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Exceptionally high abundances of microplastics in the oligotrophic Israeli Mediterranean coastal waters

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ABSTRACT

Seasonal sea surface microplastic distribution was recorded at 17 sites along the Israeli Mediterranean coast. Microplastics (0.3–5 mm) were found in all samples, with a mean abundance of 7.68 ± 2.38 particles/m^3 or 1,518,340 particles/km^2. Some areas had higher abundances of microplastics than others, although differences were neither consistent nor statistically significant. In some cases microplastic particles were found floating in large patches. One of these patches contained an extraordinary number of plastic particles; 324 particles/m^3 or 64,812,600 particles/km^2. Microplastic abundances in Israeli coastal waters are disturbingly high; mean values were 1–2 orders of magnitude higher than abundances reported in other parts of the world. Light-colored (white or transparent) fragments were by far more abundant than all other microplastic colors and types. The results of this study underline the need for action to reduce the flux of plastics to the marine environment.

1. Introduction

Marine debris impacts the health and integrity of marine ecosystems and may exert considerable stress on marine biota (Derraik, 2002; Thompson et al., 2004; Deudero and Alomar, 2015). Characterization of marine debris in various parts of the world has shown that the bulk of the solid material originates from terrestrial sources and consists of a wide array of plastic compounds (Andrady, 2011; Jambeck et al., 2015). Although many of the plastic particles that enter the sea are large (>5 mm), physical, biological and chemical processes which occur both in the water column and on the seafloor eventually reduce these to smaller particles (<5 mm), collectively classified as "microplastics" (Arthur et al., 2009). These particles are ubiquitous and the most abundant of all marine plastic debris sizes (Eriksen et al., 2014; Cózar et al., 2014). Microplastics produced by the breakdown of larger particles are known as 'secondary' microplastics, in contrast to 'primary' microplastics (pellets, cosmetic beads, etc.), which are manufactured particles that are smaller than 5 mm (Brown et al., 2007; Rios et al., 2007; Fendall and Sewell, 2009).

Until recently, microplastic debris was not recognized as an important form of marine pollution and its abundance and distribution were generally not documented (Carpenter et al., 1972; Thompson et al., 2004; Allsopp et al., 2006). Studies carried out in the past two decades indicate that microplastic particles have a cosmopolitan distribution (Brown et al., 2008; Thompson et al., 2009). As the plastic debris erodes, the availability of microplastics to organisms that occupy the water column as well as the seafloor increases (Moore et al., 2005; Cole et al., 2013; Woodall et al., 2014).

Numerous factors, such as the shape of the coast line, eddies and gyres, wind and wave action, biofouling, salinity and temperature, may influence the distribution of microplastics (Barnes et al., 2009; Andrady, 2011; Doyle et al., 2011). Moore et al. (2001a, b, 2002) found an increase in microplastic abundances inside the North Pacific Gyre and towards the coastline and river outflows, especially after heavy rains. Jung-Hoon et al. (2015) also found greater abundances of microplastics after the rainy season. Collignon et al. (2012) reported an increase in microplastic abundances in calm seas as compared to the situation following a period of strong winds, probably related to the vertical mixing of plastics to depths below the sea surface (Kukulka et al., 2012). Lebreton et al. (2012) and Cózar et al. (2015) suggest that the Mediterranean Sea is enriched in microplastics because it is a largely enclosed basin with water flowing into it from both the Atlantic Ocean and from numerous large rivers. This may lead to a high ratio of microplastic particles to biomass (Collignon et al., 2014); especially in the eastern part of the Mediterranean where waters are highly-oligotrophic (Moutin and Raimbault, 2002).

Cózar et al. (2015) assembled a large-scale review of the Mediterranean Sea and found that microplastic abundances were similar to those found in the Pacific Ocean gyres, with a mean abundance of 0.83 microplastic particles/m^3 (in communication; data from Cózar et al., 2015). In the western Mediterranean Sea, microplastic particles were found in 90% of the samples examined, with a mean abundance of

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0.012 particles/m^3 (Collignon et al., 2012) and 0.15 particles/m^3 in a more recent study (de Lucia et al., 2014). Pedrotti et al. (2016) indicates high accumulation zones in the near-shore region of the western Mediterranean coasts. In sharp contrast to the western basin, aside from the microplastics in the (Central Mediterranean) Ionian & Adriatic Seas (Ruiz-Orejón et al., 2016), there are no published data thus far on microplastics in the eastern Mediterranean Sea beyond a very general survey of marine debris (Topcu et al., 2010). Mansui et al. (2015) predicts in a recent model that the eastern part of the Mediterranean acts as a beaching zone which is likely to accumulate debris. This resembles other models that predict high abundances of microplastics in this region (Lebreton et al., 2012; Maximenko et al., 2012; Van Sebille et al., 2015).

This study presents the first results on the high abundances and other characteristics of microplastic particles along the eastern Mediterranean coast of Israel.

2. Methods

2.1. Sea surface sampling

A total of 108 sea surface samples were taken from various sites along the Mediterranean coast of Israel (Fig. 1 and Table 1). Sampling was carried out once in each season, from summer 2013 until spring 2015. Each sampling consisted of a 15-minute along-shore (either northward or southward, along the 10 m isobath) manta net tow from the R/V Mediterranean Explorer, at an average speed of 2 knots, following Ryan et al. (2009). The manta net (333 μm mesh size) had a rectangular opening of 0.2×0.6 m that sampled the upper 10 cm of the water column; it was equipped with a Hydrobios 483,110 mechanical flowmeter to quantify the volume of water sampled.

Due to time and budgetary constraints, manta net tows were not replicated at any of the sites. However, there was concern that towing in one direction only might bias the data. Therefore, in addition to the above-mentioned samplings, and in order to determine whether tow direction (north to south vs. south to north and cross-shore vs. along-shore) may have affected the results, three replicate manta tows for all four directions were carried out, at two sites, Poleg River and Herzliya North ($N = 12$ samples per site), and abundances were compared.

For statistical analysis, Environmental data, including air temperature, weather state, wind direction and speed and wave height were recorded for all samplings. Archived wind data for one week prior to each of the seasonal sampling cruises were taken from the Israel Meteorological Service website (*www.ims.gov.il*).

Trends for microplastic distribution along the coast (Fig. 1) were tested by grouping the sites into five geographic clusters. The rationale behind these clusters follows the Adler and Inbar (2007) survey on the sensitivity of the Mediterranean coastline of Israel to marine oil spills. On this basis, the clusters were defined as: "North" - Betzet & Shavey Zion (2 sites); "Haifa Bay" - from Akko to Shikmona (3 sites); "Carmel" - from Oren River to Sdot Yam (4 sites); "Sharon" - from Poleg River to Jaffa (4 sites); and "South" - from Ashdod to Zikim (4 sites) (see Fig. 1).

2.2. Laboratory work

The sampled material was fixed in 4% formalin for visual inspection and in order to preserve the biota collected in these samples. The plastic particles in the samples were inspected and sorted in the laboratory, initially by means of a magnifying glass and subsequently by a Motic SMZ171 stereo microscope and a Moticam3 adjustable camera and Canon *Power Shot* A580 to photograph and examine the particles at higher magnification. The plastic particles were sorted into three size classes: <0.3 mm, 0.3–5 mm and 5 mm–2.5 cm - defined as mesoplastic. The intermediate size class (0.3–5 mm) was further analyzed and subdivided using the following criteria: type (e.g., fragment, fishing line filament, thin film, pellet, foam) and color (e.g., Light (i.e., White-Transparent), Green, Blue, Red and Dark (i.e., Grey-Black)), as indicated in Shaw and Day (1994).

"Fragments" are defined as particles of different colors that are hard or flexible but do not tear when pulled, nor do they shatter into many small pieces when pressed with a dissecting needle. Plastic resin "pellets" (1–5 mm in diameter) are spherical particles used in the plastic extrusion industry (Mato et al., 2001) and are usually white, though other colors also occur; weathering will cause them to darken. The pellet's texture is similar to a fragment and does not crack when probed with a dissecting needle.

"Foam" includes particles that have a spongy texture. The foam is mostly white or yellow and tends to have biofouling on it. "Fishing line filaments" are mostly cylindrical, 0.1 mm diameter, shiny, pigmented and transparent. "Thin films" are smaller than 0.1 mm in width and tend to be flat, though not necessarily. Thin films are hard and do not tend to break or deform when pressed with a dissecting needle. Many soft thin films and fibers were observed in the samples, but it was not clear that they were plastic, so they were not included in the results.

3. Results

During July 2013–May 2015 a total of 94,417 microplastic particles (0.3–5 mm) from the 108 net-tow samples were measured and recorded, with a mean value of 7.68 ± 2.38 particles/m^3 (for the top 10 cm of

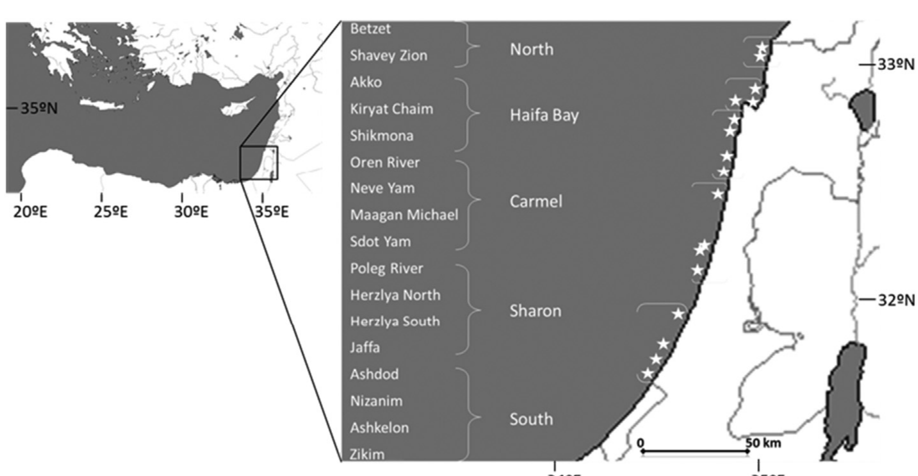

Fig. 1. Map of the 17 sampling sites along the Israeli Mediterranean coast (Betzet is the northernmost star and Zikim is the southernmost), shown with the geographical clusters for all sites.

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