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Floating plastic debris in the Central and Western Mediterranean Sea

Luis F. Ruiz-Orejón [a, *], Rafael Sardá [a], Juan Ramis-Pujol [b]

[a] Centre d'Estudis Avançats de Blanes (CEAB-CSIC), Carretera d'Accés a la Cala St. Francesc, 14, 17300 Blanes-Girona, Spain
[b] ESADE Business School, Edifici 1. Universitat Ramon Llull, Av. Pedralbes, 60-62, 08034 Barcelona, Spain

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ABSTRACT

In two sea voyages throughout the Mediterranean (2011 and 2013) that repeated the historical travels of Archduke Ludwig Salvator of Austria (1847–1915), 71 samples of floating plastic debris were obtained with a Manta trawl. Floating plastic was observed in all the sampled sites, with an average weight concentration of 579.3 g dw km^{-2} (maximum value of 9298.2 g dw km^{-2}) and an average particle concentration of 147,500 items km^{-2} (the maximum concentration was 1,164,403 items km^{-2}). The plastic size distribution showed microplastics (<5 mm) in all the samples. The most abundant particles had a surface area of approximately 1 mm^2 (the mesh size was 333 μm). The general estimate obtained was a total value of 1455 tons dw of floating plastic in the entire Mediterranean region, with various potential spatial accumulation areas.

1. Introduction

One hundred twenty years ago, Archduke Ludwig Salvator of Austria (1847–1915) explored the Mediterranean on his steam yacht, the *NIXE II*, from west to east and from north to south. During these expeditions, he focused his attention on small, undiscovered regions and islands. The archduke was considered a researcher and chronicler of the Mediterranean Sea, passionate about wildlife at a time when the world's resources seemed limitless and there was a poor understanding of ecosystems. He developed a set of monographs, totalling more than 6000 pages, describing each area's animals, plants, climate, history, folklore, architecture, landscape as well as the people and their customs, songs and poems. In 2015, the centenary of the death of Archduke Ludwig Salvator was celebrated. He never saw plastic floating in the sea because plastic had not yet invented.

The modern plastic era started in the first decades of the last century, and the material was rapidly adapted for a wide variety of commercial applications. Today's plastics are among the most commonly used materials and are indispensable in virtually all product areas. As a result, plastic waste is ubiquitous in the marine and coastal environments. The amount of plastic waste in the marine environment has increased rapidly; on study reported that 4.8 to 12.7 million tons was released into the oceans in 2010 (Jambeck et al., 2015). Today, 100 years after the death of the archduke, plastics are widely distributed across oceans and seas worldwide (Cózar et al., 2014; Eriksen et al., 2014; Moore, 2008; UNEP, 2009, 2005; van Sebille et al., 2015) and retention areas in oceanic surface gyres had been identified (Cózar et al., 2014; Eriksen et al., 2014; Law et al., 2010; Moore et al., 2001; Pichel et al., 2007).

Plastic pollution has consequences in three main areas: 1) ecosystem health, transport of non-native species (Barnes, 2002; Goldstein et al., 2012), entanglement and ingestion by wildlife (de Stephanis et al., 2013; Lönnstedt and Eklöv, 2016; Lusher et al., 2013; Tanaka et al., 2013; Teuten et al., 2009), and food-web accumulation (Hirai et al., 2011; Mato et al., 2001); 2) human health (Koch and Calafat, 2009; Meeker et al., 2009; Talsness et al., 2009; Thompson et al., 2009), and 3) economic status, with adverse effects on tourism (Ballance et al., 2000); aquaculture and fishing industry (McIlgorm et al., 2011), and transport and harbor activity (UNEP, 2005).

Because they are small, microplastics are readily available for marine biota. In addition, their high ratio of surface area to volume allows leaching or adhesion of other pollutants, contributing to their damaging effects (Ashton et al., 2010; Barnes et al., 2009; Cole et al., 2011; Farrell and Nelson, 2013; Oehlmann et al., 2009; Talsness et al., 2009). These particles tend to be concentrated in

* Corresponding author.
E-mail address: luisf.ruizorejon@ceab.csic.es (L.F. Ruiz-Orejón).

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the top few centimeters of the sea surface because their density, in general, is lower than that of seawater (Collignon et al., 2014). Taking these findings together, the presence of plastics in the sea is one of the largest social-ecological problems in the marine environment.

The Mediterranean Sea is a semi-enclosed sea with shores close to population areas (approximately 100 million people live within 10 km of the coastal strip of the Mediterranean (Cózar et al., 2015) and 200 million within 50 km (Jambeck et al., 2015)). These conditions provide high potential for plastic retention (Reisser et al., 2013; Ryan, 2013). However, the establishment of stable retention areas is difficult because of the high variability of surface currents and diverse instabilities in this sea (Mansui et al., 2015). Studies on plastic pollution in the Mediterranean Sea (Aliani et al., 2003; Collignon et al., 2014, 2012; Cózar et al., 2015; de Lucia et al., 2014; de Stephanis et al., 2013; Fossi et al., 2012; Galgani et al., 2014; Kornilios et al., 1998; Morris, 1980; Suaria and Aliani, 2014), have identified it as an ecosystem that is particularly sensitive to the accumulation of plastic debris (Cózar et al., 2015; Galgani et al., 2010) and comparable to average concentrations of five subtropical gyres (Cózar et al., 2015).

In 2009, the *NIXE III* project was created to replicate part of the expeditions of the Archduke Ludwing Salvator (Fundación Innovación, Acción y Conocimiento (FIAyC); Majorca (Balearic Islands, Spain)). Three sea voyages (expeditions) in the Mediterranean Sea were carried out. The main goal of the project was to make available in English the originals monographs of the archduke and to compare these works with new reports made in several sites visited again more than a century later. During two of these voyages, the researchers decided to evaluate changes in the Mediterranean ecosystem and to sample floating plastics. The main aim of this study was to obtain current information about the distribution, abundance and size composition of floating micro- (<0.5 mm), meso- (5–25 mm) and macro- (25–1000 mm) plastics (Lippiatt et al., 2013) in the Northwestern and Central Mediterranean Sea in accordance with established classifications under the European Union Marine Strategy Framework Directive (MSFD, 2008/56/EC).

2. Materials and methods

2.1. Study area

Data were collected from surveys conducted during two research expeditions led by the FIAyC Foundation as part of the *NIXE III* project. These expeditions repeated the travels of the Archduke with the aim of evaluating the transformations of the Mediterranean coastal landscape. The first study (25 May – 2 July 2011) covered the area from the Balearic Islands (Northwestern Mediterranean Sea) to the Adriatic Sea and was carried out on the R/V *Wizard*. The second study (30 April – 14 June 2013) covered the area from the Balearic Islands to the Ionian Sea and was conducted on the R/V *Rossina di Mare* (A Appendix, Fig. A.1).

We sub-divided the sampling areas into four regions according to the Mediterranean regional seas classification (Sea of Sardinia, Tyrrhenian Sea, Ionian Sea and Adriatic Sea) (Fig. 1).

2.2. Survey methods

Seventy-one neustonic samples were collected with a Manta Trawl net with a rectangular opening of 0.6 m × 0.25 m and a mesh size of 333 μm m. The net was towed from the side of the boat to prevent disturbance of debris (Collignon et al., 2012; Moore et al., 2001). The boat moved at an average speed of 3.13 knots for periods of 15–30 min. The net was washed to empty the entire sample into the collector, and the amount of seawater filtered was obtained using a flowmeter. Samples were fixed in 5% formalin and transferred to 50% ethanol.

The samples were drained and placed in water to separate the floating plastic from the of the sample. The top and bottom portions of the sample were inspected visually, manually separated and cleaned (with particular attention to meso- and macroplastics) under an optical microscope and categorized into six groups: plastics, tar ball-pellets (hydrocarbons and charcoal fragments), vegetable organisms (natural material from Plantae and Chromista kingdoms (Ruggiero et al., 2015), without identifiable human use), animal organisms, paper and a final category of unclassifiable materials. The plastics were sorted using Tyler sieves into three size categories—microplastics (<5 mm), mesoplastics (5 mm–25 mm) and macroplastics (25 mm–1000 mm) (Collignon et al., 2012; Lippiatt et al., 2013)—and counted. Individual plastic fragments and the remaining identified groups were dried at 65 °C for 24 h and weighed (Moore et al., 2001). The plastic particles in the samples were placed on a matte black background and photographed with a known reference (A Appendix, Fig. A.2) for digitalization. The images were processed using ImageJ software v:1.49p to determine the areas of the particles on a flat surface, including variations in shape factor from 1 to 0 (SF = 4π area/perimeter (Filella, 2015)). The results were reviewed to correct errors in particle detection (e.g. for particles with a colour similar to that of the background). The plastic concentrations were normalized using a square millimeter intervals to uniform the size classes according to the description by Filella (2015).

For each sample, we obtained the plastic weight concentration (g dw km^{-2}) and plastic particle concentration (items km^{-2}). We also measure each plastic fragment to determine the most frequent size classes in our samples. Wind data (U_{10}) were extracted from CCMP (http://podaac.jpl.nasa.gov) and Global Ocean Wind L4 Near real Time 6 hourly Observations (http://marine.copernicus.eu) databases to correct for the effect of wind mixing on the vertical distribution of plastics particles (Kukulka et al., 2012).

2.3. Statistical analysis

Nonparametric analysis was used to examine the data after assessing non-normal distribution through the Kolmogorov-Smirnov test. The distance to the coast and the sample composition were analyzed using the Spearman correlation. The distance to the nearest point of coast was calculated using the starter coordinates of each sample and the coastline of Mediterranean Sea in a geographical information system (GIS). To compare differences in plastic concentrations (by weight and pieces) between the Mediterranean regional seas, a Mann-Whitney-Wilcoxon test for pairwise comparisons was used. The software used was IBM SPSS Statistics 22 and free software R v: 3.1.3.

3. Results

3.1. Plastic distribution

Plastics were detected in all samples obtained in the Mediterranean Sea. The entire set of 71 trawls yielded a total of 17,495 particles, providing one of the first large-scale surveys of plastic waste for the Mediterranean region. The floating plastic weight concentration in samples varied from 7.43 g dw km^{-2} to 9298.24 g dw km^{-2} (average value, 579.35 ± 155.92 *s. e.* g dw km^{-2}; median value, 140.99 g dw km^{-2}). Although we found high variability in plastic concentrations, in sixty percent of the samples, the weight obtained was higher than 100.00 g dw km^{-2}. Particle concentrations ranged from 8999 to 1,164,403 items km^{-2} (average, 147,500 ± 25,051 *s. e.* items km^{-2}; median, 59,415.05 items km^{-2})