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Characterization of Seafloor Marine Litter Distribution in a Shipping Route of Ancon Bay

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Marine litter on the seafloor has been increasing for several decades. Moreover, shipping routes and fishing ports are considered as affected areas with benthic macro-litter distribution. In Peru, the available information about benthic litter is limited and only originates from cleaning campaigns. Therefore, this study aimed to conduct the first scientific report about benthic macro-litter occurrence and composition distributed in a shipping route of Ancon Bay. For this purpose, a remotely operated vehicle (ROV) was used to evaluate the marine litter composition and distribution at depths between 1 and 25 m. A total of 8.8 h of video transects were recorded, and 46 litter items were identified, where plastic represented 80.4%; and industry food and single-use bags were the most frequent items. Plastic fragments and food industry bags dominated areas closer to San Francisco Grande mud sandy beach and the anchorage zone, respectively, while non-plastic items were more common in front of rocky shores. The present work emphasizes the importance of the studies about benthic marine debris for better decision-making regarding litter management. It also highlighted the usefulness of low-cost ROVs in identifying different litter items in shallow areas.

Keywords: ROV, marine litter, Ancon Bay, shallow soft bottom, video survey, shipping route.

Introduction

Marine debris or marine litter is any human-made persistent, disposable solid thing abandoned or discarded into the ocean usually after use (NOAA, 2021). Generally, the global abundance of litter in the marine environment (surface and water column), seafloor, and beaches has increased since the 1960s (Galgani et al., 2015). However, litter distribution in these environments is highly variable and depends on several factors such as shore use, hydrodynamic aspects, and maritime activities (Bergmann et al., 2015).

The most common pathways of litter input to oceans are established based on their sources of origin. On the one hand, land-based sources (from land to ocean) are associated with river discharges, coastal population, beach tourism, and agricultural activities, as well as natural phenomena (tsunamis, hurricanes, and storms) (Barnes et al., 2009; Garcés-Ordóñez et al.,, 2020; Koutsodendris et al. 2008; Rech et al., 2014; Thiel et al., 2013). On the other hand, sea-based sources (from ocean to ocean) are more attributed to activities such as aquaculture, oil extraction, fishing, shipping, and tourism (Dixon and Dixon, 1983; Hinojosa and Thiel, 2009; Scott, 1972; Sheavly and Register, 2007; UNESCO, 1994).

Marine debris on beaches is more commonly studied by researchers because of its accessibility, ease of assessment and source identification, and aesthetics (McGranahan et al., 2007). Moreover, some relevant patterns have been clearly established. For instance, marine debris mostly originates from land-based sources on beaches with a larger population density, and the type of shore seems to affect the accumulation processes of different kinds of litter items (Bergmann et al., 2015; Moore et al., 2001). In contrast, research on benthic litter has been much less developed than those on sea surfaces or shores despite the potentially adverse impact of litter accumulation on habitats, organisms, and human health (Bergmann et al., 2015). Moreover, factors such as operational costs, technology, sampling methods, and inaccessibility limit most research to continental shelves (Miyake et al., 2011).

Traditionally, diving and bottom trawling have been used as sampling methods to assess marine debris on shallow and deep seafloor, respectively (Spengler and Costa, 2008). In comparison, remotely operated vehicles (ROVs) have been introduced for investigating deep-sea litter since 1996. However, the first litter recordings from ROVs might have come from 1982 (Galgani et al., 1996; Miyake et al., 2011). Since then, ROVs have demonstrated their potential, effectiveness, and usefulness in studying marine litter in shallow and deep areas (Miyake et al., 2011; Pham et al., 2014; Watters et al., 2010). Recently, the use of ROVs has increased because of the continued manufacturing cost reductions, new presentations (e.g., mini and small ROVs), and increased placement of sensors on these vehicles (Brun, 2012).

Thus far, research on benthic litter in the Southern Hemisphere has been overlooked (Figueroa-Pico et al., 2016; Thiel et al., 2011). Particularly, in the southeast (SE) Pacific Ocean, previous studies have focused on micro-litter and macro-litter composition and distribution in the sea surface and beaches of continents and islands (Eriksen et al., 2013; Hidalgo-Ruz and Thiel, 2013; Hinojosa et al., 2011; Purca and Henostroza, 2017; Thiel et al., 2003). The first evaluation of marine debris on the seafloor in the SE Pacific Ocean was that of Figueroa-Pico et al. (2016), who studied seafloor marine debris along the coast of Ecuador by visual diving sampling.

Although pollution brought about by seafloor marine litter is an evident global threat, only a few initiatives have been developed to solve this problem along the Peruvian coast. Among these are the cleaning seafloor campaigns led by the Ministry of Production, the Ministry of Environment, and fishers' communities. These campaigns focus on main artisanal ports and marine protected areas and record the removed volume of litter. However, they do not identify the types of marine litter. Another important initiative named *HAZla por tu playa* leads annual campaigns to clean only beaches. Despite of this, they provide important data about different types of marine litter that could enter the seafloor (Sociedad Peruana de Derecho Ambiental, 2019). Because of the limitations of each initiative, however, the current spatial distribution, composition, and accumulation rates of marine debris within benthic marine ecosystems are unknown along the Peruvian sea.

Thus, this study aims to identify and characterize marine benthic macro-litter in a shipping route in Ancon Bay, Peru, by using a ROV. To our best knowledge, this would be the first effort to characterize in situ marine debris in the Peruvian seafloor.

Methods

The study was conducted in the southern area of Ancon Bay, Lima, between December 2020 and April 2021. The study area is characterized by sandy and rocky shores and soft bottoms extending up to 30 m deep, the maximum bathymetric extension of the bay. An artisanal port is located in the middle of the bay, and apartments surround almost the entire coast as coastal urbanization expands (*Fig. 1*). During the summer season, frequent recreational (e.g., boating, sunbathing, and walking) and sports activities (e.g., swimming, windsurfing, and paddling) attract more than 10 000 people to the bay (Austermühle, 2010).

A video survey was performed in 16 stations distributed along the main shipping route towards fishing grounds. There is a gap information about shipping routes of small fishing and recreational boats into Ancon Bay. Therefore, the routes were identified during the research using a GPS in artisanal fishing vessels, and visual inspection. A ROV *BlueROV2*® was used at depths between 1.4 and 23.6 m to assess litter occurrence on the seafloor. This ROV had a depth sensor and compass that allowed it to record information from the bottom. Within each station, one or two transects of video recording were taken to seek marine litter. The number of transects and the recording time depended on the ocean current and visibility conditions (*Table 1*). All marine debris was first identified in each transect through real-time visual inspection and then corroborated through video analysis (Goodman et al., 2020). Conducting more visual transects between San Francisco Chico and the artisanal fishing port was impossible because these areas are anchorages for recreational vessels, and the abundance of ropes in these areas limited the ROV operation (*Fig. 1*).

Litter items were categorized on the basis of Morales-Caselles et al. (2021) and the LITTERBASE database classification (Alfred-Wegener-Institut, 2021) to follow global classifications of marine debris types. The first classification was used to categorize plastic types according to their shapes. Additionally, the origin of the litter items was inferred following the United Nations Environment Programme (UNEP, 2005) and Morales-Caselles et al. (2021). The bottom type and epifaunal organisms associated with the bottom were also recorded. The bottom substrate was described according to the Wentworth grain size classification (Wentworth, 1992), whereas the epifaunal organisms on the bottom were identified up to the lowest possible taxon (Consoli et al., 2018). Finally, concentration of debris items was standardized by transect and recording time to compare relative concentration between the sampling stations.

It is important to mention that the use of the ROV for

Fig. 1. *Location of the study area in Ancon Bay and distribution of sampling stations along the shipping routes. The symbols used are indicated on the map.*

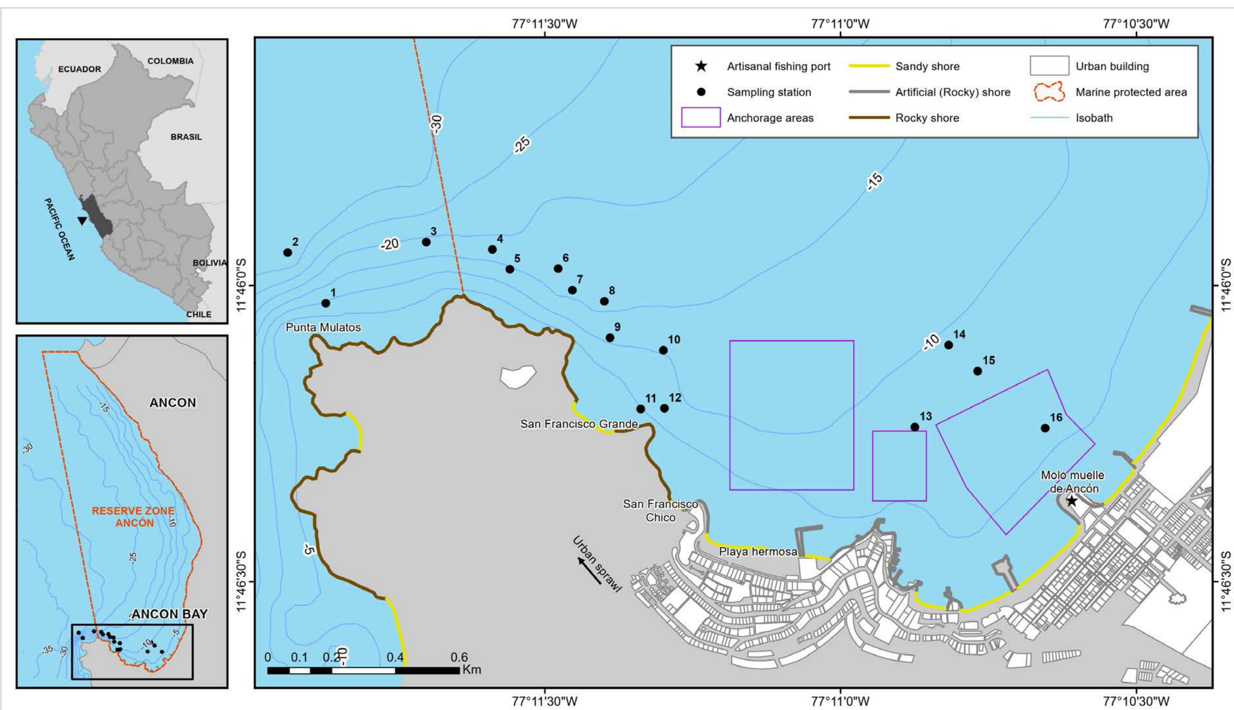


Table 1. *Characteristics of each ROV exploration at the 16 stations distributed along the shipping routes in Ancon Bay*

Station	Number of transects	Average time (min)	Substrate	Surrounding macrofauna
1	1	12.2	Mud	None
2	1	33.8	Mud	*Nassarius* sp.
3	1	23.2	Sand	*Nassarius* sp.
4	1	16.8	Sandy mud	*Nassarius* sp.
5	1	6.6	Mud	None
6	1	8.9	Mud	*Ulva lactuca* *Polysiphonia sp.* *Nassarius* sp.
7	2	27.1	Mud/ Sandy mud	Ulva lactuca *Polysiphonia sp.* *Nassarius* sp. Ophiuroidea
8	1	23.7	Sandy mud	None
9	1	16.8	Sandy mud	*Nassarius* sp.
10	2	36.6	Sand/ Sandy mud	Ulva lactuca *Polysiphonia sp.*
11	1	27	Sand	Ulva lactuca *Polysiphonia sp.* Ophiuroidea
12	1	18	Sandy mud	None
13	1	32.4	Mud	None
14	2	30.4	Mud/ Sandy mud	*Nassarius* sp.
15	2	22.4	Sandy mud	Ulva lactuca *Polysiphonia sp.* Ophiuroidea
16	2	15.3	Sand	Ophiuroidea

litter identification and classification could, however, be limited by a lack of real perception of size dimensions and material type, and therefore, it is a potential limitation of this study. To decrease the uncertainty of identification and dimension, discourses of local people were taken into account regarding the use of different materials during their sailings, and items identified were compared with those collected during the last cleaning campaign (*Table 4*).

Results and Discussion

The bottom areas comprised mainly sandy mud, where the snail *Nassarius* sp. and the fragile seastar Ophiuroidea were the most common epifaunal organisms surrounding the areas where debris was found. These species are common in hypoxic soft bottoms (Tarazona, Arntz, and Canahuire, 1996). Furthermore, fragments of the algae *Ulva* sp. and *Polysiphonia sp.* were the most frequent drifting matter on the seafloor (*Table 1*). The estimation of abundance of surrounding macrofauna was not the part of the research scope. However, the identified taxa could be further discussed in future investigations, focusing in the relationship between marine debris, associated fauna, and its impacts on it, or the selection of biological indicators.

A total of 46 litter items were observed from the 8.8 h of effective video records. Artificial polymers (plastic) represented the highest proportion of debris (80.4%), followed by processed wood (8.7%) and glass and ceramics (4.4%) following the classification of Morales-Caselles et al. (2021) (*Table 2*). The remaining item categories each had one litter item, each representing 2.2% of the total. Similar results were shown for the categories of the LITTERBASE classification. Items made of plastic were the most abundant (76.1%, considering the *plastic* and *fisheries (plastic)* categories), followed by timber (8.7%), glass/ceramics (4.4%), and each of the other categories left (2.3% each) (*Table 2*). These results are greater than those reported by Morales-Caselles et al. (2021) in their analysis of macro-litter on the nearshore seafloor (< 100-m depth) at a global scale, where plastics and metals represented 64.3% and 13.5% of the total, respectively. Our findings were also greater than those in the LITTERBASE database. The LITTERBASE analysis found that plastic items (considering both the *plastic* and *fisheries (plastic)* categories) represented 65.5% of the total number of litter items at a global scale, followed by the fisheries category, which involved all items related to fishing activities, except plastic and metal (9.1%). Nonetheless, it should be noted that their analysis considered all depth ranges. Thus, these reported proportions could differ in shallow environments, as reported by Morales-Caselles et al. (2021) (13.0% higher in deeper bottoms). Plastic predominance on the seafloor at depths between 0 and 98 m has also been reported, with plastic proportions ranging between 47% and 95% (Consoli et al., 2018; Figueroa-Pico et al., 2016; Ioakeimidis et al., 2015; Kuriyama et al., 2003; Sánchez et al., 2013; Zhou et al., 2011). This supports the notion that plastic is a common and predominant contaminant in marine environments. However, the differences in the reported proportions of several types of material debris are associated with the different categories used to classify them, the methods applied to assess the litter, the bottom type, and the proximity to human activity (Barnes et al., 2009; Madricardo et al., 2020; Spengler and Costa, 2008). All these factors must be considered when comparing material debris, and global frameworks are useful for more standardized contrasts.

Regarding litter origins and following Morales-Caselles et al. (2021), only recognizable litter items (no fragments) were considered for origin classification. From this, industrial or household (66.7%) and take-out consumer (30.3%) items dominated the study area. In addition, we inferred that 75.8% of the litter items came from marine activities such as fishing and shipping (sea-based sources), whereas 24.2% originated from land (land-based sources) (*Table 3*). Morales-Caselles et al. (2021) reported a global predominance of take-out consumer items (greater than 53.6% on the nearshore seafloor), whereas the Latin American and Caribbean (LAC) region showed results similar to that of the global pattern (> 57.7%). In both cases, industrial and household items presented lower proportions (< 3%). Nowadays, the classic reported global proportion of 80% land-based / 20% sea-based sources of marine debris has lost acceptance and even credibility among researchers (Gilardi et al., 2020; Jambeck et al., 2015; Morales-Caselles et al., 2021). Moreover, the determination of debris sources can be subjective and even challenging (Cunningham and Wilson, 2003; Lee et al., 2006). In this work, the origins of litter items were inferred according to their characteristics and reported uses. For instance, metal

Table 2. *Percentage of occurrence, categories, and plastic types of marine litter items on the seafloor found along the shipping route in Ancon Bay*

<table>
<tr><th>Item types</th><th>Occurrence</th><th>Proportion (%)</th><th>Classification following Morales-Caselles et al. (2018)</th><th>%</th><th>Classification following LITTER-BASE</th><th>%</th><th>Plastic type</th><th>%</th></tr>
<tr><td>Food industry bags (PP bags)</td><td>16</td><td>34.8</td><td rowspan="8">Artificial polymers (plastic)</td><td rowspan="8">80.4</td><td>Fisheries (plastic)</td><td>34.8</td><td rowspan="3">Film</td><td rowspan="3">83.8</td></tr>
<tr><td>Bags</td><td>4</td><td>8.7</td><td rowspan="5">Plastic</td><td rowspan="5">41.3</td></tr>
<tr><td>Soft plastic fragments (> 1 mm)</td><td>11</td><td>23.9</td></tr>
<tr><td>Bottles</td><td>2</td><td>4.3</td><td rowspan="4">Rigid</td><td rowspan="4">13.5</td></tr>
<tr><td>Hard plastic pieces (2.5–50 cm)</td><td>1</td><td>2.2</td></tr>
<tr><td>Cutlery and trays</td><td>1</td><td>2.2</td></tr>
<tr><td>Food containers</td><td>1</td><td>2.2</td><td>Styrofoam</td><td>2.2</td></tr>
<tr><td>Synthetic rope</td><td>1</td><td>2.2</td><td>Rope</td><td>2.2</td><td>Line</td><td>2.7</td></tr>
<tr><td>Wood (processed)</td><td>4</td><td>8.7</td><td>Processed wood</td><td>8.7</td><td>Timber</td><td>8.7</td><td></td><td></td></tr>
<tr><td>Glass bottles incl. pieces</td><td>2</td><td>4.3</td><td>Glass and ceramics</td><td>4.3</td><td>Glass/ceramics</td><td>4.3</td><td></td><td></td></tr>
<tr><td>Middle size metal containers</td><td>1</td><td>2.2</td><td>Metal</td><td>2.2</td><td>Fisheries (metal)</td><td>2.2</td><td></td><td></td></tr>
<tr><td>Sacking (hessian)</td><td>1</td><td>2.2</td><td>Cloth and textiles</td><td>2.2</td><td>Textiles/fabrics</td><td>2.2</td><td></td><td></td></tr>
<tr><td>Others</td><td>1</td><td>2.2</td><td>Others</td><td>2.2</td><td>Biotic</td><td>2.2</td><td></td><td></td></tr>
</table>

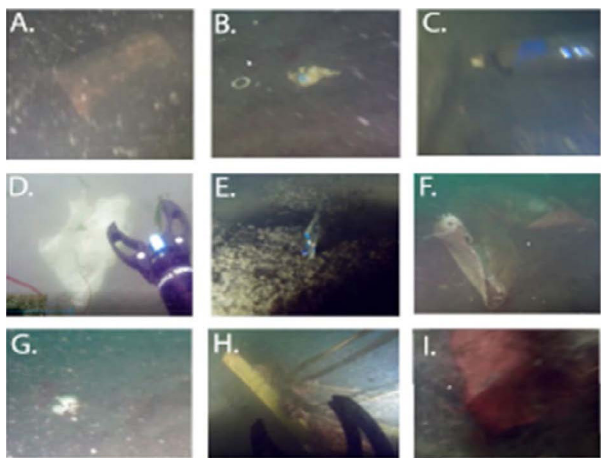
Table 3. *Proportions of marine litter items on the seafloor according to origin distributed along the shipping routes in Ancon Bay*

Item types	Classification following Morales-Caselles et al. (2018)	%	Classification following UNEP (2002)	%
Food industry bags (PP bags)	Industrial and household	66.7	Sea-based	75.8
Sacking (hessian)				
Food containers				
Wood (processed)				
Middle size metal containers				
Synthetic rope	Ocean and waterway	3.0		
Glass bottles incl. pieces	Take-out consumer	30.3		
Bottles			Land-based	24.2
Hard plastic pieces (2.5–50 cm)				
Cutlery and trays				
Bags				
Soft plastic fragments (> 1 mm)				
Others				

containers and glass bottles do not float long distances; therefore, they were probably discarded during maritime activities (Botero et al., 2020; Koutsodendris et al., 2008). Processed wood pieces are also commonly reported on sea bottoms but in low proportions, and they could sink easily depending on their quality. However, the highest proportion of sea-based items comprised polypropylene (PP) bags, which is discussed in detail below. Notably, the classification of Morales-Caselles et al. (2021) showed ocean and waterway items as the second most predominant across environments (22%, mean). However, limitations in their classification system are found when the retrieved industrial items came from maritime activities, as is reported for all items mentioned earlier, except for glass bottles (*Fig. 2*).

Film-type plastics, such as bags (including recognizable fragments), were the most prevalent items on the seafloor (72.1%), as has been reported in various studies (Goodman et al., 2020; Maes et al., 2018; Morales-Caselles et al., 2021). Interestingly, only PP bags (51.6%) and single-use bags (48.4%) were found in the current investigation (*Table 2*). These PP bags usually come from the flour industry and are commonly reused to package ice for fishing trips and shellfish transportation when fish boxes are unavailable (personal communication of fisherman, 30/07/2021). Although PP is positively buoyant in seawater, final products can be compounded by different components that modify the density of the

Fig. 2. *Seafloor debris litter in the southern area of Ancon Bay, Lima, Peru. A) Processed wood, depth 9.5 m.; B) plastic bottle, depth 19.6 m.; C) glass bottle, depth 12 m.; D) plastic bag, depth 1.5 m.; E) plastic fragments (> 1 mm), depth 12 m.; F) polypropylene bag, depth 6.6 m.; G) styrofoam cup, depth 18.6 m.; H) processed wood, depth 9.5 m.; I) polypropylene bag, depth 18.1 m.*



virgin material (Bergmann et al., 2015). Furthermore, most of the two bag types were seen partially buried or filled with sand, showing their high capacity to sink and be ballasted by sediments. Plastic bags seem to be more persistent on the sea bottoms of LAC than they are in other regions (Morales-Caselles et al., 2021). Although policies curtailing the use of single-use plastic bags have increased worldwide since 1991 (particularly in LAC since 2017), these are insufficient because current trends indicate that the entry of land-based plastic litter alone into the oceans would keep increasing by 2025 (Jambeck et al., 2015; Xanthos and Walker, 2017). Additionally, the present work highlights the worrying disposal of debris unrelated to fishing gears, such as these PP bags, which have also been seen in other Peruvian coasts (personal observation of the first author).

Some patterns about the debris distribution were evidenced along the coastline of the study area (*Fig. 3*). The highest concentrations of benthic debris, mainly plastic fragments and food industry bags (PP bags), were found close to San Francisco Grande beach (SFG) and the anchorage for artisanal fishing boats. Diverse non-plastic items were found between SFG and Punta Mulatos (PM) in front of rocky shores. Interestingly, fewer items were found from the bay to westward (*Fig. 2*). The relatively high concentrations of single-use plastics close to SFG could be associated with both shoreline and nearshore water inputs to the nearshore seafloor, with beach tourism activity being the probable main source, followed by fishery and recreational vessels (Botero et al., 2020; Morales-Caselles et al., 2021). In contrast, important fractions of fishing-related debris items are known to

Fig. 3. *Distribution of marine debris found on the bottom along the coastline of the southern area of Ancon Bay. The relative size of the pie charts indicates the mean number of items per transect in each station. The symbols and color scale used are indicated on the map.*

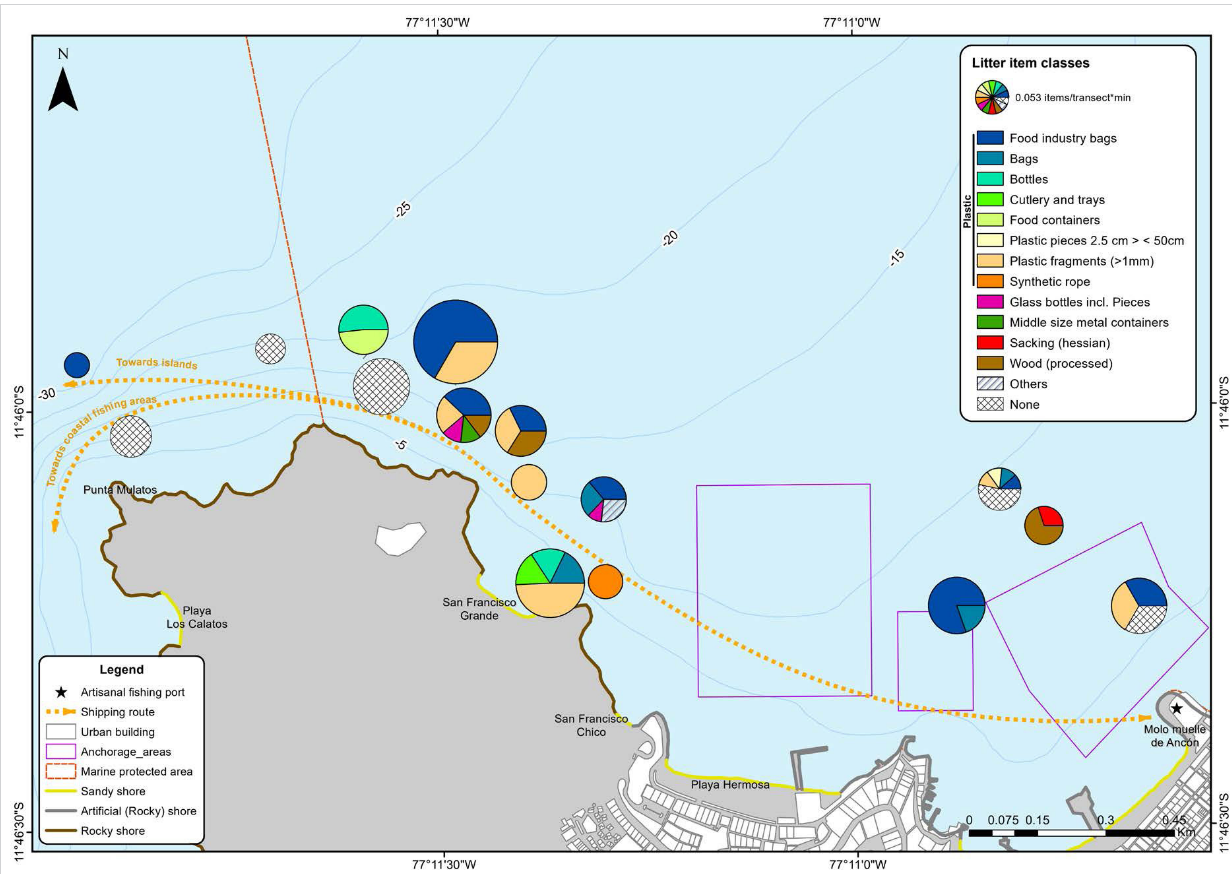


Table 4. *List of seafloor cleaning campaigns conducted in Ancon Bay*

Organization	Marine litter removed (Tm)	Litter material	Composition (kg)	Year	Reference
Association of artisanal divers and The Production Ministry (PRODUCE)	3	Not evaluated	Not evaluated	2019	Ministry of Production
Association of artisanal fishers and The Production Ministry (PRODUCE)	1.7	Artificial polymers (plastic)	709.9	2021	This study
		Metal	503.4		
		Rubber	361.8		
		Cloth and textiles	82.8		
		Wood	48.0		
		Glass and ceramics	0.5		

occur close to fishing ports (Barnes et al., 2009; Gilardi et al., 2020; Kanehiro et al., 1995). In the study area, both fishery and recreational vessels could be the main sources of marine litter between SFG and PM because these coastal areas are currently inaccessible for tourists. In addition, mobile debris could be transported by upwelling process and currents to these inaccessible areas. Nevertheless, benthic litter transportation dynamics are still unknown and would require further research.

Finally, as the aim of this study was limited to evaluate the composition and distribution of benthic debris over the seafloor by using a ROV, undetectable litter items and their abundances may have been underestimated. Nevertheless, plastic and fishery-related debris clearly dominated the bottoms of Ancon Bay, and this is in accordance with what has been found in the last cleaning campaign in Ancon Bay (*Table 4*).

Conclusions

Based on all these findings, this study indicated the dominance of plastic material along the shipping route in Ancon Bay for first time and the persistence of debris items related to maritime activities, such as fishing, tourism and navigation. Furthermore, this investigation underscored the need to go beyond annual cleaning campaigns since marine debris was found further away than the fishing port. It also stressed the need to enhance the basic knowledge on marine debris on the seafloor, such as its distribution and hotspots, to come to sound decisions about debris management in the context of a global circular economy. Finally, although ROVs have limitations in detecting buried debris, they were effective in generating information on the current distribution and predominance of benthic litter in Ancon Bay. Thus, their use could be promoted for this type of study in other polluted areas.

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