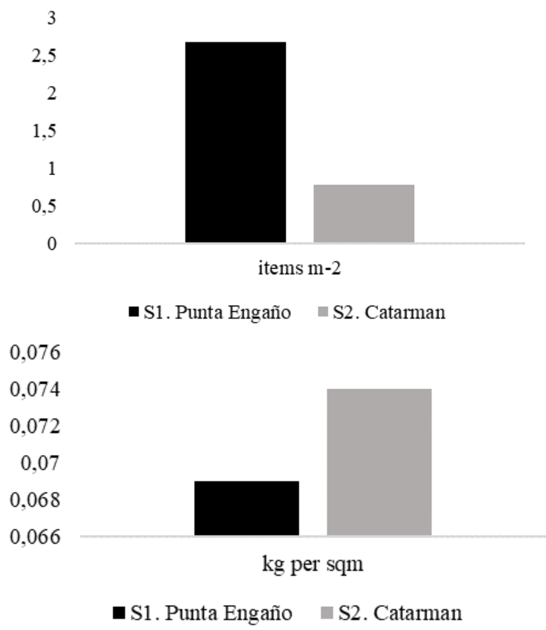

Figure 3. Average (A) count (no. of items) of AMD in Punta Engaño and Catarman per square meter; Average (B) weight (kg) of AMD in Punta Engaño and Catarman per square meter

Table 3. Results of two-way ANOVA on the effect of material composition and zonation on AMD count

Sampling site	Source	df	Sum of squares	Mean square	F-value	*p*-value
S1 - Punta Engaño	Material composition	8	736,653.30	92,081.66	3.61	0.00094
	Zone	2	95,945.08	47,972.54	1.88	0.1578
	Interaction	16	681,086.78	42,567.92	1.67	0.0642
	Error	108	2,758,179.60	25,538.70		
	Total	134	4,271,864.77			
S2 - Catarman	Material composition	8	39,278.33	4,909.79	30.27	<0.0001
	Zone	2	1,579.84	789.91	4.87	0.00945
	Interaction	16	7,457.50	466.09	2.87	0.00061
	Error	108	17,520.00	162.22		
	Total	134	65,835.66			

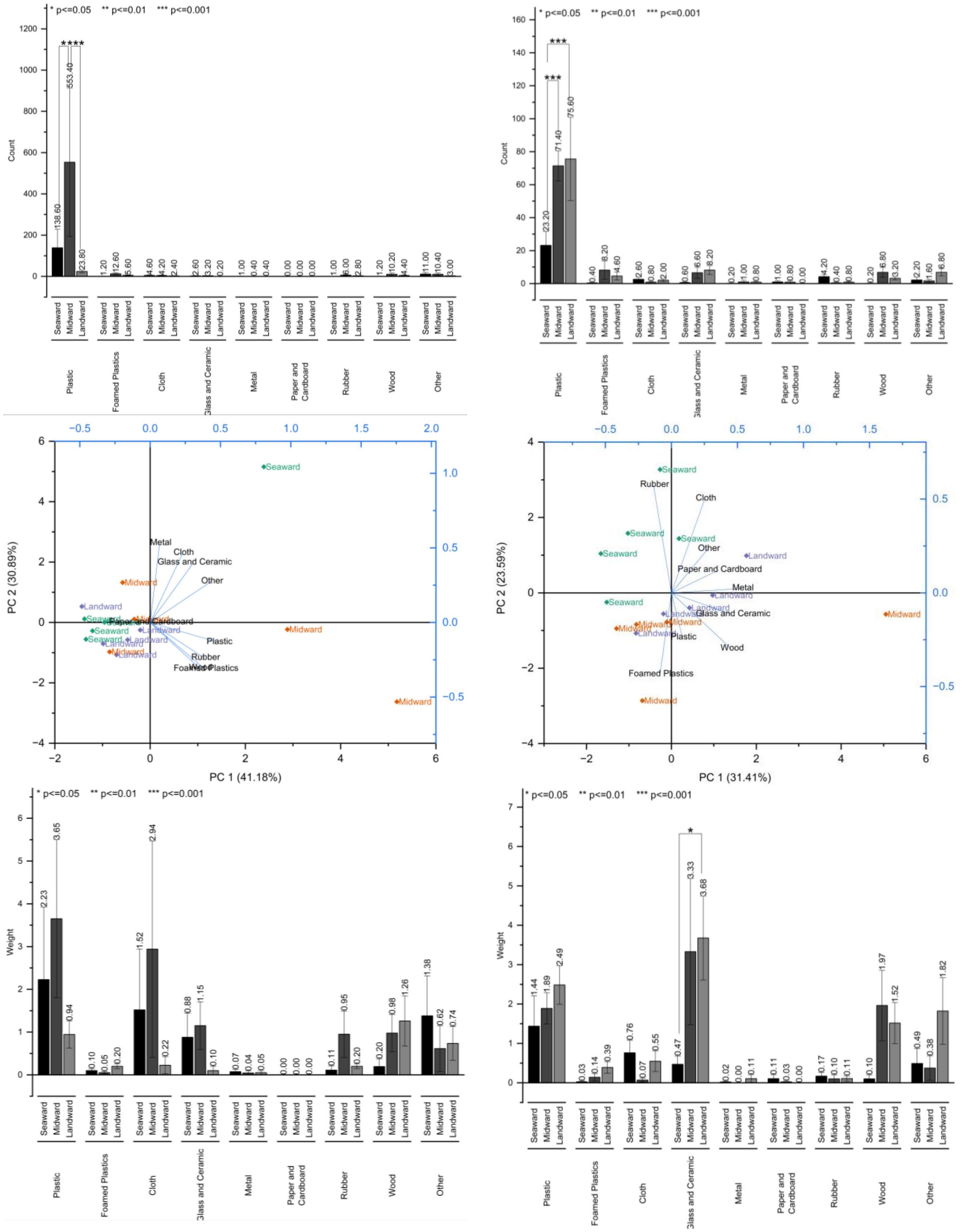

Figure 4. Average count of AMD in each zone per material composition in (A) S1 and (B) S2; principal component analysis results on the association AMD count and zonations in (C) S1 and (D) S2; (E) Average weight (kg) of AMD in each zone per material composition in (E) S1 and (F) S2

The high count and density of plastics in these sampling sites suggest the influence of various anthropogenic activities in the areas coupled with improper waste disposal. S1 is surrounded by hotels and other tourist' accommodation establishments near one of the historical places in Mactan, attracting thousands of local and international tourists yearly, and adjacent to urban poor communities. Meanwhile, S2 is a mangrove area that serves many functions, such as recreation for beachgoers and fishing and boating for fisherfolks. Its coast is a residential area and a temporary makeshift market for selling fishermen's catch. The plastic wastes from these residential and industrial zones may be incidentally and intentionally dumped into the mangrove areas untreated. Li et al. (2016) reviewed the literature and pointed out these as land- and ocean-based sources of plastic entering the marine environment, with domestic, industrial, and fishing activities being the most important contributors.

Second, there was no significant effect of zonation on debris count in Punta Engaño, F (2,108)=1.87, p<.05, as shown in Table 3, meaning AMD count do not vary across three zones. Nonetheless, in Figure 4.A, when the count or number of items in each zone across all categories of AMD composition are added and the mean is obtained, the results indicate that the average debris count per zone is different. Most of the debris accumulated in the midward (66.71 items±44.52) zone of the mangrove forest, followed by seaward (17.91 items±11.21) and landward (4.73 items±1.36). The principal components analysis was performed and the biplot confirms these results reflecting the vectors to point the quadrats established in the zones with high AMD count (i.e., midward and seaward zones) (Figure 4.C). The material composition accumulating in two quadrats established in midward are plastics, foamed plastics, rubbers, woods, and other unclassified debris. Meanwhile, the vectors for metals, clothes, and glasses and ceramics are pointing toward one quadrat in seaward zone. All these quadrats were positioned on the left side of the sampling site, which is adjacent to a tourist and residential area, meaning the potential point source of these AMD was from them. Meanwhile, zonation has a significant main effect on debris count in Catarman, F (2,108)=4.87, p<.05, meaning AMD count varies across three zones. In Figure 4.B, the total debris count in landward (11.33±4.31) and midward (10.84±3.46) are higher than in seaward (3.84±1.38). The principal components analysis was also performed and the biplot confirms these findings (Figure 4.D). The vectors which represent AMD composition are pointing toward the midward and landward zones where the density of AMD is high. While Luo et al. (2021) ascertain that mangroves are efficient at retaining debris in the landward or interior zones of the mangrove, the findings of this study suggest that the density of debris is based on proximity to areas with higher anthropogenic activities. As evidence, most of the vectors in the biplot for Punta Engaño are pointing to seaward and landward while most of the vectors in the biplot for Catarman are pointing to midward and landward. In Punta Engaño, the quadrats established in seaward and landward zones are closest to urban poor housing. Meanwhile, in Catarman, the quadrats established in landward and midward zones are close to the temporary makeshift market for selling catches of fishermen, recreational activity (e.g., picnic), and wharf. These anthropogenic activities are known as major contributors of litter in mangroves (De et al. 2023).

Finally, the interaction effect between material composition and zonation on debris count was found insignificant in Punta Engaño, F (16,108)=1.67, p>.05, as shown in Table 3. On the contrary, the interaction effect between material type and zonation was significant in Catarman, F (16, 108)=4.56, p<.05. The effect of material composition on debris count was different between seaward, midward, and landward. For instance, post-hoc analysis using Tukey indicated that in landward, plastics (75.60±25.30) had significantly higher count than other material types. The same observations apply in midward (71.40±9.06) and seaward (23.20±8.50), where plastics dominated the zones.

AMD count and weight by material form in S1 and S2

To determine the uses of the AMD found in both sampling sites, these were examined according to material form. There count and weight were also compared across zones. Initially, a two-way ANOVA was conducted in Punta Engaño to examine the effects of material form and zonation on AMD count, which results are shown in Table 4. First, there was an insignificant effect of material form on debris count, F (6, 84)=1.86, p>.05, indicating that the number of items do not significantly differ when the AMD are grouped according to material form. Nonetheless, descriptive statistics using mean reveals that the average count with its corresponding weight (mean item±SE; mean kg±SE) of each AMD based on form reveals variability.

Table 4. Results of two-way ANOVA on the effect of material form and zonation on AMD count in S1

Sampling site	Source	df	Sum of squares	Mean square	F-value	*p*-value
S1 - Punta Engaño	Material form	6	226,796.99	37,799.49	1.86	0.0972
	Zone	2	122,587.68	61,293.84	3.02	0.05428
	Interaction	12	408,223.12	34,018.59	1.67	0.0872
	Error	84	1,706,501.60	20,315.50		
	Total	104	2,464,109.39			
S2 - Catarman	Material form	6	22,991.92	3,831.99	15.07	<0.0001
	Zone	2	1,500.25	750.12	2.95	0.05783
	Interaction	12	3,791.22	315.93	1.24	0.26899
	Error	84	21,366.00	254.36		
	Total	104	49,649.39			

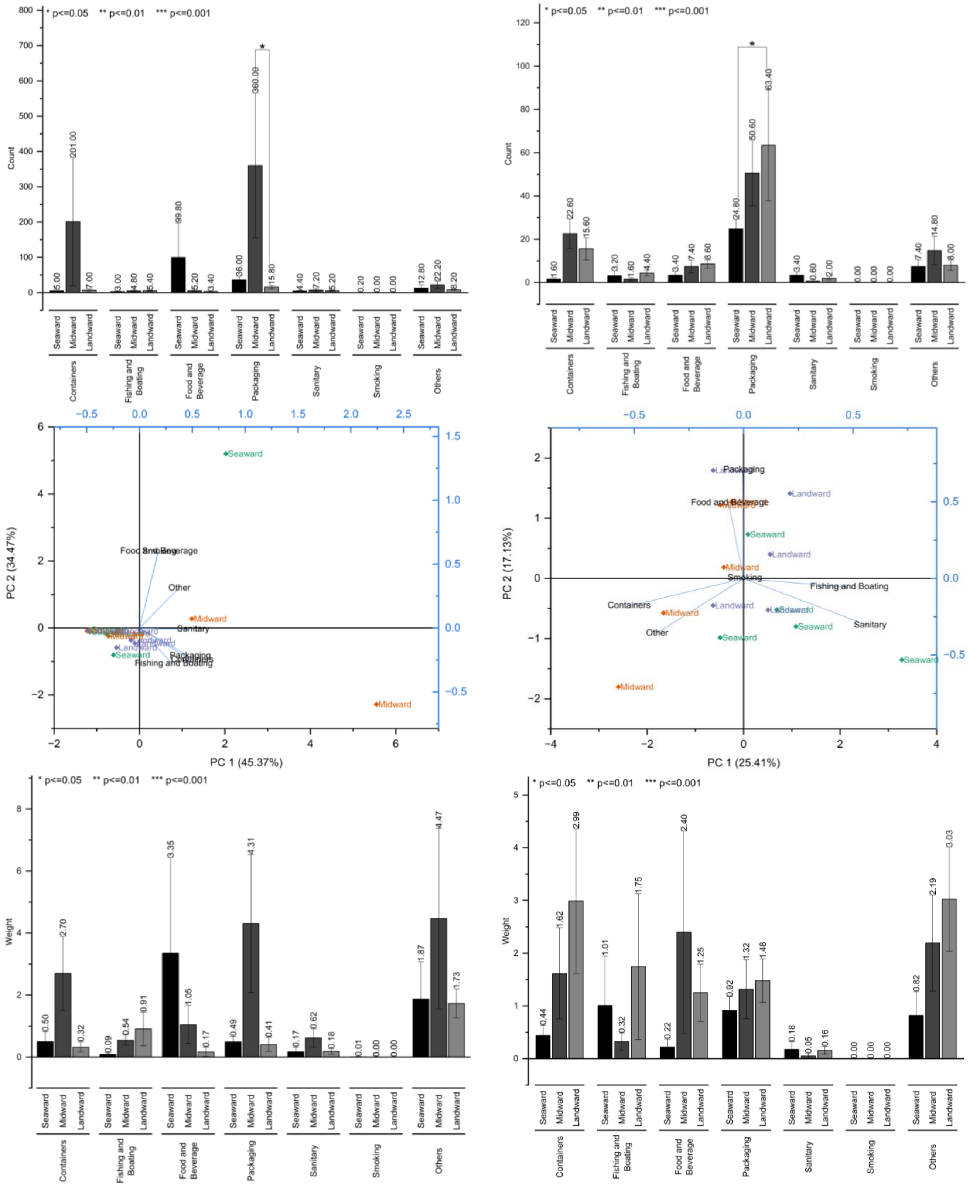

Figure 5. Average count of AMD in each zone per material form in (A) S1 and (B) S2; principal component analysis results on the association AMD count and zonations in (C) S1 and (D) S2; average weight (kg) of AMD in each zone per material form in (E) S1 and (F) S2

Waste from plastic packaging (137.27 items±76.16; 1.74 kg±0.85) was recorded the highest. The rest of the AMD are containers (71.00 items±61.30; 1.74 kg±0.48), food and beverage (36.13 items±36.72; 1.52 kg±1.04), other unclassified AMD (14.40 items±4.55; 1.69 kg±1.04), sanitary (5.60 items±1.60; 0.32 kg±0.12), fishing and boating (4.40 items±1.26; 0.51 kg±0.20), and smoking (0.07 item±0.07; 0.003 kg±0.003). Figure 5.E explicitly presents the average weight of each AMD per material form and per zone. On the contrary, there is a significant effect of material form on debris count in Catarman, F (6, 84)=15.065, p<.05. Figure 5.B reveals that packaging waste (46.27 items±10.24; 1.23 kg±0.24) had highest total count accounting 57.03% of all debris by material form. Waste from containers (13.27 items±3.51; 1.68 kg±0.58), other unclassified debris (10.07 items±2.55; 2.01 kg±0.50), food and beverage (6.47 items±1.35; 1.29 kg±0.66), fishing and boating (3.07 items±0.89; 1.03 kg±0.54), and sanitary (2.00 items±0.67; 0.129 kg±0.05) account the remaining 42.07%. There was no smoking debris recorded in the sampling site. Paler et al. (2022) explained that the high density of plastic packaging in both sites come from their huge demand in developing economies like the Philippines. These come out from economic necessity and convenience, and are essential in retaining food quality, sanitation, and longevity of product shelf life. However, with mangrove roots being efficient traps of plastic debris and over time covering the forest floor, these could oppress pneumatophores and knee-roots resulting to tree death (van Bijsterveldt et al. 2021).

Second, there was an insignificant effect of zonation on debris count in Punta Engaño, F (2,84)=3.02, p>.05, suggesting that the average number of items do not differ when the AMD is grouped based on zonation. In Figure 5.A, it indicates that the total debris count per zone are comparatively the same but descriptive statistics reveal that most of the debris are accumulating in the midward (85.77±42.03) zone followed by seaward (23.03±14.12) and landward (6.43±1.22). The principal components analysis was performed and the biplot confirms these results reflecting the vectors of most AMD form to point the midward and seaward zones (Figure 5.C). Similarly, there was an insignificant effect of zonation on debris count in Catarman, F (2,84)=2.95, p>.05. Nonetheless, the total debris count per zone is different with most of the debris accumulating in the landward (14.57 items±4.90) and midward (13.94 items±3.73) while trace average count of debris in seaward (6.25 items±1.59). The principal components analysis was again performed and the biplot confirms these results reflecting the vectors of each AMD form to point toward the landward and midward zones (Figure 5.D). The results support findings on the association between material type and zonation that the density of debris is based on proximity to areas with higher anthropogenic activities. The vectors in the biplot for both sampling sites are usually pointing to zones with high density of AMD by weight and not essentially on the landward and midward alone as established by Luo et al. (2021).

Finally, the interaction effect between material form and zonation on debris count was insignificant in Punta Engaño, F (12, 84)=1.67, p>.05. Similarly, the interaction effect between material form and zonation on debris count was insignificant in Catarman, F (16,108)=1.67, p>.05. In other words, there is no significant combined effect of material form and zonation on the amount of debris in both sampling sites.

In conclusion, this study assesses the composition of mangrove species and the AMD in the mangrove forest of Mactan Island. Specifically, it provides information regarding their count and weight per material type and form. In conclusion, our findings confirmed the presence of AMD covering the forest floors of the mangrove areas. Consistent with previous findings, the AMD by material type, which accounted for the majority of waste on the forest floors, is single-use plastics used chiefly for packaging. Their accumulation and other types of waste can cover mangrove roots, eventually leading to the death of trees. The study also found that the count and weight of AMD are not specific to zonation but instead associated with zones with proximity to higher anthropogenic disturbances. This study underscores the urgent need for effective waste management policies and strategies for reducing single-use plastics. This could involve policy measures, information education campaigns, and community extension projects to reduce and improve waste disposal practices. Further, the presence of an endangered mangrove species in one area strengthens the need to take action to conserve and propagate it.

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