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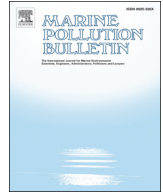
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Baseline

Composition, abundance and sources of anthropogenic marine debris on the beaches from Ecuador – A volunteer-supported study

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ABSTRACT

This study represents an inter-institutional effort that was supported by more than 400 volunteers. We sampled Anthropogenic Marine Debris (AMD) on 26 beaches, including one beach from Galapagos Islands. AMD was mainly composed of plastics (> 60%), followed by cigarette butts, paper and metal. Average AMD density on the continental beaches was 1.31 ± 1.03 items m^{-2} (mean \pm SD). AMD densities and the proportion of plastics were higher on some beaches located on the Gulf of Guayaquil, suggesting that many of the plastic items found on these beaches were, likely, drifted by the swift currents of the Guayas River. Additionally, the overall results indicate that most litter on continental beaches from Ecuador has local sources. Recommendations include marine pollution education and public awareness campaigns to reduce the consumption of plastic bags, as well as a ban on harmful single-use plastics.

Anthropogenic marine debris (AMD) is a growing problem in the world's oceans (Galgani et al., 2015; Ostle et al., 2019). Marine litter, primarily plastic pollution, can have serious and even deadly impacts on marine life (Kühn et al., 2015), as well as negative effects on human health and economy (Newman et al., 2015), and is therefore of great concern to citizens and decision-makers. Supported by the growing public awareness and based on available knowledge about the sources and causes of marine litter, mitigation strategies are being designed in many parts of the world (Hartley et al., 2018) to stop the ever-growing plastic pollution of the oceans.

High densities of marine plastic litter have been reported in the

open ocean, coastal waters, and on shorelines of the Pacific Ocean (Díaz-Torres et al., 2017). Studies from the North Pacific Ocean have documented diverse types and variable densities of AMD on sandy beaches, occasionally suggesting marine origins (Hong et al., 2014), but often pointing at beach visitors as sources of marine litter (Silva-Iñiguez and Fischer, 2003). With the exception of several studies from Chile (e.g. Hidalgo-Ruz et al., 2018; Honorato-Zimmer et al., 2019), little information about marine litter is available for the Central and Southern Pacific Ocean. Those studies from Chile suggested that beach visitors generate most AMD on beaches (Bravo et al., 2009; Hidalgo-Ruz et al., 2018). In the South-East Pacific, coastal upwelling conditions

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associated with the Humboldt Current System facilitate the offshore transport of floating marine debris, and consequently almost no AMD is reaching the continental beaches from sea-based sources (Thiel et al., 2018). A similar process occurs on the North-East Pacific coasts where upwelling currents keep sea-based debris from reaching the shores, resulting in a predominance of land-based debris on local beaches (Ribic et al., 2012). Given the complex coastal circulation in the central East Pacific (e.g. Collins et al., 2013), it can be expected that marine debris might accumulate in certain areas, but not in others. In particular, the Ecuador Coastal Current, which has a north-northeastward orientation (Collins et al., 2013), might concentrate sea-based AMD on southern beaches of Ecuador.

For the central East Pacific, information about marine litter is limited. One study from northern-central Ecuador (1°S) had shown that most marine debris trapped on subtidal reefs were plastic items originating from fishing activities (Figueroa-Pico et al., 2016). A more extensive study on beaches from continental Ecuador and Galapagos suggested that a large proportion of this litter is coming from beach users (Mestanza et al., 2019). While that study provided important first hints that debris pollution is a serious problem in Ecuador, it focused on the less densely populated Northern provinces. Furthermore, estimates are presented as general cleanliness grades (four categories) and no numerical data on the densities and composition of AMD are provided.

In the present study, we quantified AMD densities on 26 Ecuadorian beaches and classified the main litter types in order to allow for a wider comparison with other studies from the region and from other areas of the world. The specific objectives were to (i) estimate AMD densities, (ii) determine the composition of AMD, and (iii) infer the sources of AMD on Ecuadorian beaches, based on the first two objectives.

This study represents a joint effort among governmental, academic and non-governmental organizations from Ecuador (for institutions, see Table 1). A coordination team was responsible for the selection of study beaches, the public invitation to participate, the training of volunteers, and their supervision in the field. All members of the coordination team participated in a training workshop in September 2018, where they learned the sampling method, and had the opportunity to apply and explore the benefits and shortcomings of this method in comparison to other marine litter sampling protocols.

More than 400 volunteers participated in this baseline study, distributed across the different beaches (Table 1). For the sampling of each beach, a member of the coordination team introduced the corresponding volunteer participants to the marine litter problem as well as to the sampling methodology several days before performing the research activity in the field. The samplings were conducted on 25 continental beaches, covering the northern, central and southern zones of the Ecuadorian coast, and one beach in Galapagos. Sampling was done between October and December 2018, corresponding to the dry season in continental Ecuador.

The protocol employed by Ecuadorian institutions is based on the methodology developed by the citizen science program “Científicos de la Basura” (“Litter Scientists”; www.cientificosdelabasura.cl) and previously applied on Chilean, but also on Peruvian and German beaches (Thiel et al., 2011; Hidalgo-Ruz et al., 2018; Honorato-Zimmer et al., 2019). Transects were established on each beach, extending from the waterline to the upper edge of the beach (e.g. the base of dunes, a road, or a promenade). Along each transect, volunteers marked between four and six sampling stations, and at each station they established a 3 m × 3 m (9 m²) quadrat. The width of the beach determined the number of stations per transect. There were six stations on wider beaches whereas the number of transect stations was reduced to four on narrower beaches (for details see e.g. Honorato-Zimmer et al., 2019), on most of the 26 studied beaches we sampled four or more transects, and the minimum number of transects was two (see also Table S1).

Within each 9 m² quadrat, macro litter items (≥ 25 mm) were collected from the beach surface, and classified and quantified into the following categories: plastics, papers, metal, glass, cigarette butts, and others. At the end of the sampling process, a member of the coordination team checked the data sheets, entered all the data into a single spread sheet, and finally sent the file to the central data management person. All sampled AMD was taken from the beach and deposited either in recycling or litter bins.

To compare AMD composition along the sampled beaches the main litter categories were evaluated using an agglomerative nesting analysis (hierarchical cluster) with Euclidean distances, in terms of percentage (%) of the total AMD per beach. In addition, a Principal Component Analysis (PCA) was performed to describe each of the groups found in the cluster. The density of litter (items m⁻²) was calculated and evaluated to obtain comparable measures of the magnitude of this problem on different sandy beaches of the coast of Ecuador. Statistical computing and graphics were done using the R 3.6.0 software.

Litter was found on all sampled beaches, but the density (items m⁻²) of AMD was highly variable along the continental coast of Ecuador (Fig. 1). A total of 288 (40.6%) of all 710 sampling quadrats had no AMD. The two mainland beaches with the highest percentage of sampling quadrats without AMD were Los Frailes (84%) and Playa Bahía Muyuyo (79%), which are located in a marine protected area and in a very remote area, respectively. The only sampled beach in Galapagos also had a high percentage of sampling quadrats without AMD (82%). Beaches with high AMD densities were mostly found in the southern parts of the study area (with the exception of the northernmost beach Las Palmas). Highest densities in single sampling quadrats (above 10 items m⁻²) were found on beaches of the Gulf of Guayaquil (Playa Delfín, Playa Varadero, Anconcito, Isla Puná, La Diábrica; Fig. 1). The national average of AMD densities for continental beaches was 1.31 ± 1.03 items m⁻² (mean ± SD).

Plastics were among the most common litter items (food containers,

Table 1

Institutions and numbers of volunteers participating in the first national sampling of anthropogenic marine debris (AMD) on sandy beaches of Ecuador.

Institution	No. of participants	No. of beaches	Sampled beaches*
Instituto Nacional de Pesca (INP)	34	3	Salinas (STE), Jambelí (EOR), Puerto Engabao (GYE)
Instituto Oceanográfico de la Armada (INOCAR)	301	13	Las Palmas (ESM), Atacames (ESM), Murciélago (MAN), Jaramijó (MAN), San Mateo (MAN), Punta Carnero (STE), La Lobería (STE), Santa Rosa (STE), Anconcito (STE), Chipipe (STE), Valdivia (STE), Montañita (STE), Isla Puná (GYE)
Mingas por el Mar	11	1	Km 7.5 Playas-Data (GYE)
Universidad Península de Santa Elena (UPSE)	61	3	La Diábrica (STE), San Pablo (STE), Ballenita (STE)
Escuela Superior Politécnica del Litoral (ESPOL)	15	3	Playa Delfín (GYE), Playa Bahía Muyuyo (GYE), Playa Varadero (GYE)
Ecology Project International (EPI)	35	1	Tortuga Bay (GPS)
Universidad de Guayaquil (UG)	20	2	Los Frailes (MAN), General Villamil (GYE)
Total	477	26	

* The Ecuadorian provinces where the beaches are located are indicated with their official abbreviations as follows: (ESM) Esmeraldas; (MAN) Manabí; (STE) Santa Elena; (GYE) Guayas; (EOR) El Oro, (GPS) Galápagos.

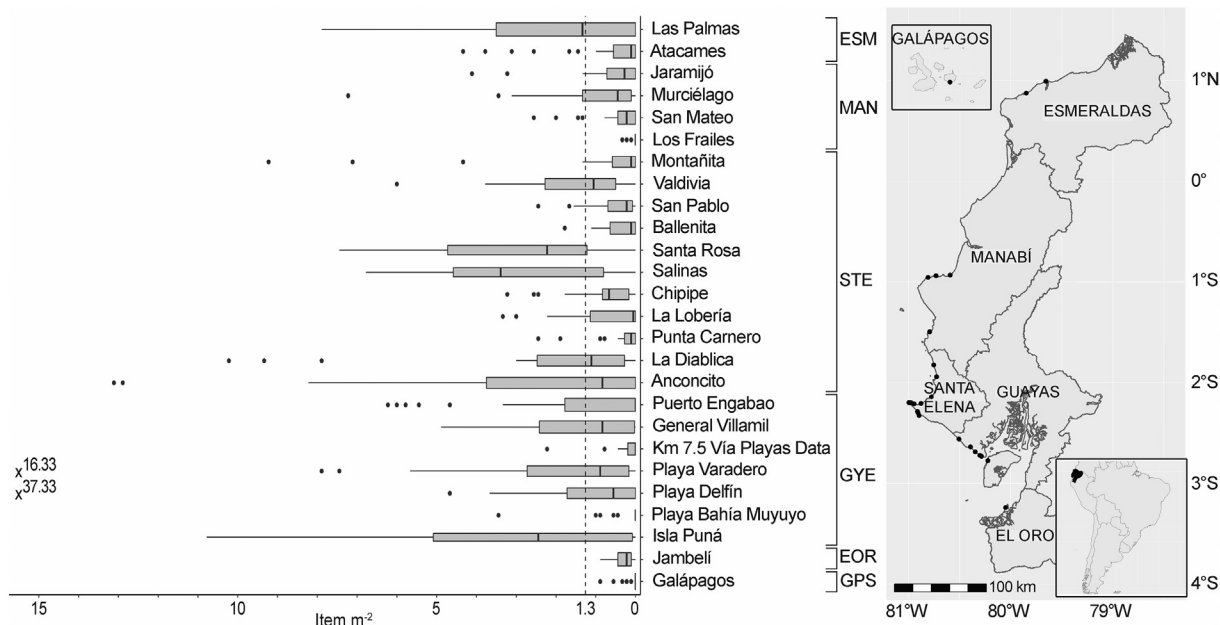


Fig. 1. Densities (items m^{-2}) of anthropogenic marine debris (AMD) on Ecuadorian sandy beaches in 2018; boxes show the first and third quartiles, lines in the boxes show the medians, horizontal lines show the highest and lowest observations, and dots represent outliers; x shows two values outside of the scale of the figure. The right-hand map shows the Ecuadorian provinces and black dots represent the sampled beaches. ESM, Province of Esmeraldas; MAN, Province of Manabí; STE, Province of Santa Elena; GYE, Province of Guayas; EOR, Province of El Oro; GPS, Province of Galápagos.

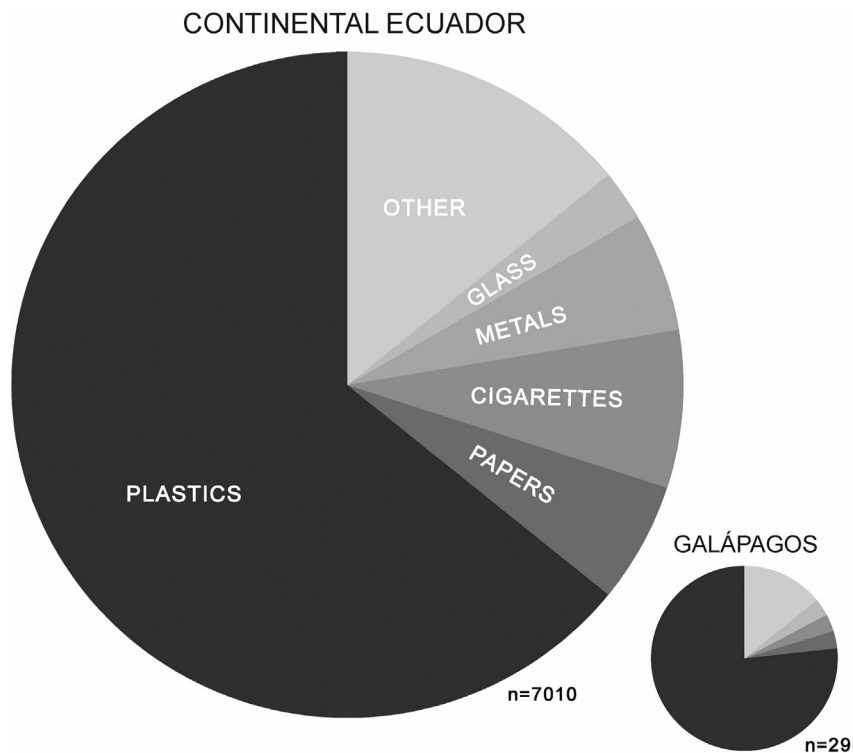


Fig. 2. Percentage of types of anthropogenic marine debris (AMD) found on the 26 sandy beaches sampled along the coastal zone of continental Ecuador and Galapagos; n = total number of items collected and classified.

fishing lines, straws and plastics bags) on all sampled beaches, followed by others (wood, coal), cigarette butts, papers, metals and glass (Fig. 2). On the beach in Galapagos, the proportion of plastics was slightly higher (75.9%) than on continental beaches (64.8%). Along the continental coast, there is a tendency of higher proportions of plastics towards the southern beaches (Fig. 3). Some of the northern beaches also had high proportions of cigarette butts (up to 44%), paper (up to 13%),

or metal (14%). On several of the southern beaches no cigarette butts or metal were found (Fig. 3).

The hierarchical cluster analysis revealed two major groups of beaches with AMD along the coast of Ecuador. One more heterogeneous cluster (light gray shadings) is characterized by high percentages of metal, papers, cigarette butts and low percentages of plastics, while the more homogeneous cluster (darker gray) unites the beaches with high

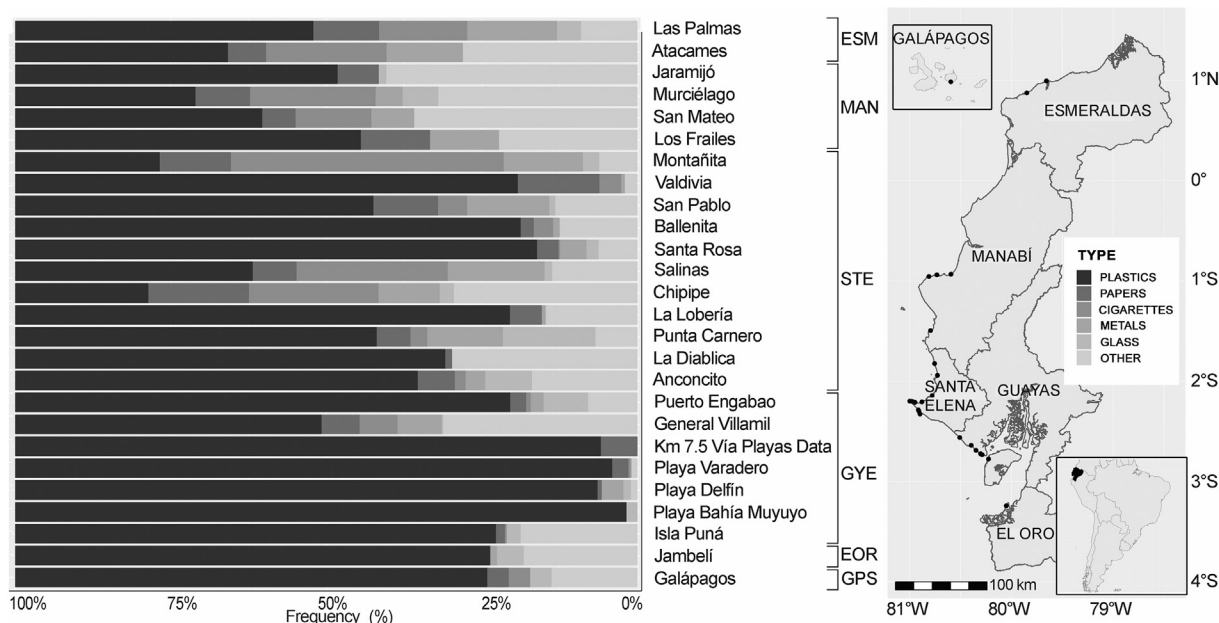


Fig. 3. Proportions of different types of anthropogenic marine debris (AMD) on Ecuadorian sandy beaches in 2018.

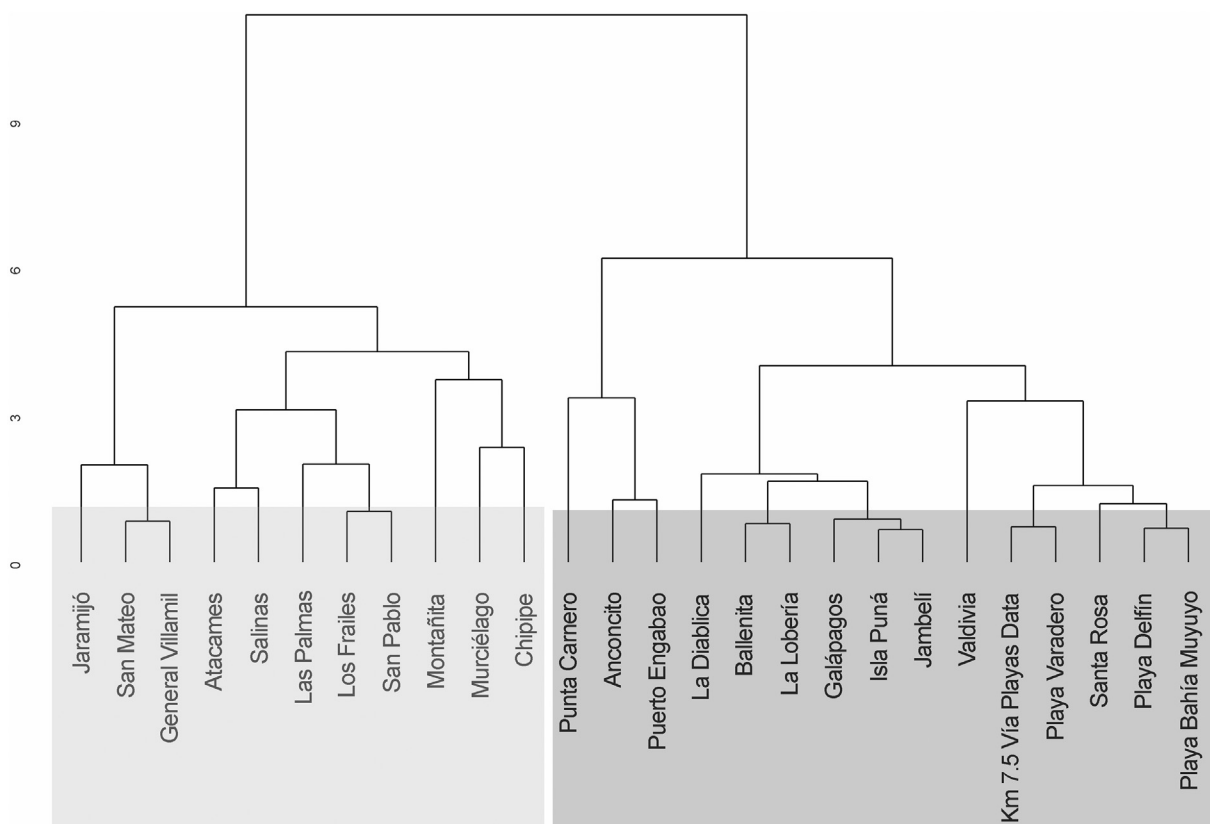


Fig. 4. Multivariate cluster analysis based on coefficients of similarity comparing percentages of anthropogenic marine debris (AMD) per type (plastic, paper, cigarette butts, metal, glass, others) along the continental coast of Ecuador and Galapagos.

percentages of plastics and few other items (Fig. 4). These findings by the hierarchical cluster analysis are strongly supported by the Principal Component Analysis (PCA), where beaches dominated by plastics and those dominated by papers, cigarette butts and metals are visibly differentiated (Fig. S1). There is a clear geographical stratification among the different beaches. Northern beaches tend to have more items belonging to local sources and beach users. The beach from Galapagos

groups within the second cluster with no difference with southern continental beaches.

The densities of AMD on the beaches of Ecuador were variable, but highest densities were observed on central and southern beaches. Plastics dominated on most beaches, but the frequent observation of paper, metal, glass, and cigarette butts suggests that much litter comes from local sources and beach users, because these items are unlikely to

contributed a large percentage of the observed plastics (personal observation of all coauthors).

CRedit authorship contribution statement

Nikita Gaibor: Conceptualization, Project administration, Writing - original draft, Validation. **Verónica Condo-Espinel:** Writing - original draft, Formal analysis, Validation. **María Herminia Cornejo-Rodríguez:** Formal analysis, Validation. **Jodie J. Darquea:** Writing - review & editing, Formal analysis, Validation. **Beatriz Pernia:** Formal analysis, Validation. **Gustavo A. Domínguez:** Writing - review & editing, Formal analysis, Validation. **María Esther Briz:** Writing - review & editing, Formal analysis, Validation. **Lady Márquez:** Writing - review & editing, Formal analysis, Validation. **Enrique Laaz:** Writing - review & editing, Formal analysis, Validation. **Carlos Alemán-Dyer:** Data curation, Formal analysis, Validation. **Ulises Avendaño:** Writing - review & editing, Formal analysis, Validation. **Johanna Guerrero:** Writing - review & editing, Formal analysis, Validation. **Mercy Preciado:** Writing - review & editing, Formal analysis, Validation. **Daniela Honorato-Zimmer:** Methodology, Writing - original draft, Validation. **Martin Thiel:** Methodology, Writing - original draft, Validation.

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

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2020.111068>.

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