Marine Pollution Bulletin 133 (2018) 636–646

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain)

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, Blanes-Girona 17300, Spain
[b] ESADE Business School, Edifici 1, Universitat Ramon Llull, Av. Pedralbes, 60–62, Barcelona 08034, Spain

ARTICLE INFO

Keywords:
Microplastics
Floating plastics
Plastic pollution
Balearic Islands
Mediterranean Sea

ABSTRACT

Coastal ecosystems are under significant human pressure, partly due to the proximity of pollution sources. In this study, a total of 20 samples were taken in summer around the coastal waters of the Balearic Islands (Spain) using a manta trawl net to examine the concentrations of floating plastic debris through the NIXE III project campaign. Although plastic concentrations showed high variability along the coast, the higher particle concentration (max: 4,576,115 $items \cdot km^{-2}$) and weight (max: 8,102.94 $g(DW) \cdot km^{-2}$) values were located at the north of the Balearic Promontory. The particle size analysis showed the high prevalence of microplastics (< 5 mm) in these waters, where particles of approximately 0.7 mm and 1 mm^2 were the most frequent in the range analyzed. The high plastic concentration values in the N-NW coast of Ibiza and Mallorca in sparsely populated locations suggest that the plastic particle distribution was mostly conditioned by the hydrodynamic surface conditions.

1. Introduction

Coastal areas provide diverse ecosystem services able to improve the socio-economic activities and human well-being of societies living along (Brenner et al., 2010; Lozoya et al., 2011; Krelling et al., 2017). Nevertheless, coastal ecosystems are subjected to human pressures such as plastic pollution, whose presence poses a recognized environmental threat (e.g. UNEP, 2005, 2009; Thompson et al., 2009a; Ivar do Sul and Costa, 2014; Galgani et al., 2015; UNEP/MAP, 2015).

Plastic has become the most widely used human-made material in current societies. Its global production continues to increase, reaching 335 million tons in 2016 (PlasticsEurope, 2018) and an estimated total accumulated manufacturing volume of 8300 million tons to date (Geyer et al., 2017). Although social unawareness and unsustainable behaviors with regard to marine pollution has diminished over the years (Chilvers et al., 2014; Gelcich et al., 2014; Wyles et al., 2014, 2015, 2016), there is still a certain lack of knowledge about microplastics (< 5 mm) litter (Santos et al., 2005; Jacobs et al., 2015; Chang, 2015; Anderson et al., 2016) which together with the inadequate waste management processes, have contributed to the entrance of plastic debris directly or indirectly into marine ecosystems from land-based sources (e.g. Mato et al., 2001; Moore et al., 2001; Bravo et al., 2009; Galgani et al., 2010; Mouat et al., 2010; Andrady, 2015; Jambeck et al., 2015; Pahl and Wyles, 2017).

Plastic particles that reach marine ecosystems are subjected to different physical dispersion factors from the release points of origin, wind and ocean currents being the most important ones (Aliani et al., 2003; Critchell et al., 2015; Critchell and Lambrechts, 2016). Despite the well-known subtropical ocean gyres acting as accumulation areas for floating plastic debris, the spatial distribution of these particles in the Mediterranean Sea is affected mainly by the variability of the surface circulation which hampers the formation of stable retention zones (Cózar et al., 2015; Mansui et al., 2015). In addition, recent studies have shown elevated concentrations of floating plastics in the first kilometers from the coast suggesting the contribution of other factors such as prevailing boundary surface currents in the Mediterranean as well as coastal populations as land-based sources (Pedrotti et al., 2016; Ruiz-Orejón et al., 2016; Gündoğdu and Çevik, 2017; van der Hal et al., 2017). Since microplastics represent the majority fraction of floating plastics, the distribution of these particles has been among the most analyzed; notwithstanding, the distribution processes affecting plastic waste may differ according to the size of the particles (Ourmieres et al., 2018). In the Balearic area, the surface currents are conditioned by the North Current (NC) that runs along the coasts of southern Europe and by the mesoscale circulations coming from the Algerian sub-basin, which favor the formation of the Balearic current (BC) (e.g. Pinot et al., 2002; Millot and Taupier-Letage, 2005; López-Jurado et al., 2008; El-Geziry and Bryden, 2010; Barberá et al., 2014).

During dispersion processes in marine environments, floating plastic debris are mainly affected by photo-oxidative degradation and

* Corresponding author.
E-mail addresses: luisf.ruizorejon@ceab.csic.es, luisf.ruizorejon@gmail.com (L.F. Ruiz-Orejón), sarda@ceab.csic (R. Sardá), juan.ramis@esade.edu (J. Ramis-Pujol).

https://doi.org/10.1016/j.marpolbul.2018.06.010
Received 10 January 2018; Received in revised form 1 June 2018; Accepted 2 June 2018

mechanical abrasion factors that result in fragmentation into smaller particles (e.g. Thompson et al., 2009b; Andrady, 2011; Crawford et al., 2017); in addition to some primary plastics which are already manufactured in these micro sizes. Direct and indirect adverse effects produced by these particles on numerous marine and freshwater organisms have been demonstrated throughout the food web (e.g. Cole et al., 2011; Fossi et al., 2012; Lusher et al., 2013; Rochman et al., 2013; Fossi et al., 2014; Cole et al., 2015; Romeo et al., 2015; van Franeker and Law, 2015; Nadal et al., 2016; Alomar and Deudero, 2017; Horton et al., 2017). However, adverse effects are not only limited to the ecological dimension but also involving also social-economical aspects which may affect relevant critical sectors in specific territories as tourism or fisheries (e.g. Mouat et al., 2010; Antonelis et al., 2011; Bilkovic et al., 2014; Leggett et al., 2014; Newman et al., 2015).

The marine plastic pollution problem is not external to the Balearic Islands (Spain), where significant amounts of these debris have been reported on their sea floor (Ramirez-Llodra et al., 2013; Pham et al., 2014), beaches and coastal shallows (Martinez-Ribes et al., 2007; Alomar et al., 2016). At coastal level, values exceeding 320,000 $items \cdot km^{-2}$ of floating plastics were reported around Ibiza, the mouth of the bay of Palma (Mallorca) and the Menorca Channel (Faure et al., 2015; Ruiz-Orejón et al., 2016). Moreover, the Balearic Islands became an area of relatively high concentration of plastics when running different numerical models (Lebreton et al., 2012; Eriksen et al., 2014; Mansui et al., 2015; van Sebille et al., 2015; Zambianchi et al., 2017; Coppini et al., 2018).

Continuous monitoring is critical for building a substantial evidence of the variability in the distribution process of plastic litter as a reference state of the coastal waters; however, this information is still limited in the Mediterranean and also the Balearic Islands. In the present work, floating plastic debris were sampled in the coastal waters of the Balearic Archipelago during the summer of 2014 to contribute to the European Marine Strategy Framework Directive (2008/56/EC) objectives. The main aim of this study was to describe the summer conditions of coastal waters of the Balearic Islands (within 10 km of its coasts) regarding the floating plastic pollution problem (composition, concentration and distribution of particles). As these islands in summer host a large human population density, we used this sampling effort to discern possible causes of this floating plastic distribution and variability.

2. Materials and methods

2.1. Study site

The Balearic archipelago is located in the Western basin of the Mediterranean Sea between around 38°30′ – 40°10′ N and 1°02′ – 4°28′ E (Fig. 1). It is part of the extension of the Betic Mountain Range, within the denominated Balearic Promontory (Duran, 2006). The islands are formed by two main groups called: *Gimnesias* (Mallorca, Menorca, and Cabrera) and *Pitiusas* (Ibiza and Formentera). Concerning its marine surface circulation, the Balearic Islands present two main different hydrodynamic regimes on both sides of the Balearic Promontory. On the northern basin (Balearic sub-basin), the presence of the Northern Current running along the coast of the Iberian Peninsula towards SW with slightly colder and saline waters. While on the southern basin (Algerian sub-basin), more influenced by the Alger Current, with temperate and less saline waters, together with the high variability of the eddies that are formed in its route towards the center of the Mediterranean Sea (La Violette et al., 1990, Monserrat et al., 2008; Pinot et al., 2002; Pessini et al., 2018). Still, there is some exchange on the surface between the two promontory slopes through the channels of Ibiza and Mallorca (Pinot et al., 2002).

The Balearic region had a resident population of 1,103,442 inhabitants in 2014 (IBESTAT, 2014c). However, due to the significant tourist attraction of these islands (3*rd* autonomous community in Spain as a tourist destination in 2014 and 2*nd* in 2015; source: S. G. de Conocimiento y Estudios Turísticos (2015)), the seasonal peak of the population went up to almost 1,863,051 people in August 2014 (2 million people in 2016; source: IBESTAT (2014b)).

2.2. Sampling and laboratory work

In the summer of 2014 a total of 20 samples were collected in the framework of the research *NIXE III* project (www.nixe3.com), using a Manta trawl net (0.6 m × 0.25 m, rectangular frame opening) characterized by the two rigid fins attached to its outside to allow some buoyancy when it is towing. The tool was equipped with a net of 333 μm mesh size, a collecting bucket (cod-end) at the end of it and a flowmeter installed at the center of the manta net mouth to record the volume of seawater filtered. According to previous research recommendations (e.g. Collignon et al., 2012; Moore et al., 2001), the net was towed from the side of the boat at some distance to prevent the disturbance of floating debris. The net was towed at a speed of 2.0 –3.4 knots for periods of 15–30 min at each sampling station. After this period, the net was rinsed on board with seawater to accumulate the entire sample in the cod-end and transferred to 225 μm sieve to ensure the retention of the microplastic fraction. Then, each sample was washed in 5% formalin and fixed in 50% ethanol (EtOH).

In the laboratory, samples were extracted from the preservation medium using a Tayler sieve with a mesh size of 225 μm and transferred into a 5 L container of filtered water to carry out the density separation. Both the supernatant and sink (water column and bottom) fractions were separately extracted. Each fraction was inspected visually and manually separated under a dissecting stereo-microscope (Olympus). In case of doubt about the nature of a particle (particularly, particle sizes < 5 mm), it was identified with an optical microscope (Nikon). Plastics were counted and reclassified 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 categorized by the kind of plastic (i.e. rigid fragment, foams, fibers, film fragments, fishing lines, industrial pellets, plastic rope, bottles and caps). Fibers were counted but were not considered in the concentration computation, to avoid an error for environment contamination (i.e. volatile fibers not present at the time of sampling). The plastic particles were introduced into the laboratory oven (Heraeus) at a temperature of 65 °C for a minimum of 24 h. After cooling down in the desiccator, they were weighed on a precision balance (Sartorius) to obtain the dry weight (DW).

2.3. Plastic size (surface area and length size)

Plastic size was analyzed by digitizing all particles from each sample. Plastic particles were placed on a matt black surface, on their higher stability side, with a calibrate and known reference. Calibrated photographs were obtained by a camera equipped with an 8-megapixel sensor resolution and processed with free software ImageJ (National Institute of Health, NIH) v1.50f (Schneider et al., 2012). The entire range of particle shapes was determined including variations in the shape factor from 1 to 0 (SF = 4π area/perimeter) according to the recommendations of Filella (2015). The results of the digitization were reviewed to correct possible failures in the detection of the particles, particularly with the dark particles that resembled the background.

Following Cózar et al. (2017) methodology, frequency of plastic particles were divided by its size class obtaining the normalized abundance and in turn, it was divided by the sum of the normalized abundances to be independent of the dimensions and number of particles analyzed whose results were the dimensionless relative normalized distribution (N_{di}). The surface size of plastic particles was measured using the calibrated photographs where the particles were separated into thirteen size classes (1–50; 50–100; 100–150; 150–200; 200–250; 250–300; 300–400; 400–500; 500–1000; 1000–1500;