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A temporal assessment of anthropogenic marine debris on sandy beaches from Ecuador's southern coast

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Anthropogenic marine debris (AMD) is an environmental pollution that affects marine life, human health, wellbeing, and the economy. This marine litter can deposit in the coastlines, particularly on tidal zones and beaches. To pursue future mitigation strategies to reduce AMD is important to monitor the amount, type and frequency of litter being dumped on shores. This study presents the composition, temporal distribution, abundance and size of AMD on three sandy beaches from Guayas province, Ecuador. The field data was recollected from December 2018 to February 2020. A total of 12,362 items of AMD were collected with an abundance of 1.95 macro-litter items/m^2. The composition of AMD was marked by the predominance of plastic items (91.8%), followed by wood and cloth (1.9%), while cigarettes were only present in village beaches. Our results suggest that sites with more AMD abundance are beaches nearby small coastal villages and fishing communities. Also, the AMD abundance is slightly higher at the beginning of the dry season than in the rainy season. Our findings indicate that it is necessary to implement concerted solid waste management measures and proactive environmental education programs to empower the local population, as well as investigate the anthropogenic sources and other variables influencing the AMD abundance coming onto sandy shores.

KEYWORDS
anthropogenic marine debris, marine litter, plastics, sandy beaches, Ecuador

Research highlights:

1. Anthropogenic marine debris (AMD) showed a temporal trend on study sites.
2. An average of 1.95 AMD items/m^2 was found on all sites.
3. Plastics items were highly abundant across all sites (91.8%).
4. Cigarettes butts were only present on village beaches.

Introduction

The anthropogenic marine debris (AMD) causes diverse types of ecological impacts in the environment, marine life, human health, and socio-economic wellbeing (Bravo et al., 2009; Thiel et al., 2011; Hidalgo-Ruz et al., 2018; Honorato-Zimmer et al., 2019; Gaibor et al., 2020; Olivelli et al., 2020). The AMD is present in different marine environments such as shorelines, estuaries, sea surface, ocean bottom and mangrove areas (Iñiguez et al., 2016; Luo et al., 2021). Marine debris is defined as everything persistent manufactured or processed solid material, disposed of, or neglected in a marine environment by different users deliberately or unintentionally. These anthropogenic materials can be transported to the oceans by wind, rivers, or sewage systems. The AMD can be made of paper, metal, plastic, textile, glass, and rubber, but plastic is the most abundant material (STAP, 2011; NOAA, 2021).

The composition and abundance of AMD present in sandy beaches may vary temporarily by the influence of dissimilar factors. For example, the density of AMD is high during the rainy season (December – May) in tropical countries (Sulochanan et al., 2019; Suteja et al., 2021), or increase in summer seasons of the northern and southern hemisphere (Asensio-Montesinos et al., 2019; de Ramos et al., 2021). Also, the increase of debris is influenced by the presence of river discharges (Lebreton et al., 2017; Sulochanan et al., 2019; Meijer et al., 2021; Mugilarasan et al., 2021) into the coastal areas, where another factor such as the presence of tourists (Garcés-Ordóñez et al., 2020b; Zalewska et al., 2021; Nigam et al., 2022) contribute to the total loads of AMD, entering into shore environments.

It is thought that during summer seasons, an increase of travelers to the touristic shores is expected so that the origin of marine litter is considered local, especially associated to the beachgoers. Moreover, marine debris associated with fishing activities at sea (e.g., abandoned and discarded fishing gear) has also been found (Macfadyen et al., 2009; Gilman, 2015), as well as solid waste and debris coming from wastewater discharges (Asensio-Montesinos et al., 2020). Tourist beaches, however, may present a low density of marine debris because are usually cleaned (Portz et al., 2021).

Several studies document that AMD generates negative impacts with deleterious health effects on marine biodiversity because marine species ingest and get entangled, injured and suffocated with different sizes and types of AMD (Schuyler et al., 2014; Kühn et al., 2015; Agamuthu et al., 2019; López-Martínez et al., 2021). For ingestion cases, tubenose seabirds are critically affected because they ingest large amounts of ocean plastics than other seabirds (Kühn and van Franeker, 2020). The mortality for AMD ingestion is considerably high and increasing in seabirds (Wilcox et al., 2015; Roman et al., 2019). A considerable number of studies show that other marine fauna are also capable to ingest AMD, including sea turtles (Schuyler et al., 2014; Yaghmour et al., 2021), filter-feeding sharks (Abreo et al., 2019), cetaceans (Lusher et al., 2018; Alzugaray et al., 2020; Brentano and Petry, 2020), and benthic fauna (Coughlan et al., 2020). Entanglement are on the rise with lethal cases of marine biota entangled with plastics pieces and fishing gear such as sea turtles (Yaghmour, 2020), marine mammals (Hamilton and Baker, 2019; López-Martínez et al., 2021), rays and sharks (Parton et al., 2019). The magnitude of the impact by entanglement incidents may escalate close to the oceanic gyres, semi-enclosed seas, and coastlines (Høiberg et al., 2022) where AMD accumulate in high amounts.

The accumulation of marine debris has been observed on the seafloor, and much of marine debris is fishing gear-related in the upper layer of seamounts (Angiolillo et al., 2021). Therefore, the implications of the negative effects that AMD may have on bottom-living fauna is of great concern. Few studies have reported the potential negative impacts of entanglement of AMD on benthic organisms such as presence of longlines in coral colonies (Angiolillo et al., 2021), followed by signs of coral bleaching (De et al., 2022), and behavioral changes of benthonic fauna (Prestholdt and Kemp, 2020). Marine debris also causes direct economic impact in the fishing and aquaculture industry, shipping, and marine tourism. It has been estimated the cost of the marine litter of the global economy representing $21.2 bn in 2020, and it will depict $434 bn in 2050 (McIlgorm et al., 2022).

In Ecuador, few studies of AMD have previously been conducted, but AMD temporal abundance and composition have not been evaluated. According to Gaibor et al. (2020), plastic items are the most abundant type of AMD. Especially, the kind of plastic found is derived from fishing activities and consumer items. The beaches with the highest AMD density are close to the Gulf of Guayaquil (Gaibor et al., 2020). Similarly, another study that examined the beaches of continental Ecuador concluded that Ecuadorian shores are deteriorated and affected by human activities and local drainage systems (Mestanza et al., 2019). This study also highlighted that the international tourist beaches from the Galapagos Islands are the cleanest ones. However, a recent publication reported a high accumulation of plastic on Galapagos beaches influenced by the Humboldt Current, as well as the possible risk of damage in 27 marine animals (Jones et al., 2021). Finally, a prior study observed evidence of plastic ingestion in a squid associated with fishing gear debris or material used by fisheries in waters off Ecuador's main coast (Rosas-Luis, 2016). Altogether, these studies point out that AMD represent a concerning problem in Ecuador, and more studies are needed to generate a baseline of information to tackle this environmental problem.

The main objective of this paper was to (i) quantify the composition of AMD, (ii) evaluate the distribution of AMD, (iii) provide insights into a temporal abundance of AMD on sandy beaches, and (iv) investigate the relation the AMD size with seasons and sites. To conduct our investigation, we chose a coastline sector of Ecuador known as Data de Posorja, located on Guayas province. In this Ecuadorian south coastal region, there are sandy beaches like the ones selected for our study that are experiencing a human population expansion (Quintero, 2014). As a result, different economic activities such as food sales, tourism and fishing generate distinct types of waste, and among them, there is pervasive plastic pollution. Although there are multiple awareness campaigns against marine pollution, the lack of a robust municipal solid waste management plan in this region causes AMD to enter the sea and accumulate on nearby beaches. Therefore, basic AMD studies are key to understand this environmental issue and to better design strategies to first avoid AMD build-up on the coast, and secondly to successfully manage the presence of AMD on Ecuadorian marine shores.

Materials and methods

Study area

The field work was conducted based on the beaches exhibiting the highest density of AMD, previously identified by Gaibor et al. (2020): Varadero beach (2°43'25.86" S, 80°17'58.69" W), Delfin beach (2°43'39.30" S, 80°17'27.00" W) and Bahia Muyuyo beach (2°44'0.14" S, 80°16'54.36" W) in Data de Posorja coastal zone, Guayas Province, Ecuador (Figure 1). The Data de Posorja coast forms a straight line, embraced by a coastal barrier and dune fields. The sandy beaches of the study area contain medium to fine sand, especially in Varadero and Delfin (PMRC, 1988; Vera et al., 2009; Ajila, 2020; Sadaka, 2020). Varadero beach is >100 m wide and two sectors. One is considered as a tourism area, which is normally cleaned by local tour operators at the end of the day. Our sampling efforts were all made in the sector of Varadero beach that has not a cleaning program. Close to Varadero, the coastal zone records a clear accretion and there is a sand spit that extends along the mouth of the Data de Posorja River several hundred meters parallel to the coast with a predominant direction of coastal transport to the southeast (PMRC, 1988; Vera et al., 2009; Pacheco et al., 2021). Also, Delfin beach is >100 m wide, but presents several outcrops of sandstone and conglomerate rock at low tide and are separated from each other by tens of meters and are perpendicular to the coastline (PMRC, 1988). Our observations indicate that this beach has a wider surf zone than the other sites. Finally, Bahia Muyuyo beach has a steep narrow coastline that has medium to coarse sand and is approximately 20 m wide.

During the rainy season on Data de Posorja, the predominant winds are from the southwest and northwest quadrants, with a predominance of winds from the southwest. Normal wind speeds exceed 6 m/s in the rainy season and 8 m/s in the dry season (INOCAR, 2015). Coastal currents reach a maximum speed during May and June. The maximum tidal currents speeds are 0.51 m/s heading east during flooding tide and 0.56 m/s heading west during ebbing tide (Vera et al., 2009; INOCAR, 2015). The wave climate in Ecuadorian coastal waters is influenced by the wind South Pacific conditions. The highest waves are particularly observed from July – August. In Data of

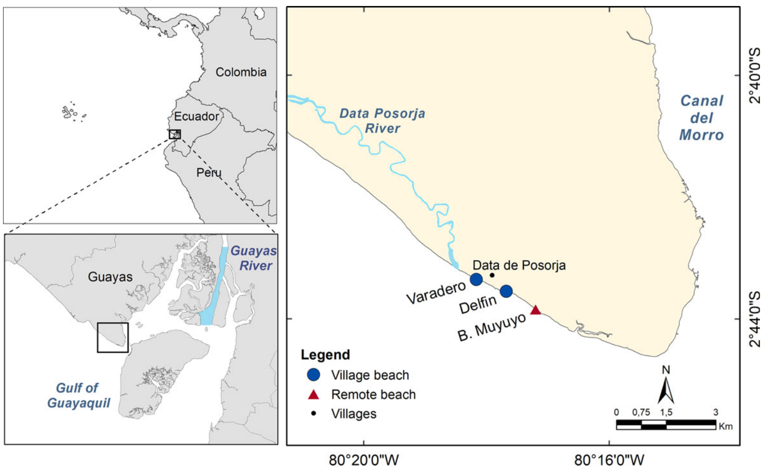

FIGURE 1
Study area map showing all sampling locations (Varadero, Delfin and Bahia de Muyuyo) on Data de Posorja, Guayas province (Ecuador).

Posorja area, wave heights range from 1.7 m in May to 1.9 m in August (INOCAR, 2015), and the average wave height is small (0.31 m) for this area, then the energy release is low (Pacheco et al., 2021). On the other hand, Varadero and Delfin may be classified as villages beaches, while Bahia Muyuyo may be considered as a remote beach according to the Bathing Area Registration and Evaluation (BARE) classification system (Williams and Micallef, 2009; Khattabi et al., 2011).

The tourism sector and hospitality service are exclusively offered and focused on Varadero beach (Cuñez and García, 2020). This area is a hot spot for regional tourism because it is mostly visited by beach enthusiasts coming from the Guayaquil area. Beach season goes from January to May, so the number of tourists increases during this period. However, from June through December, the number of beach visitors decreases significantly (Tapia Arias et al., 2015). Moreover, there are two small-scale (artisanal) fishing associations based on Data de Posorja area, and two important Ecuadorian industrial fishing companies, targeting tuna fisheries and located in the nearby Posorja area (Tapia Arias et al., 2015).

Collection of samples

We conducted all AMD field samplings during ten field surveys from December 2018 to February 2020. The temporal spacing between surveys was approximately one month and the field work was conducted in the rainy and dry seasons. In Ecuador the rainy season occurs during December – May, while the dry season is from June to November. To sample AMD items, we employed the methodology of "Litter Scientists" or "Científicos de la Basura" (www.cientificosdelabasura.cl), as described elsewhere (Thiel et al., 2011; Hidalgo-Ruz et al., 2018; Honorato-Zimmer et al., 2019). Briefly, four transects between 50 and 80 m apart were used perpendicular to the lowest tide line on the beach. The transect starts in the landward limit until the lowest point close to the seawater line. Each transect was divided into 6 stations with a 3 x 3 m quadrat (9 m^2). The number of stations (1-6) was deployed depending on the width of the beach. The center of each station was approximately 5 m apart from the center of the next station. The quadrant nearest to the landward beach limit was named station 6 (S6) and the station closest to the waterline was named station 1 (S1). Within the quadrants, all surface macro-litter from anthropogenic origin greater than 25 mm was collected by hand. The samples collected were taken to the Ecotoxicology lab at ESPOL Polytechnic School (Guayaquil) to be counted and classified following the methodology of "Litter Scientists."

Sample analysis

The AMD items were classified according to the following categories: plastic, paper, metal, glass, cigarette butts, and others. A metric tape measure was used as a reference to make a photographic record. After the acquisition of the photographic record (Figure 2), distinct types of AMD were counted and recorded on a datasheet to gather the information from each sampled location. Moreover, we calculated the size of AMD items from the photographic record using software ImageJ 1.8.0 (Schneider et al., 2012). By employing the measuring tape on each photo, we set out the scale in cm to estimate the longest size for each AMD item except for fishing ropes, and plastic bags. In addition, we compared the AMD abundance (items/m^2) in the beach cross section by grouping stations 1, 2, and 3 to represent the foreshore and stations 4. 5, and 6 to outline the backshore. Then, the average abundance for each section of the beach was determined.

Clean coast index

The Clean Coast Index (CCI) was calculated to evaluate the coast cleanliness, based on Alkalay et al. (2007).This approach measures the marine debris as a beach cleanliness factor, using the following equation (Alkalay et al., 2007):

$$CCI = \frac{\text{total AMD items}}{\text{Area}(m^2)} \times K \qquad \text{(Eq. 1)}$$

Where CCI is the number of the AMD collected in square meter (items/m^2), and K, is the coefficient that equals to 20. The CCI have a scale, classified as "very clean" (0-2), "clean" (2-5), "moderate" (5-10), "dirty" (10-20) and "extremely dirty" (>20).

Data treatment and statistical analysis

The density of AMD (items/m^2) was calculated and evaluated temporally among the three sandy beaches. Then, we compared the abundance of marine litter in terms of percentage (%) according to each type (i.e., glass, plastic, metal, paper, cigarette butts, and other residues). The statistical analysis was performed using RStudio 4.1.2 software for Windows (RStudio Team, 2020). The spatial data did not meet the normality criteria, so AMD abundance between the sampling sites and seasons was assessed for significance using a non-parametric test Kruskal-Wallis one-way analysis of variance and Wilcoxon test. For AMD size comparisons between sites and seasons, we also used the same non-parametric tests. The data set for AMD size were log10 transformed to account for the high variability of the values plotted in the figures and for display purposes. A significance level of 0.05 was used in all the tests.

A multiple regression model was determined for this study based on the AMD abundance considering the time effect in months and the effect of each site, as follows: $y = \mu + \tau + (MR)_j + \varepsilon_{ijk}$, when i = 1,2,3,j=1,…,10, and k = 1,2,3,4. The μ is the mean,

FIGURE 2
AMD collected from a single sampling quadrat on Delfin beach on Data de Posorja, Guayas (Ecuador).

τ_i is the effect of the different sites, $(MR)_j$ is the time effect in months and ε_{ijk} is the aleatory error of observations. Thus, the repeated measures analysis was applied to know the significance difference with AMD abundance in each site and months.

Results

AMD density

Marine litter was surveyed along the coasts on 3 different beaches of Data de Posorja during the rainy (December-May) and dry (June-November) seasons. The total number of items collected was 12,362. The maximum number of items by sites was 7,237 in Varadero, followed by Delfin with 4,388 and Bahia Muyuyo with 738. The average abundance of litter was 1.95 items/m^2 for all sites and sampling periods, ranging between 0 to 11.07 items/m^2. The density of the AMD according to each site follows the same order as the total number of items: Varadero having the maximum value with 3.35 items/m^2, was followed by Delfin and Bahia Muyuyo, each one with 2.16 and 0.34 items/m^2, respectively (Supplementary Table 1). AMD abundance presented a significant difference among the sites (Figure 3). AMD abundance for Bahia Muyuyo was significantly lower with respect to the other sites (P= 2.20x10^{-16}, H= 74.14), while Varadero and Delfin beaches showed no significant differences.

The cross-section analysis revealed that the backshore of Varadero and Delfin beaches accumulated on average 27.3 and 17.2 items/m^2, respectively. Bahia Muyuyo only showed 2.7 items/m^2 on average. Moreover, the results from repeated measures analysis showed that the AMD abundance in each study site presented a significance difference with respect to temporality in months and sites sampled (P=0.04, F=6.24).

Temporal AMD distribution

The average AMD abundance was compared by seasons. No significant differences were found between AMD abundance and seasons ($p > 0.05$). AMD abundance was higher during the dry season with 2.27 items/m^2 ranging from 0.07 to 6.89 items/m^2 than the AMD abundance observed in the rainy season (i.e., 1.63 items/m^2, ranging 0 —11.07 items/m^2). Varadero beach contributed with the highest abundance of AMD both in the rainy season with 2.46 items/m^2 and dry season with 4.24 items/m^2, with a maximum peak close to 8 items/m^2 in June 2019. Bahia Muyuyo site exhibited the lowest abundance of AMD both in the rainy season (0.45 items/m^2) and dry season (0.23 items/m^2) (Figures 4B, C).

AMD composition

The most abundant debris was plastics (i.e., fishing lines, bags, caps, and food packing containers) in the two seasons and on all sampled beaches, followed by other items (i.e., such as wood and cloth), as well as papers, metal, glass, and cigarette butts (Figure 5). The percentage of plastic accounted for 91.8% of the total AMD, while other items were 4.2% others (wood and

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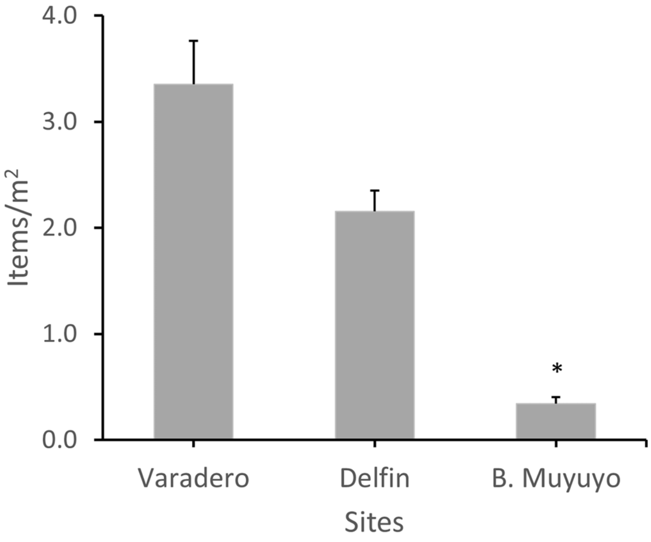

FIGURE 3
Average AMD abundance per monitored sites. Data was graphed as mean ± SE. Asterisk (*) indicates significant differences (Kruskal-Wallis test, p<0.05).

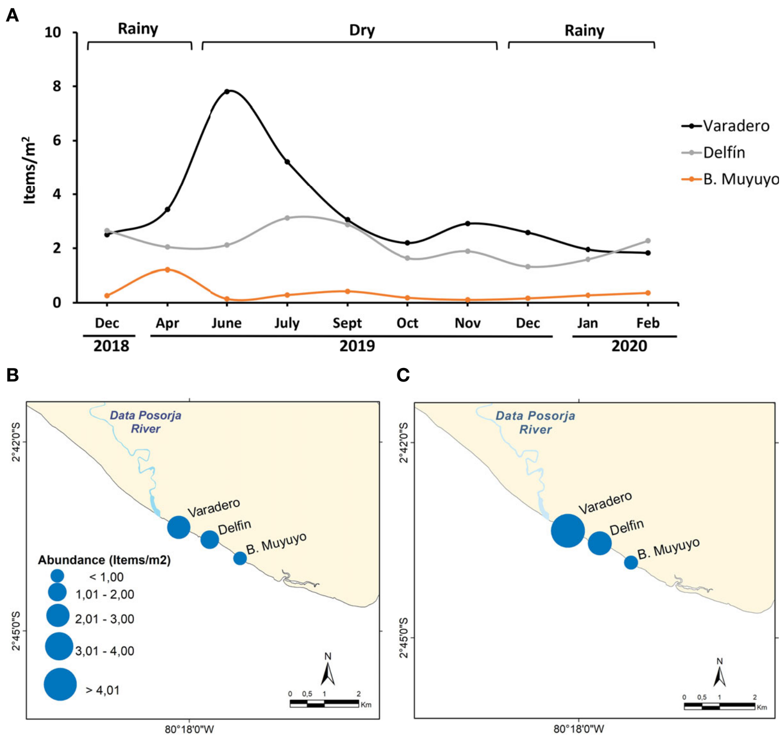

FIGURE 4
Changes in temporal AMD abundance on Data de Posorja, Guayas. **(A)** AMD abundance registered over the periods 2018, 2019 and 2020. **(B)** AMD distribution during rainy season, **(C)** AMD distribution during dry season. Size of blue points indicates the abundance (items/m^2).

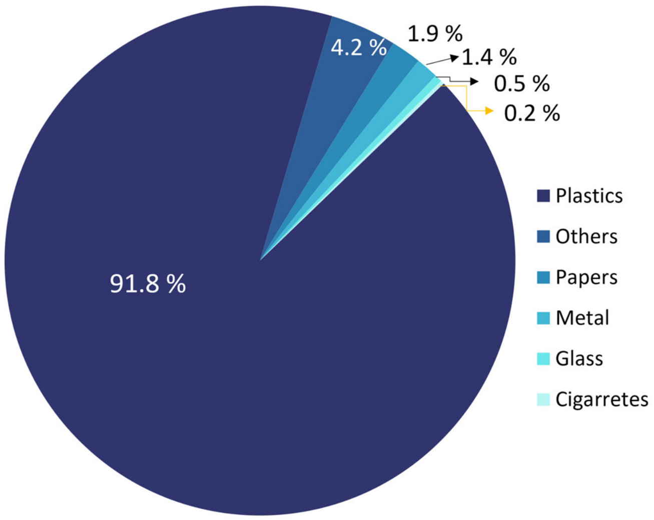

FIGURE 5
AMD types found in all samples on Data de Posorja, Guayas.

cloth), 1.9% papers, 1.4% metals, 0.5% glass and 0.2% cigarette butts. Delfin Beach showed the highest percentage of plastics (96.2%), followed by Bahía Muyuyo (93.2%), and Varadero (89.0%). The frequency of plastics in the rainy season (92.9%) was slightly higher than that in the dry season (90.9%). Plastic is the most common items in all the months (11,347) and the cigarette butts are the lowest (28) (Table 1).

AMD size frequency

The average of AMD size was 9.70 cm ranging from 2.50 to 142.80 cm (Supplementary Table 2). Bahia Muyuyo showed the highest average AMD size with 11.41 cm, followed by Delfin with 9.56 cm, and Varadero with 9.53 cm. AMD size frequency presented a significant difference among the sites ($P= 1.27x10^{-5}$, H= 22.55) (Figure 6A). AMD size for Bahia Muyuyo was significantly higher with respect to the other sites, while Varadero and Delfin beaches showed no significant differences. Most of the large items present in Bahia Muyuyo were plastic straps and processed wooden pieces. On the other hand, when AMD size was compared by seasons (Figure 4), we observed that AMD size average of dry season (9.91 cm) was slightly higher than AMD size average for the rainy season (9.52 cm). Significant differences were found between AMD size and seasons ($P= 5.41x10^{-3}$, $H= 2.72x10^{6}$) (Figure 6B).

Clean coast index

The CCI mean for the rainy season was 32.6, while in the dry season was 45.3. The CCI mean for each site was 67.0 for Varadero, 43.1 for Delfin, and 6.8 for Bahia Muyuyo. Varadero exhibited the highest CCI with 84.8 in the dry season and Bahia Muyuyo ranked with the lowest values of 4.6 in the dry season, as well. According to the CCI scale, Varadero

TABLE 1 Total AMD items of litter composition reported in a monthly basis on Data de Posorja, Guayas (Ecuador) from December 2018 to February 2020.

	2018	2019							2020		Total
	Dec	Apr	June	July	Sept	Oct	Nov	Dec	Jan	Feb	
Plastic	1112	1243	1835	1774	1013	857	954	838	791	930	11347
Others	11	129	281	30	6	2	25	10	12	11	517
Papers	18	47	30	19	80	7	14	7	7	7	236
Metal	21	16	10	28	2	1	65	11	9	13	176
Glass	8	4	12	9	2	1	2	12	4	4	58
Cigarette Butts	2	8	7	3	2	1	1	1	3	0	28

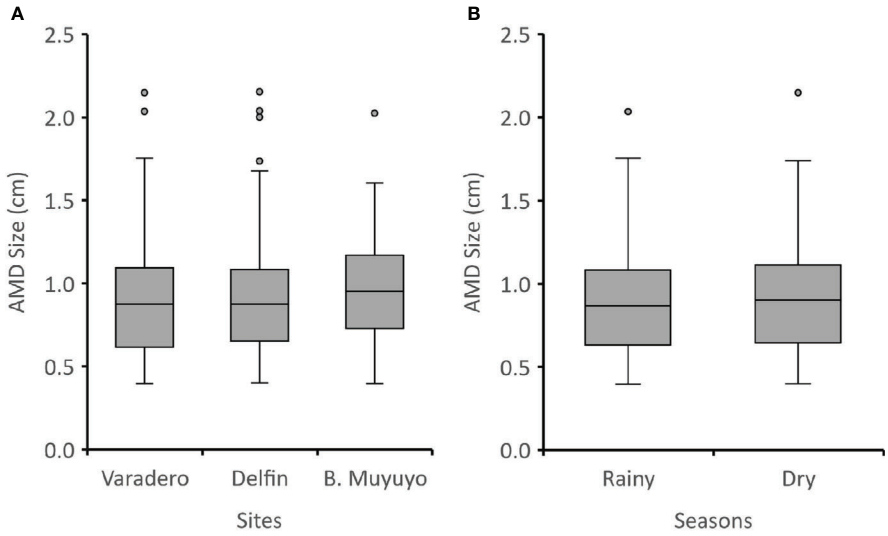

FIGURE 6
AMD size per sites **(A)** and seasons **(B)** on Data de Posorja, Guayas (Ecuador). Data was transformed using log10. Significant differences were observed among sites and seasons.

and Delfin beaches in the rainy and dry seasons are extremely dirty, while the degree of cleanliness in Bahia Muyuyo was moderate during the rainy season and clean in the dry season (Table 2).

Discussion

The overall average of AMD abundance (1.95 items/m^2) in all sampling sites of Guayas province was similar to the values of 1.80 items/m^2 determined by Bravo et al. (2009) and 2.2 items/m^2 reported by Honorato-Zimmer et al. (2019) on Chilean beaches, 1.51 items/m^2 by Laglbauer et al. (2014) on Slovenia, and 1.31 items/m^2 by Gaibor et al. (2020). on continental beaches of Ecuador. The AMD abundance data reported here are much higher than the maximum average observed on beaches of the Galapagos Islands (i.e., 0.27 items/m^2) by Jones et al. (2021), coastal sites in Spain with 0.06 items/m^2 (Asensio-Montesinos et al., 2020), and Mkomani beach in Kenya with 0.38 items/m^2 (Okuku et al., 2021). Conversely, AMD abundance for our study is lower than the litter reported on beaches receiving a large influx of tourists such as those in the Colombian Caribbean (Garcés-Ordóñez et al., 2020a) and India (Sulochanan et al., 2019).

The average AMD abundance found in Bahia Muyuyo was the lowest compared to the other two beaches. This result can be explained due to the fact that this site is a remote beach and is not touristic at all, contrasting to the other two beaches hosting a considerable tourist influx, especially during beach season (December-May) on this part of Ecuador. In addition, there are villages nearby zones around Varadero and Delfin beaches, which surpassed 10 items/m^2 in single sampling quadrats, being consistent within the same value as reported by Gaibor et al. (2020). The AMD densities of these two sandy beaches are also similar to the study of Honorato-Zimmer et al. (2019) on Chile. Even so, Varadero and Delfin showed a lower average of AMD abundance relative to other studies on tourist beaches (Sulochanan et al., 2019; Garcés-Ordóñez et al., 2020a). However, both sites have a higher average than other tourist beaches that are constantly cleaned because of their economic

TABLE 2 Clean Coast Index classification by seasons of studied beaches (Varadero, Delfin and Bahia de Muyuyo) from Data de Posorja, Guayas (Ecuador).

	Seasonal CCI		CCI classification	
	Rainy	Dry	Rainy	Dry
Varadero	49.3	84.8	Extremely dirty	Extremely dirty
Delfin	39.6	46.6	Extremely dirty	Extremely dirty
B. Muyuyo	9.1	4.6	Moderate	Clean

importance as in Seaflower Biosphere Reserve in Colombia (Portz et al., 2021), beaches of Galapagos Islands (Gaibor et al., 2020; Jones et al., 2021), and Rio de Janeiro in Brazil (Oigman-Pszczol and Creed, 2007).

The average of AMD density by season was higher than those observed in other studies (Santos et al., 2020; Suteja et al., 2021). These studies reported that the rainy season has AMD abundances higher than the dry season. While in our study, the average AMD of dry season was higher than the rainy season, especially in Varadero, Delfin and Bahia Muyuyo showed opposite seasonal trends. Our study showed a great AMD abundance during the months of April, June, and July of 2019 (Figure 4A). The month of April being the penultimate month of rains, while June and July are the first months of the dry season; thus, we may deduce that there is a greater AMD accumulation over these months because domestic litter is discharged onto rivers that transport solid waste into our study area located nearby the Gulf of Guayaquil. Furthermore, a vacation period (i.e., Easter and carnival holydays) coincides with the rainy season in the coastal region of Ecuador. Additionally, the monthly and seasonal fluctuations on AMD abundance may also well subject to the variability in oceanographic and meteorological/atmospheric conditions including currents (i.e., Humboldt and Panama/El Niño currents), plastics residence time floating on the ocean surface and tidal regimes (Gaibor et al., 2020), as well as onshore Stokes drift and winds influencing the spatial AMD abundance on beaches (Olivelli et al., 2020) such as those monitored in this study.

Plastic items were the most abundant AMD category according to the AMD composition assessed in our study (91.8%), which is consistent with AMD abundances reported in other studies (Asensio-Montesinos et al., 2019; Binetti et al., 2020; Abelouah et al., 2021; de Ramos et al., 2021). For instance, similar percentages were found on beaches of western Mediterranean with 93% (Haddad et al., 2021), 88.54% on the coast of Cádiz, Spain (Asensio-Montesinos et al., 2020), 86.9% on touristic beaches in the south of Bali Island, Indonesia (Suteja et al., 2021), and 84.6% on northeast beaches of India (Mugilarasan et al., 2021). Because of this significant percentage of plastic, we may conclude that rivers (e.g., Guayas River in the Gulf of Guayaquil) and fishing activities at sea mainly favor the accumulation of this type of AMD since fishing lines and nets were one of the most common items found in our study. Guayas is the second province harboring most of the population of artisanal fishers (17,643 individuals) (Arriaga and Martinez, 2002), and also in Posorja area (Guayas), there are two large industrial fishing companies (Tapia Arias et al., 2015). For instance, ocean plastics can remain more than 7 days in the oceanic environment and deposited on the coasts due to the currents (Gaibor et al., 2020). Secondary contributions of solid waste and plastics from local communities and urban/rural settlements surrounding these beaches cannot be ruled out.

The other types of AMD, including papers, metals, glass, and cigarettes butts were below 5%, although others category (i.e., clothing and wood) is the one that stands out the most with 4.2%. On the other hand, there were no cigarettes in all the samples from Bahia Muyuyo beach. This finding is consistent with another study where no cigarette butts were found on remote beaches from the Moroccan Mediterranean coast (Maziane et al., 2018). On other remote beaches, cigarette butts were observed in a few surveys (Kataržytė et al., 2020; Asensio-Montesinos et al., 2021). On the Ecuadorian village beaches surveyed here, the low number of cigarettes is similar to that reported in the same places assessed by Gaibor et al. (2020). Thus we may suggest that the Ecuadorian people do not smoke a lot because the smoking population represent 13.7% versus 25.9% in European countries (MSP et al., 2020; Gallus et al., 2021). In contrast, the percentage of papers and metal categories were slightly high in Varadero beach compared to the other two beaches, which may suggest that the beach users or local population throw this type of AMD directly on the beach. This finding is consistent with other studies reporting similar results (Honorato-Zimmer et al., 2019; Gaibor et al., 2020). In addition, there is no management of solid waste in the surrounding villages, which facilitates AMD accumulation on various places on the shore areas including sandy beaches. The rest of the AMD categories did not differ much, and AMD frequencies were also remarkably similar regarding the seasons.

The AMD size average estimated in our study was similar to other studies (Fazey and Ryan, 2016; Blanke et al., 2021). Besides, the AMD size was significantly related to sampling site and seasons. This may occur due to the effects of wave motion at the waterline, currents, and wind (Olivelli et al., 2020). Moreover, the remote beach (Bahia Muyuyo) exhibited large items than the village beaches; thus, our data suggests that the AMD found in Bahia Muyuyo may have a high buoyancy causing the items to disperse long distances, and accumulating the debris in the backshore when the wind cannot move it because of the weight (Fazey and Ryan, 2016; Olivelli et al., 2020; Andriolo et al., 2021).

Regarding with the CCI outcomes the beaches of Ecuador are dirtier than the beaches on the southern coast of Bali Island in both seasons (Suteja et al., 2021). When comparing with other studies, without a temporal study, the CCI values are similar to those reported in Mkomani beach, Kenya (Okuku et al., 2021), and some beaches in Slovenia (Laglbauer et al., 2014). In addition, a previous study by Mestanza et al. (2019) showed that most of the mainland beaches of Ecuador have a Grade C according to the EA/NALG, evidencing poor quality and high levels of litter.

While our field work and monitoring to assess AMD ended up by the onset of the lockdowns and socio-economic impacts associated to the COVID-19 pandemic in early 2020 (i.e., January and February), questions linger on changes in the temporal abundance and composition of AMD, mainly plastics (e.g., single-use plastics), and the massive usage of personal protection equipment (PPE) items used and discarded into the global ocean during the pandemic to prevent the COVID-19 transmission (Peng et al., 2021), following regional and international mandates by public health authorities.

As a general overview, the sampling sites influenced by the AMD abundance and size. The highest abundance of AMD occurred in the dry season at Varadero, also this beach was determined as the dirtiest possibly due to poor municipal solid waste management in the village. Plastic was the most common litter on all sites, and cigarettes were only present on village beaches. Moreover, large litter pieces related to fishing activities and single-use plastics were found in the remote beach. Therefore, our findings indicate that AMD has become a real coastal pollution stressor on the beaches of southern Ecuador as previously reported (Mestanza et al., 2019; Gaibor et al., 2020), and it is necessary to adopt concerted solid waste management strategies. A systematic, well-planned framework is recommended in conjunction with the municipalities and the local population for the appropriate management of solid waste, as well as policies, sanctions, local incentives and environmental education in schools and the community. As an example, Alpizar et al. (2020) developed an impact pathway framework to track the plastics flow through the socio-ecological system and identify the role of specific policy instruments and country-specific recommendations in achieving behavioral changes to reduce marine plastic waste for developing nations.

Of particular importance would be the assessment and monitoring of the temporal AMD abundance on other beaches in Ecuador for future studies. It is also essential to investigate the sources and the dynamics of AMD, as well as to identify factors related to AMD abundance such as oceanographic and atmospheric variables, topology, river influx, and urban agglomerations, among others. Finally, more research is essential to know the AMD abundance in other types of environments such as rivers, mangroves, or seafloor, and if there is evidence of impacts in marine organisms by AMD related to fishing gear used, discarded, or abandoned from small-scale (artisanal) and industrial fisheries activities in Ecuadorian waters.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

JS was responsible to writing the manuscript and analyzing data. RG wrote a section of the manuscript and field work. AN contributed to field work. PC and JA edited, provided insights for data analysis and reviewed the final version. GD conceived the study and conducted the project administration. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.977650/full#supplementary-material

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