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Baseline

Protected areas in the Atlantic facing the hazards of micro-plastic pollution: First diagnosis of three islands in the Canary Current

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ABSTRACT

Coastal zones and the biosphere as a whole show signs of cumulative degradation due to the use and disposal of plastics. To better understand the manifestation of plastic pollution in the Atlantic Ocean, we partnered with local communities to determine the concentrations of micro-plastics in 125 beaches on three islands in the Canary Current: Lanzarote, La Graciosa, and Fuerteventura. We found that, in spite of being located in highly-protected natural areas, all beaches in our study area are exceedingly vulnerable to micro-plastic pollution, with pollution levels reaching concentrations greater than 100 g of plastic in 1 l of sediment. This paper contributes to ongoing efforts to develop solutions to plastic pollution by addressing the questions: (i) Where does this pollution come from?; (ii) How much plastic pollution is in the world's oceans and coastal zones?; (iii) What are the consequences for the biosphere?; and (iv) What are possible solutions?

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Coastal zones are the most productive regions in the world, both biologically and economically, but they are also highly vulnerable, and the most densely-populated by our societies. Following the MARPOL Convention, signed in 1973, many national and transnational efforts have sought to better understand and regulate marine pollution. These efforts have led to tangible outcomes in the forms of improvements in environmental culture and national and international agreements, including: the MARPOL Protocol from 1978; the most recent communication from the European Commission to the Council and the European Parliament; the European Economic and Social Committee's work with the Committee of Regional Cooperation on marine pollution after 2007; and the United States' public law 109-449-dec. 22, 2006 "to help identify, determine sources of, assess, reduce, and prevent marine debris and its adverse impacts on the marine environment and navigation safety." These legislative efforts reflect societal awareness of open-ocean and coastal pollution. However, despite growing awareness of the mounting plastic pollution problem, plastics continue to be produced, consumed, and discarded at an increasing rate. This is problematic for the biosphere for a number of reasons. For example, wildlife can be physically harmed by plastics, which in turn negatively impacts biodiversity (Rochman et al., 2013). Another concern is that plastics can absorb and transport chemical pollutants, or can be toxic in and of themselves. Because of this, they serve as a proxy for chemical pollution, which has demonstrably crossed the boundary within which humanity can operate safely (Rockström et al., 2009). Transgressing a planetary boundary means we have entered into a time of high uncertainty, where abrupt global environmental change can no longer be unexpected (Rockström et al., 2009). With plastic pollution piling up, it seems that we are quickly approaching the planetary limit for plastics, if it has not already been surpassed.

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Concerted efforts to change the current inertias of plastic consumption, recycling, and pollution must continue. Such efforts must also include productive collaborations with concerned communities to answer four key questions:

(i) Where does this pollution come from?
(ii) How much plastic pollution is in the world's oceans and coastal zones?
(iii) What are the consequences for the biosphere?
(iv) What are possible solutions to the problem of plastic pollution in marine environments?

Our work in the Canary Islands addresses these questions by creating dialogue between local stakeholders and the scientific community, and by focusing on a specific component of the problem: micro-plastics. We chose micro-plastic pollution because it is a wide-spread problem and because the local populations and administrations working with us are struggling to confront it. The first step of this collaborative project was to determine the extent of micro-plastic pollution in the study area, in order to evaluate the magnitude of the problem, identify the most vulnerable sites, and establish baseline data for future actions.

Our study area included three of the Canary Islands in the Canary Current, located off the northwestern coast of Africa in the Atlantic Ocean. The studied islands were: Lanzarote, La Graciosa, and Fuerteventura, which share the same volcanic shelf (Fig. 1). They belong to the same national and regional governments, but have distinct local administrations. This area contains many well-preserved and protected natural areas, including: national parks, natural parks, marine protected areas, and Natura-2000 areas. It also contains two distinct UNESCO Biosphere Reserves.

The islands are relatively rural. In 2012, Lanzarote and La Graciosa had a combined population of 138,364 residents and Fuerteventura had 103,423 residents. However, they experience a tremendous influx of tourists every year: in 2012, Lanzarote and La Graciosa had 839,290 visitors and Fuerteventura had 296,907 (National Statistics Institute, *www.ine.es*).

The study area supports a fragile eco-systemic equilibrium, which includes the following flora and fauna: over 40 species of endemic plants; more than 350 species of terrestrial invertebrates, 15 of which are endemic and exclusive to the study area; numerous marine birds and raptors, four species of which are in danger of extinction; one species of terrestrial mammal, *Crocidura canariensis*; 304 species of macroalgae and one phanerogam in the marine environment, the greatest example of biodiversity in the Canary Islands; 20 threatened marine invertebrates, classified through a combination designations from the ICONA and Catalog of Threatened Species of the Canary Islands (2001); four species of marine reptiles threatened by extinction: *Caretta caretta, Eretmochelys imbricate, Chelonia mydas*, and *Dermochelys coriacea;* and nine species of marine mammals, five species of which are in danger of extinction.

Unfortunately, the extensive protections for this area are not sufficient to prevent plastic pollution from threatening the ecology of its coasts and its larger ecosystem. The plastic pollution we found here largely originates inland, from sources ranging from local urban areas to urban areas in other countries, where it is typically transported to the ocean by water runoff and wind. In addition to land-based pollution, plastics also reach the ocean through sea-based industrial activity and unregulated or illegal trash dumping from shipping activity (Whiting, 1998; Lewis et al., 2003; Edyvane et al., 2004; Ng and Obbard, 2006). The Canary Current brings this pollution from the open Atlantic Ocean to the Canary Islands and deposits it on their shores.

This article presents the first published research results from a longitudinal project that began at the end of 2008, and will continue to 2020. The project focuses on Atlantic coastal zones, beginning with the Canary Islands, and its main goal is to develop common solutions to the ecological issues threatening these areas while working collaboratively with coastal communities and keeping their values at the core of the project. The problem of plastic pollution in this region was identified as the team's research priority for three reasons: (1) it reflects the extreme fragility of planetary equilibrium; (2) it represents the evident risks threatening preservation and development in the area; and (3) of identified critical concerns, the issue of plastics drew the most support from stakeholders and citizens associated with the project. Within the larger issue of plastic pollution, the initial research of this project focused on determining the extent of micro-plastic pollution in the area. Both macro- and micro-plastics are the main visible pollutants in the study area.

For this study, we define micro-plastic as a piece of plastic with at least two of its three dimensions less than 5 mm. Such criteria are applied in order to quantify the plastic that cannot be cleaned

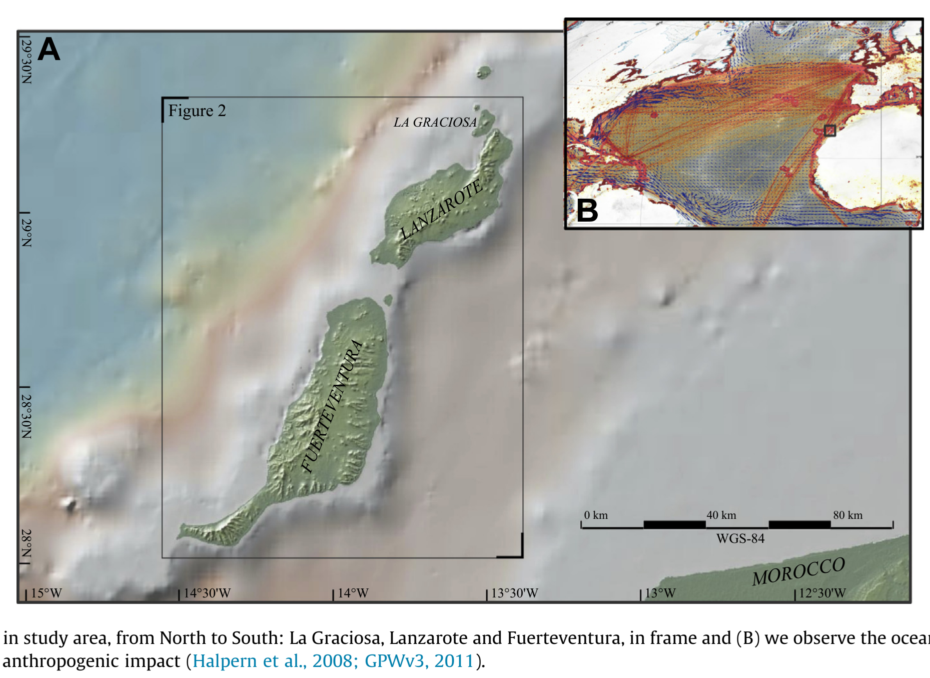


Fig. 1. (A) The three islands in study area, from North to South: La Graciosa, Lanzarote and Fuerteventura, in frame and (B) we observe the oceanographic conditions and the Atlantic regional context of anthropogenic impact (Halpern et al., 2008; GPWv3, 2011).

by hand through coastal cleaning programs and, therefore, remains in the natural system. Our choice of <5 mm is in agreement with the size used by the U.S. National Oceanic and Atmospheric Administration (NOAA) for the Marine Debris Program. The advantage of using this size limit is that it allows pellets to be included in the sampling criteria. In an optimal fieldwork situation, we could imagine characterizing all of the plastics from each sample based on their possible original source, buoyancy, size, and plastic-type. On the 125 studied beaches, the plastics deposited by the tides are mostly in small pieces of already degraded plastic, which is why the 5 mm criteria from NOAA was helpful for us, and why we used it for the sampling.

We designed this research as a first step to better understand and address the micro-plastic pollution problem in these highly protected areas. We expect this work will provide valuable insight into determining the origins of this pollution, and that it will also offer a starting point for stakeholders, and society more broadly, to develop community-centered initiatives to reduce or even eliminate plastic pollution in coastal zones.

This study focuses on three of the Canary Islands: Lanzarote, La Graciosa, and Fuerteventura. Sand samples were collected from every single sandy beach on each island in the study area. A total of 125 beaches were sampled, and 194 samples were collected: 71 samples from 58 beaches on Lanzarote; 35 samples from 23 beaches on La Graciosa; and 88 samples from 44 beaches on Fuerteventura (Fig. 2). All of the sandy beaches were sampled; the rocky shorelines do not have the geomorphological conditions for micro-plastic deposition. While we found macro-plastics on the rocky shores, we did not find micro-plastics because sand and micro-plastics are not deposited in these areas due to their geomorphological profiles and the high energy of the waves when they collide with the rocks along the coast in these areas.

Selected pictures and all tables used for this paper are under creative commons Cc-By-Sa license, and available by e-mail request.

The methodology for this study was developed to achieve three objectives:

(i) Collect baseline data on micro-plastic pollution to establish a preliminary evaluation of the conditions of the beaches on these highly protected islands.
(ii) Establish a standard sampling methodology so collected data can be compared with data from beaches around the Atlantic Ocean and other coastal areas, and thereby contribute to solving the increasing plastic pollution problem on the Earth's coasts; and
(iii) Present communities with a simple and affordable method for sampling micro-plastics on beaches, with the aim of "providing" stakeholders and institutions that may have limited resources and expertise the means to monitor sensitive areas, track changes occurring on the coast, and assess the impact of implemented environmental actions.

The methodology was calibrated in the middle section of Famara Beach, located on the northern shore of the island of Lanzarote, in a sandy area of 140 m (Fig. 3) that is heavily used by tourists and recreationists. We collected samples from the high tide line, but specifically avoided the "highest high tide" or "spring tide" line that occurred during the sampling period. We also did not collect samples on the storm line, as the "highest high tide" and storm lines are areas where several generations of trash could accumulate. We sampled on the "lower high tide" line as an initial approach to determine the amount of plastic that remains in the ocean's inter-tidal zone after the "highest high tide," and excluded the abnormal concentrations of multi-generational accumulation lines. Using these criteria, a sample was collected every 10 m to calibrate the sampling methodology (Figs. 3 and 4).

For each sample, we collected subsurface sediment from an area of 0.25 m^2 that was crossed by the sampled high tide line (Fig. 4A). We sampled the sub-surface sediment at a depth of no more than 1 cm, because we only wanted to sample micro-plastics that had been deposited by the most recent tide, which can be found in the uppermost section of the sedimentary cover. At this sample volume, the sediment of our study area primarily consisted of sand, along with natural organic materials and plastics. To analyze a sample, we first transferred it into a five-liter tub and added water. The plastic fragments in the sample floated to the top of the water, enabling us to separate them from the rest of the sampled materials and remove them from the tub manually with a skimmer. Once removed, the plastics were labeled with their corresponding sample point and saved for further analysis (Fig. 4B).

Each sample was dried and any organic material was separated from the plastic. The plastic was then weighed and the following information was entered into a standard format text file that could be easily read by "Quantum GIS" – the Open Source Geographic Information System used in this study: sample name, geographical coordinate position, beach orientation, and sample weight. The plastic fragments from each sample were then visually analyzed in order to determine their potential origins and to separate out pellets from the rest of the fragments (Fig. 5).

Once the tide timing and the sampling methodology were calibrated, the next step was to conduct the sampling on each beach of the three study islands. Our sampling on Fuerteventura (Fv), Lanzarote (Lz), and La Graciosa (LG) demonstrated that the length of the beach and the variability of the deposits on the tide line are the main parameters to consider for sampling. Concerning the tide, during the field work period of January 10 – January 26, 2013, the highest tide was the night of the 12th and the night of the 13th, when the tide was a little higher than 1.5 m from the point-of-reference tide gauge's measure of 0 at the port in Arrecife (Fig. 3). We did not collect samples along the tide lines left by these two highest high tides in order to avoid measuring the unrepresentative accumulation of plastics deposited on the highest high tide line (Fig. 3B).

The period of sampling was determined based on the optimal meteorological conditions: the lowest wind probability for any period during the year. Our study is the first step in a longer research project, and serves as a baseline diagnosis in order to identify crisis areas and prepare an action plan that will require several sampling periods throughout the year in order to monitor the most vulnerable beaches.

In this section we provide the results from the samples we collected from the high tide lines of each beach on the three islands in the study. We will also present information on the vulnerability of these coastal areas, and suggest potential explanations for the presence or absence of micro-plastics on beaches in our study area.

On the island of Fuerteventura, we did not find substantial accumulation of micro-plastics on its rocky beaches. Similarly, we did not find much micro-plastic accumulation on its sandy beaches, which have no available space to collect debris during high tide. To illustrate this, we have the example of the beaches on "La Pared," located on the northern shore of the Jandía peninsula. This area has three pocket beaches and a large sandy beach. The four beaches have a general orientation of 320° north. They share both azimuth and sedimentary characteristics, and have the same type of very well-sorted fine sand. Working from north to south, we did not find any plastic on the first two beaches we sampled. However, at high tide these beaches were completely submerged and we observed macro-plastics floating in the water. These plastics remained in the inter-tidal water column because there was not sufficient space available for them to be deposited onshore. The next two sample sites were separated by a small rock pit of no more than 5 m during high tide, and connected at low tide. Here

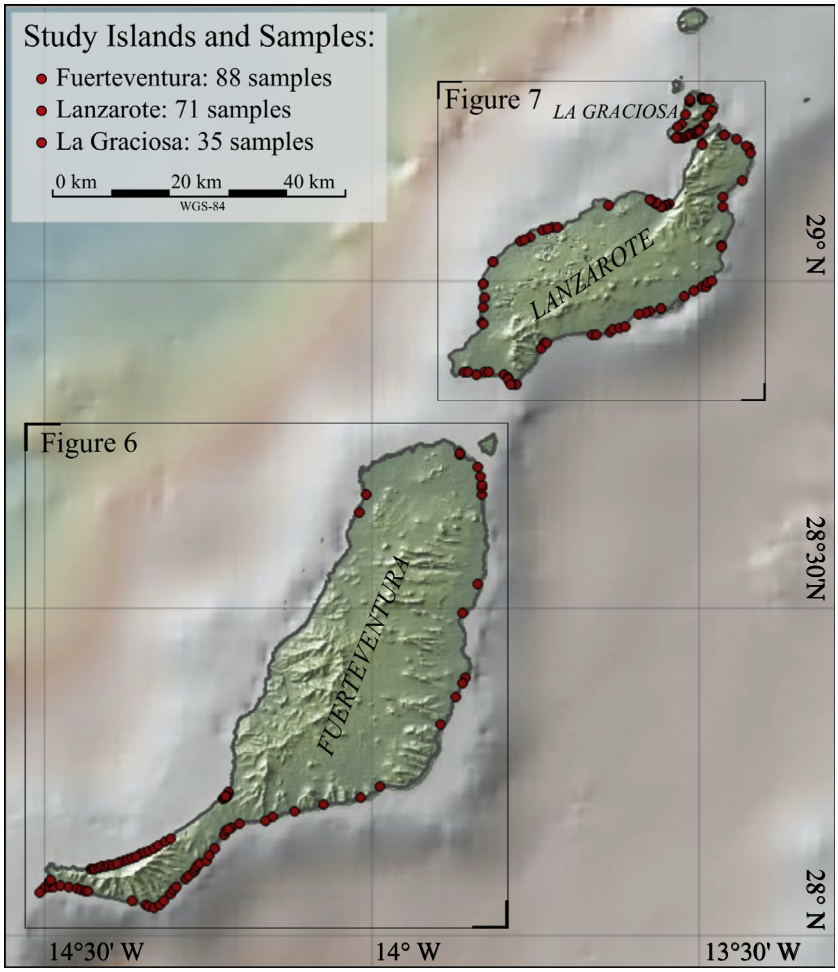


Fig. 2. Three study islands with the distribution of the 125 sampled beaches and the location of Figs. 6 and 7.

plastic was found in an average concentration of 15 g/l. The higher concentration of plastic is explained simply by the availability of space for it to be deposited on these beaches at high tide. This observation allows us to:

(i) Establish a criterion to identify beaches that could potentially be polluted by micro-plastics and those that are not as likely to be at risk, and
(ii) Underline the fact that the absence of plastics on beaches does not mean that plastics are not in the water column, and consequentially, able to spread throughout the biosphere.

Ultimately, these findings indicate that the assessment of micro-plastic pollution on beaches can be only done on beaches with enough available space at high tide for debris to be deposited.

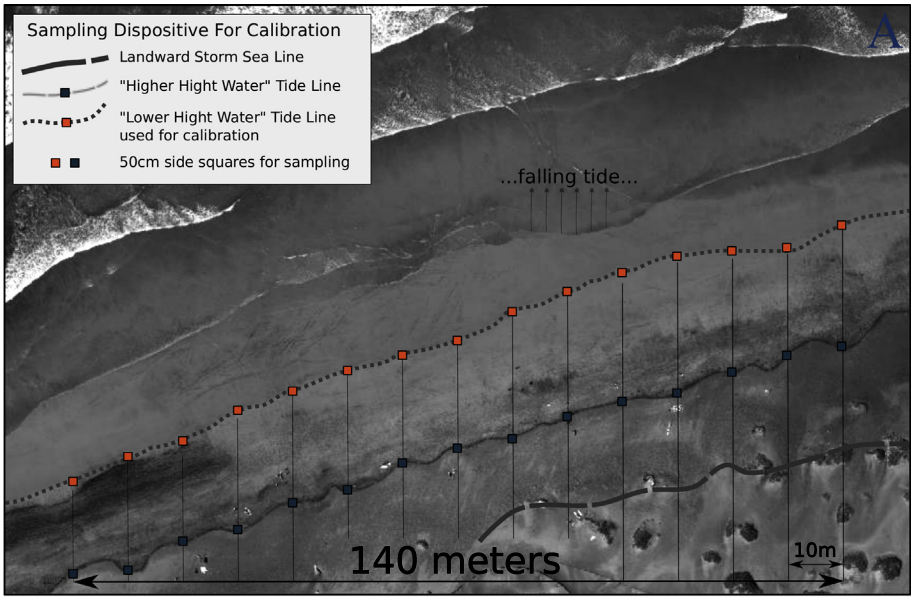
All sampled beaches confirm this finding. Of sites on Fuerteventura with space available for disposition, the micro-plastic concentrations reached a maximum of 30 g/l on the high tide line. This maximum value was found south of "La Pared" on the Barlovento Beaches. These are sandy beaches of northwestern orientation, with an average azimuth of 340°, located in the center of the Natural Park of Jandía and the Biosphere Reserve of Fuerteventura. They consist of more than 13 km of sandy beaches and the small village of Cofete. The Barlovento Beaches are the best example of high-vulnerability beaches on Fuerteventura. All of the Barlovento Beaches had extremely polluted storm lines, with substantial amounts of deposited macro- and micro-plastics.

This observation raises a point concerning the correlation of the orientation of beaches and their vulnerability to micro-plastic pollution (Fig. 6). Our samples clearly show a link between micro-plastic pollution, available sandy deposition space, and beach azimuth.

The most touristic places on Fuerteventura, including the areas with the highest concentrations of illegal resorts, are found on the island's east side. While micro-plastics were found in low concentrations here, other pollution was observed. One of the most evident pollutants was cigarette butts, which are only present on beaches people visit frequently. Due to their low buoyancy and lack of durability, cigarette butts dropped on shore are not resilient enough to be transported by natural vectors along the coast or across oceans. This highlights a concern that can be solved by the local population and foreign visitors who leave cigarette butts on the beaches and surrounding areas.

Samples from the study islands of Lanzarote and La Graciosa confirm the results from Fuerteventura, and also offer some variations and complementary facts. We confirm that for the sampling period, plastic transport is determined by the ocean surface currents related to the theory of Ekman transport, as we explain in the Discussion and Conclusion section below.

Northerly winds bring the majority of micro-plastics to these beautiful places, with concentrations in some areas reaching more than 100 g/l, such as we found in the middle section of Famara Beach (Lz), a sandy beach that is 3 km long. Even on small, well-protected beaches like Caleta Caballo (Lz), we found micro-plastic concentrations of more than 20 g/l. One disappointing surprise was finding high concentrations of micro-plastics on beaches with



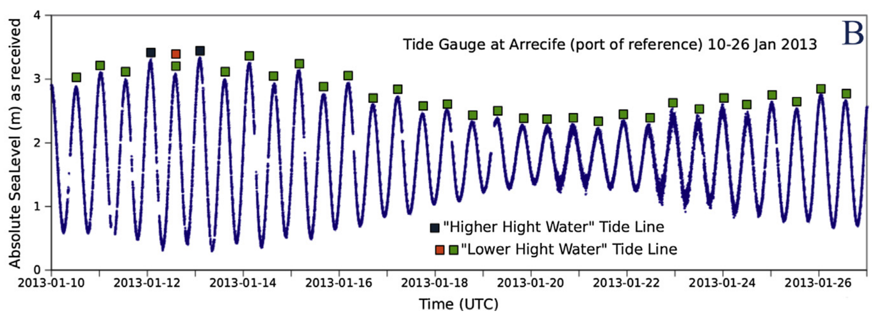


Fig. 3. (A) Sampling calibration and (B) tides at point-of-reference gauge during field work period of 10/01/2013–26/01/2013. Note that blue squares are on the "highest high tide" line and red and green ones on the "lower high tide" lines; the red squares show the calibration for experiments and the green squares show sampling done on the other beaches. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

orientations of nearly 340°, as is the case with the Cochinos Beach (Lz) in the heart of Timanfaya National Park. Here, we found concentrations of micro-plastics at more than 40 g/l, along with tonnes of macro-plastic accumulation on the storm line. Pictures and other complementary material are available by e-mail request. This part of Lanzarote is an uninhabited area of 51 km^2, visited year-round by increasingly respectful tourists, and the plastics here clearly come from the ocean and remain partially in the inter-tidal zone.

As we observed on Fuerteventura, the most polluted beaches on Lanzarote and La Graciosa were located on the northern sides of the islands, with the azimuth of vulnerable beaches ranging from 240° to 120° (see Fig. 7). The beaches surrounded by the populated areas of southern Lanzarote and La Graciosa showed lower concentrations of micro-plastics, and very high quantities of cigarette butts, plastic bags, and other macro-plastics.

Given the results presented above, this section will discuss plastic pollution in coastal zones as a common challenge, and suggests responses to the four questions we posed in the introduction:

(i) Where does this pollution come from?
(ii) How much plastic pollution is in the world's oceans and coastal zones?
(iii) What are the consequences for the biosphere?
(iv) What are possible solutions to the problem of plastic pollution in marine environments?

Where does this pollution come from? To answer this question, we look to the "plastic lifecycle," which involves processes that fall into one of two categories: (1) human production, consumption, and disposal of plastics, and (2) transportation and degradation of plastics once they enter natural systems.

The demand and production of plastics has been sharply increasing over the past 60 years. In 2012, over 300 million tonnes of plastics were produced worldwide (Rochman et al., 2013), continuing the dramatically escalating trend in plastic production from the 1950s, when only 1.4 million tonnes of plastics were produced (PEMRG, 2012).

This drastic growth in plastic production corresponds with our increasing dependence on plastics. Plastics have become inextricably integrated into daily activities in both developing and developed countries. Our societies' use and disposal of plastics, in domestic and industrial settings, is the cause of any and all plastic pollution that ends up in natural systems, such as the system of oceanic currents. Once in the oceanic system, plastic pollution can then be transported around the world.

For example, in the maritime corridors that run from the North Sea south to the studied area of the Canary Islands, maritime transport has increased, and with it so has the frequency of *illegal waste dumping in the ocean along this corridor. Once in the ocean, plastics begin their slow* degradation process (Cooper and Corcoran, 2010; O'Brine and Thompson, 2010), turning into the tiny micro-plastic fragments we found on beaches located thousands of kilometers from where they were initially discarded.

Waste water is another source of pollution threatening the beaches in our study area. On these three islands, water treatment plants manage less than 50% of the waste water generated by human activity. At the time of our study, we observed low levels of micro-plastics at sewer outlets in urban areas. These low levels will continue to contribute to the micro-plastic problem until water

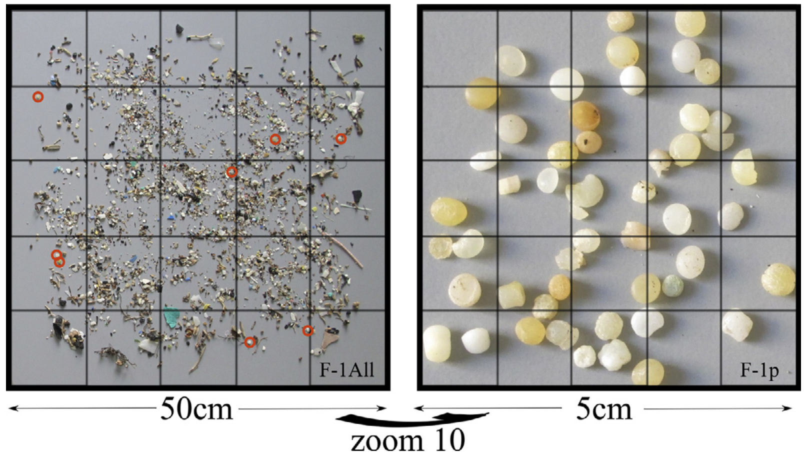


Fig. 5. Example of plastic collected in one sample of 1 l of sediment.

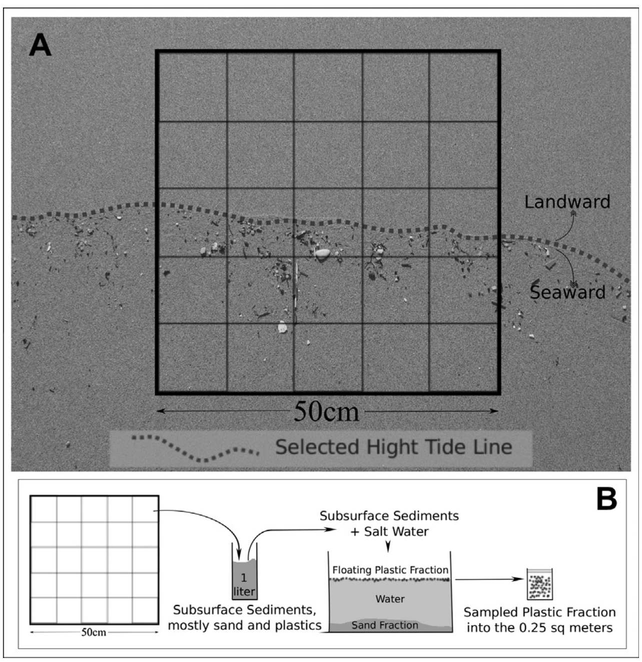


Fig. 4. Sequence for collecting each sample: (1) collect 1 l of surface sediment from a 50 cm by 50 cm square, at a depth of 1 cm; (2) transfer the liter of sediment to a tub with a larger volume; (3) add water; (4) scoop the floating plastic fragments from the water and place them into another container and (5) label the plastic from the sample with the sample point where it was collected.

treatment plant processes are improved to ensure that plastics are not released into coastal environments.

The urban areas on the study islands are primarily oriented toward the south, as is the case of Arrecife on Lanzarote or Puerto del Rosario on Fuerteventura. While these areas did not show high levels of micro-plastic pollution, macro-plastic and other pollution caused by residents and tourists were also present. Cigarette butts are one of the biggest macro-pollutants in these areas. They are not observed in the unpopulated areas of the islands, or on natural beaches; due to their fragility, cigarette butts appear to be locally-generated pollution that disintegrates in the intertidal water column.

Given the location and orientation of the major urban areas in our study area, we realized that we needed to look beyond the local populations to identify additional sources of the micro-plastic pollution we found. To do this, we considered the common characteristics of the most polluted beaches in the study. We found that they shared similar orientation and exposure to surface and subsurface currents from the open Atlantic Ocean. Due to their exposure to the Ekman layer of the ocean's mass transport currents, we determined that the majority of the micro-plastic pollution we found was probably generated thousands of kilometers away and brought to these islands from the open ocean.

For all the legal protections in place to preserve these valuable areas of high-biodiversity, micro-plastics slip by. We expected these results due to the location of our study area. The Canary Islands are situated on the eastern edge of one of five regions where wind-driven surface currents cause the convergence of marine debris, as shown by Lumpkin et al. (2012) and Maximenko et al. (2012). Floating marine debris is principally carried by wind and ocean currents. At the ocean surface, both effects can be significant, depending on the buoyancy of the debris and its direct exposure to the wind. Surface ocean currents can be deconstructed into several contributing factors: the wind-forced Ekman velocity, which rapidly decreases with depth; the geostrophic current, which is related to the slope of the sea surface height as measured by satellite altimetry, the same way surface winds are related to atmospheric sea-level pressure isobars; and the Stoke drift from surface waves. One reliable source of surface ocean current data is the long-running Global Drifter Program, supervised by NOAA. The program collects satellite-tracked trajectories from surface velocity program (SVP) drifting floats with holey-sock style drogues, which are attached at an approximate depth of 15 m, and act as sea anchors. Occasionally, floats come loose from their drogues, and the loose floats provide researchers the opportunity to analyze their untethered trajectories. These analyses may provide the best estimate for extrapolating floating marine debris drift (Pazan and Niiler, 2001). The most polluted beaches in our study area are directly exposed to the main surface and subsurface currents from the open Atlantic Ocean, which explains why we observe significantly higher micro-plastic pollution levels on beaches with northern exposure.

The micro-plastic pollution brought to the study area from the ocean and other sources only ended up on these beaches if there was space available for it to be deposited as the tide went out. If a beach is completely submerged during high tide, the micro-plastics will not be deposited on the sediment of the beach, even if they are present in the inter-tidal water column. This was the case for most of the beaches in our study area with northern orientations that did not show micro-plastic pollution at the high tide line. On these beaches, the rocky coast is too close to the sandy beach and therefore there is no available space for deposition. This explains the variability in micro-plastic concentration on beaches that are geographically close to each other or connected, as is the case with the northern section of Famara Beach (Lz), where no micro-plastics were observed, in contrast to the middle section of the

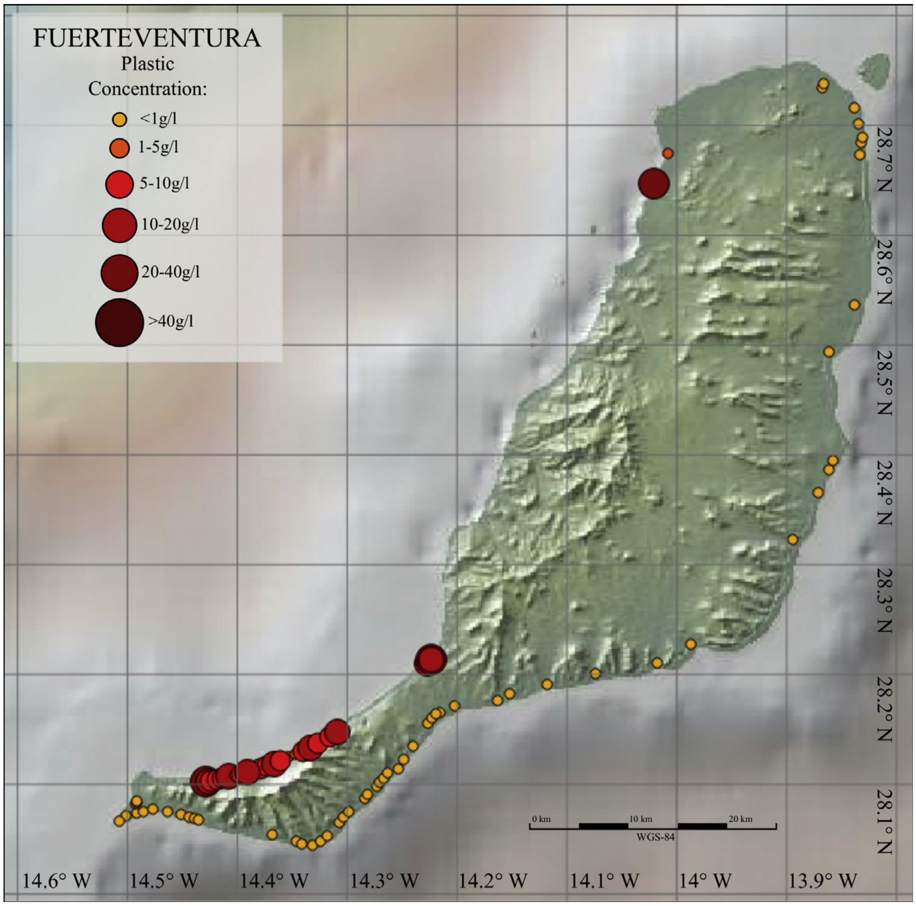


Fig. 6. Fuerteventura Island with the concentrations of micro-plastics from sampled beaches.

beach where the concentration of micro-plastics was higher than 100 g/l (see Fig. 8).

Box 1: Origins of micro-plastic pollution found on the islands of Lanzarote, La Graciosa, and Fuerteventura.

- Industrial and domestic use of plastics: plastic pollution is mainly generated as waste from urban areas and shipping activity. The ocean is the main sink for plastics. Sandy shores create the optimal location for micro-plastics to be deposited as part of the sediment that is left behind when the tide goes out. For the study area, the beaches with the most micro-plastic pollution were in non- or very low-urbanized areas, which indicates the micro-plastics came from the open ocean.
- Surface and subsurface waters in the Canary Current bring most of the micro-plastics from far away coasts and the open ocean to the coasts of Lanzarote, La Graciosa, and Fuerteventura.
- Micro-plastic pollution comes from the degradation of macro-plastics and the industrial pelletizing process to create ''plastic-pellets.''
- Water treatment plants introduce micro-plastics into the ocean and beaches in the study area by using limited techniques for eliminating micro-plastics.

How much plastic pollution is in the world's oceans and coastal zones? Today, we know that cumulative plastic waste is a problem for the entire biosphere, and it is also a threat to human health. We know the origin of plastic pollutants and have devised some possible solutions for reducing plastic pollution; but answering the question of "How much plastic pollution is there in the ocean?" requires further research. Given what we currently know, micro-plastic pollution in the ocean is a cumulative problem due to ever-increasing consumption and disposal of plastics, and is further compounded by the gradual degradation of macro-plastics already accumulated in the world's oceans and polluting our shores.

The approach we use in this study allows us to evaluate the amount of plastics in the inter-tidal zone of the beaches in our study area, and provides an initial step to evaluate the amount micro-plastics that remain suspended in the ocean.

Box 2: Baseline Data for the protected island areas of Fuerteventura, Lanzarote, and La Graciosa. Baseline measures of micro-plastic pollution from January 2013 in areas protected under the Natura-2000 and other conservation designations show that:

- Even if we find micro-plastics only on beaches where sedimentological conditions allow them to be deposited, the entire study area is vulnerable to micro-plastic pollution.
- On Lanzarote, the micro-plastic pollution reached a maximum of 109 g/l for a beach with a northern orientation.
- On La Graciosa, the micro-plastic pollution reached a maximum of 90 g/l for a beach with a northern orientation.
- On Fuerteventura, the micro-plastic pollution reached a maximum of 30 g/l for a beach with a northern orientation.

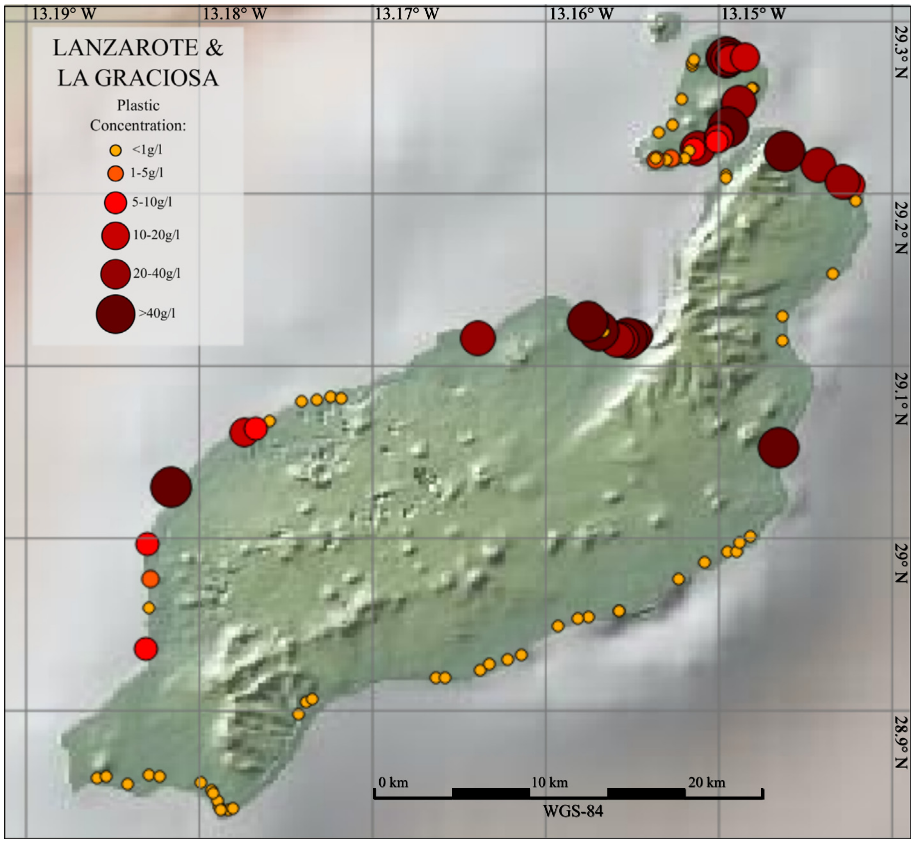


Fig. 7. Lanzarote and La Graciosa Islands with the concentrations of micro-plastics from sampled beaches.

What are the consequences of micro-plastic pollution for the biosphere and for our societies? As mentioned in the introduction, several natural conservation areas overlap between our three study islands. This reflects a great concern for preserving the high-quality ecosystems found in this area, and an effort to protect the large number of vulnerable and endemic species that contribute to coastal biodiversity in this area. By bringing in contaminants that are harmful to local flora and fauna, micro-plastic pollution could seriously disrupt these delicate ecosystems.

It has been widely documented that micro-plastics are vectors for metals and other contaminants found in open surface waters (e.g. Moore, 2008; Zarfl et al., 2011). It has also been demonstrated that metals in or adhered to micro-plastics are absorbed into the surface of the plastics, or can be associated with their hydrogeneous or biogenic phases, and as such they can potentially become bio-accessible in a way that could harm the fauna that ingest them (Ashton et al., 2010).

Recent legislation in the United States, Canada, and the European Union demonstrates that not only should we be concerned with plastic pollution's impact on environmental health, but also that we must question the impact of plastics on human health. Examples of such legislation include: the addition of BPA on the Canadian list of toxic substances, the prohibition of BPA for use in children's bottles by Canada in 2010 and by the United States Food and Drug Administration in 2012, and the European Union banning BPA in some food packaging. Two clear examples of health risks for humans include a study that demonstrated BPA causing endocrine disruption and leading to the development of breast cancer (Lopez-Carillo et al., 2010), and a study of phthalate that showed a reduction masculine play in boys as consequence of prenatal phthalate exposure (Swan et al., 2010).

As many studies have shown, the ingestion of plastics can have lethal consequences for wildlife (e.g. Jantz et al., 2013; de Stephanis et al., 2013; Bond et al., 2012; Lusher et al., 2013; Bravo Rebolledo et al., 2013; Hong et al., 2013; Lindborg et al., 2012; Fossi et al., 2012; Gray et al., 2012; Rodríguez et al., 2012; Avery-Gomm et al., 2012; Kühn and van Franeker, 2012; Cole et al., 2011; Van Franeker et al., 2011; Ryan and Jackson, 1987). Our findings emphasize the fact that, even in areas with substantial measures for natural resource conservation and protection, pollution from plastics of any size, is still present and poses a serious threat to wildlife.

Additionally, a study published by Saido Katsuhiko in 2009 demonstrated that as drift plastic decomposes, it releases hazardous chemicals into the ocean. Polystyrene (PS) was found to begin decomposing at 30 °C, and to produce styrene monomer (SM), 2,4-diphenyl-1-butene (styrene dimer, SD), and 2,4,6-triphenyl-1-hexene (styrene trimer, ST) (Katsuhiko et al., 2009). This point raises another important element to keep in mind: plastic is not an inert material, and on top of its own toxicity it has the potential to agglomerate and transport Persistent Organic Pollutants (POPs). For example, samples from beaches in South Africa have shown that polyethylene pellets concentrate and transport POPs in the forms of Polychlorinated biphenyls (PCB), Hexachlorocyclohexane (HCH), and the pesticide Dichloro Diphenyl Trichloroethane (DDT) (Ryan et al., 2012), the same POPs have also been found on remote non-industrialized islands (Heskett et al., 2012). The hydrofuge surfaces of micro-plastics, which contain toxic chemicals, are transported to pristine areas and then these chemicals are mostly liberated when ingested by organisms. This finding is highlighted in two novel perspectives on the global plastic debris issue, namely the presence of plastic in some commonly consumed pelagic fish species and the suggestion that plastic pollution continues to extend into the deep ocean through interconnected epi- and mesopelagic food webs (Choy and Drazen, 2013).

Benthic and pelagic ecosystems are affected by micro-plastic pollution (see reviews by: Cole et al. (2011); Goldstein (2012);

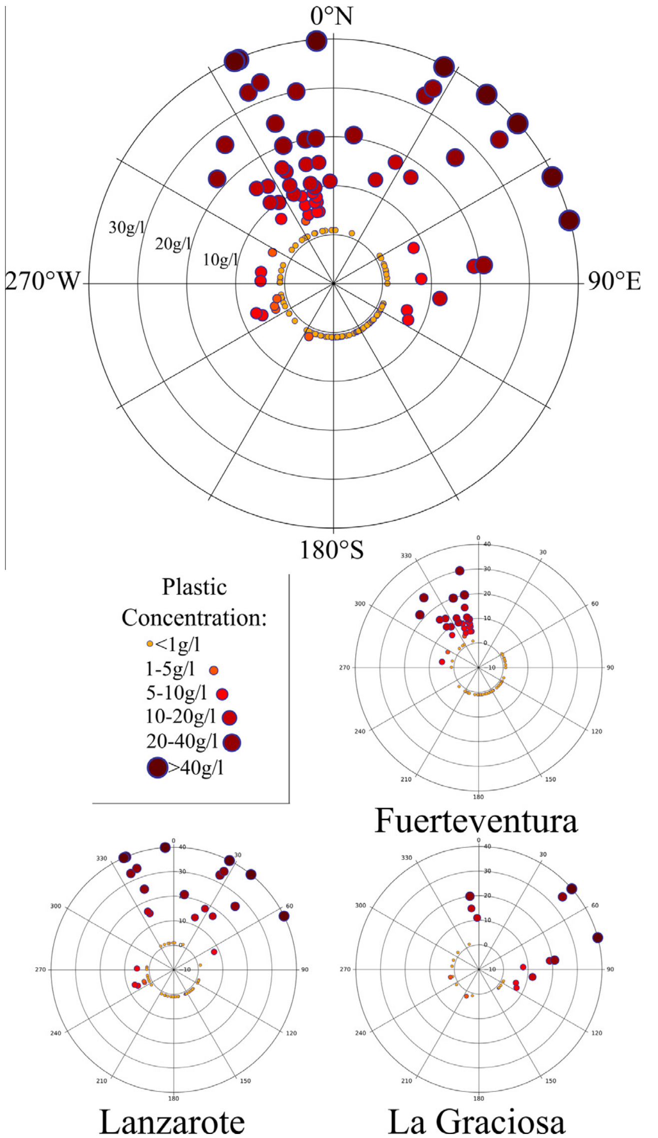


Fig. 8. Azimuths and concentrations of the samples from the three islands; the most vulnerable areas are oriented between 300°N and 90°E.

Andrady (2011)). There is little research available that identifies micro-plastics as a transport vector for pathogens in the marine environment. However, *vibrio* bacteria, which can be carried by micro-plastics, are known to cause illness and mortality in mollusks and fishes (cf. reviews of Paillard et al. (2004); Austin (2010)). Felsenfeld discovered that fomites - any inanimate object or substance capable of carrying infectious organisms and transferring them from one individual to another – can allow *V. cholera*, a human pathogen, to survive for several days without a host (Felsenfeld, 1965). As fomites, plastics and micro-plastics could potentially harbor other pathogenic bacteria. For example, the *V. harveyi* bacteria, an aggressive pathogen in marine environments that affects mollusks and fishes, forms biofilms on plastic, which gives it a high resistance to antibiotics and fosters its long-term survival in adverse conditions. The latent impact of micro-plastics as transport vectors of pathogenic bacteria must be considered as a grave threat to coastal zones and the marine environment. This is especially true for areas like the Canary Islands, which are showing a rapid increase in the use of aquaculture to raise potentially high value shellfish and fish, such as abalone.

We strongly agree with Rochman et al. (2013) when they state: "the physical dangers of plastic debris are well enough established, and the suggestions of the chemical dangers sufficiently worrying, that the biggest producers of plastic waste — the United States, Europe and China — must act now. These countries should agree to classify as hazardous the most harmful plastics, including those that cannot be reused or recycled because they lack durability or contain mixtures of materials that cannot be separated" (Rochman et al., 2013).

Box 3: Consequences.

- Plastics are not inert materials and pose physical and chemical threats to wildlife and humans.
- Micro-plastics come directly from industrial processes and from macro-plastic degradation; both products have indirect and direct lethal consequences for the entire biosphere.

What are possible solutions to the problem of plastic pollution in marine environments? In our study area, efforts to combat plastic pollution are already underway at all levels of the local communities. The efforts are mainly focused on regularly removing garbage from the land and water near urban development, improving the recycling process, and education. Unfortunately, these efforts in and of themselves are not enough. Triggered by increasing social awareness, in February 2013 the working group guiding this research launched a social campaign called "Plastic 0: Agüita con el Plástico." Already, the initial results of this social networking effort are beginning to take shape through school involvement, citizens sharing knowledge with each other, and progress made in concerted, collaborative actions taken by the communities. This campaign serves as a major step in laying the groundwork for additional pertinent and on-going actions rooted in and driven by the interests and values of local communities.

Efforts are also underway to improve the coordination of social agents, governmental administrations, civil society, and other stakeholders in order to change the trajectory of ever-increasing plastic waste, and commit to reducing plastic pollution to zero. Such collaborative approaches to this problem are necessary to determine possible solutions and convince state agencies to assume their responsibilities with regards to citizens' health, and the health of the environments they live in.

Box 4: Solutions.

- Improve the implementation of protocols, directives, and laws.
- Reduce industrial and domestic use of plastic.
- Increase awareness of plastic pollution hazards for all levels of society and for all stakeholders.
- Develop collective, collaborative, and concerted actions between stakeholders.

Our research on the islands of Lanzarote, Fuerteventura, and La Graciosa has only begun to scratch the surface of the further research that must be done to understand the impact of micro-plastic pollution on food chains and marine environments. For now, the diagnosis is clear: on each of the protected islands in our study, we found undeniable evidence of unacceptable amounts of micro-plastic pollution. When even our protected coastal and marine areas are threatened by plastic pollution, we must recognize we are facing dangerous circumstances that put our coastal biodiversity and human communities at risk. While there is still much that we do not know about plastic pollution, what we do know sufficiently demonstrates that we must assume our ethical responsibilities to better control the processes of domestic and industrial plastic production, consumption, and disposal.

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