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Floating debris in the Mediterranean Sea

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ABSTRACT

Results from the first large-scale survey of floating natural (NMD) and anthropogenic (AMD) debris (>2 cm) in the central and western part of the Mediterranean Sea are reported. Floating debris was found throughout the entire study area with densities ranging from 0 to 194.6 items/km^2 and mean abundances of 24.9 AMD items/km^2 and 6.9 NMD items/km^2 across all surveyed locations. On the whole, 78% of all sighted objects were of anthropogenic origin, 95.6% of which were petrochemical derivatives (i.e. plastic and styrofoam). Maximum AMD densities (>52 items/km^2) were found in the Adriatic Sea and in the Algerian basin, while the lowest densities (<6.3 items/km^2) were observed in the Central Tyrrhenian and in the Sicilian Sea. All the other areas had mean densities ranging from 10.9 to 30.7 items/km^2. According to our calculations, more than 62 million macro-litter items are currently floating on the surface of the whole Mediterranean basin.

1. Introduction

The ubiquitous presence of anthropogenic debris in the marine environment is now recognized as one of the most pervasive pollution problems affecting the oceans worldwide (UNEP, 2005, 2009; Sheavly and Register, 2007; Moore, 2008). Vast debris accumulation zones have been identified in all the main oceanic gyres (Moore et al., 2001; Pichel et al., 2007; Martinez et al., 2009; Law et al., 2010; Morét-Ferguson et al., 2010; Eriksen et al., 2013; Ryan, 2013a) and despite a growing recognition of the problem, increasing amounts of litter are being found resting on the seabed, floating on the ocean's surface, or stranded on coastlines throughout the world (Thompson et al., 2004; Barnes, 2005; Katsanevakis, 2008; Barnes et al., 2009, 2010; Ryan et al., 2009; Thiel et al., 2013; Goldstein et al., 2013; Schlining et al., 2013).

Far from being an aesthetic problem, this massive invasion of floating debris constitutes an environmental and economic threat which, together with other global key issues such as overfishing, global warming and ocean acidification, seriously jeopardize the biodiversity of marine ecosystems and the goods and services they provide (Sutherland et al., 2010; CBD, 2012). Negative interactions between marine debris and marine organisms have been reported for 663 different species (CBD, 2012). With this representing a 40% increase since the last review (Laist, 1997). Entanglement or ingestion of floating debris by marine mammals, sea birds, turtles, fishes and other animals is a well reported phenomenon of increasing magnitude (see for reviews: Laist, 1997; Derraik, 2002; Allsopp et al., 2006; Katsanevakis, 2008; Schuyler et al., 2013). Drifting debris has been found also to act as a dispersal vector for invasive marine species (Barnes, 2002; Barnes and Fraser, 2003; Barnes and Milner, 2005; Gregory, 2009), bloom-forming algae (Masó et al., 2003), bacterial pathogens (Harrison et al., 2011; Carson et al., 2013; Zettler et al., 2013) and organic and inorganic contaminants (Mato et al., 2001; Teuten et al., 2009; Rios et al., 2010; Engler, 2012; Holmes et al., 2012; Tanaka et al., 2013). In addition, the socio-economic repercussions of marine litter include damages to fishing gear and aquaculture plants (Nash, 1992; Havens et al., 2008; McIlgorm et al., 2011), the threat of floating debris to navigation (Jones, 1995; Sheavly, 2005), the reduced recreational value of beaches and coasts and the subsequent loss of income to the tourism industry and increase in the cost of clean-up activities for local governments (Ballance et al., 2000; Hall, 2000; Mouat et al., 2010).

In a recent numerical model aimed at identifying the accumulation zones of floating debris in the world's oceans, the Mediterranean Sea was found to have one of the highest concentrations of marine litter in the world, potentially retaining between 6% and 8% of all the particles introduced into the model (Lebreton et al., 2012). However, despite being recognized as a singularly sensitive ecosystem (Galil et al., 1995; Barnes et al., 2009; Galgani et al., 2010), very few data are presently available on the distribution, types, quantities and sources of marine debris in Mediterranean waters, and no information is available at the basin scale.

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Most of the studies conducted to date, have been focusing on beach litter (Shiber, 1982; Shiber, 1987; Shiber and Barrales-Rienda, 1991; Golik and Gertner, 1992; Gabrielides et al., 1991; Tudor et al., 2002; Martinez-Ribes et al., 2007; Ariza et al., 2008; UNEP/MAP/MEDPOL, 2009; Turner and Holmes, 2011; Kordella et al., 2013), and on the accumulation of marine debris on the sea floor (Bingel et al., 1987; Galil et al., 1995; Galgani et al., 1995b,a, 1996, 2000; Stefatos et al., 1999; Katsanevakis and Katsarou, 2004; Koutsodendris et al., 2008; Güven et al., 2013; Mifsud et al., 2013; Ramirez-Llodra et al., 2013; Sánchez et al., 2013). Floating debris has received less attention. Four studies dealt with the abundance of neustonic microplastics (Kornilios et al., 1998; Collignon et al., 2012; Fossi et al., 2012; Hagmann et al., 2013), and only a few studies have been published on the abundance of floating macro and mega debris in Mediterranean waters (Morris, 1980; Saydam et al., 1985; McCoy, 1988; Aliani et al., 2003; UNEP/MAP/MEDPOL, 2009; Topcu et al., 2010).

The EU Marine Strategy Framework Directive (MSFD, 2008/56/EC) was launched in 2008 with the main goal of achieving Good Environmental Status (GES) of European marine waters by 2020. Eleven qualitative descriptors were defined, including marine litter (Descriptor 10), which was recognized as one of the main causes of marine pollution. All EU member states were required to undertake an initial evaluation on the characteristics of litter in the marine and coastal environment and to monitor trends and dynamics of litter accumulation, as well as its potential interactions with marine life (Galgani et al., 2010, 2013). Within this framework, we present results from the first large-scale survey of floating macro (2–10 cm) and mega (>10 cm) debris on the surface of the central and western Mediterranean Sea, with the main goal of providing new information on the abundance, distribution and composition of marine litter in the Mediterranean region. Debris abundance and distribution are also discussed in relation to natural and anthropogenic processes such as river discharge, coastal population density, oceanographic features, fishing, shipping and touristic activities.

The abundance and distribution of floating debris in the world's ocean has been widely estimated using surface net trawls (e.g. Gregory et al., 1984; Ryan, 1988; Day et al., 1990; Shaw and Day, 1994; Moore et al., 2001; Yamashita and Tanimura, 2007; Zhou et al., 2011; Law et al., 2010; Collignon et al., 2012; Van Cauwenberghe et al., 2013). However, such surveys typically focuses only on small litter items (<2 cm) and they generally tend to under-sample the patchy distribution of larger debris items at sea (Barnes et al., 2009; Ryan et al., 2009). Aerial surveys (Ryan, 1988; Lecke-Mitchell and Mullin, 1997; Pichel et al., 2007) and remote sensing techniques (Kako et al., 2012; Mace, 2012; Veenstra and Churnside, 2012) have also been used to sample large areas rapidly, but these studies are often too expensive and they are unlikely to yield reliable information on different litter types especially for smaller items (Ryan, 2013b). Shipboard sighting surveys instead, have been extensively used to monitor the abundance and distribution of floating debris in the North Pacific Ocean (Venrick et al., 1973; Dahlberg and Day, 1985; Day and Shaw, 1987; Mio and Takehama, 1988; Matsumura and Nasu, 1997; Shiomoto and Kameda, 2005; Titmus and Hyrenbach, 2011; Zhou et al., 2011; Goldstein et al., 2013), North Sea (Dixon and Dixon, 1983; Thiel et al., 2011b), South Pacific (Thiel et al., 2003; Hinojosa and Thiel, 2009; Hinojosa et al., 2011; Thiel et al., 2013), Indian Ocean (Ryan, 2013b), Atlantic Ocean (Barnes and Milner, 2005; Ryan, 2013a), and in waters around Antarctica (Barnes et al., 2010). They have proven useful in providing a continuous record of macro- and mega-debris that can be analyzed to multiple spatial scales and since they do not require dedicated ship time, they can be easily conducted from ships of opportunity (e.g. UNEP/MAP/MEDPOL, 2009), or as a by product of oceanographic cruises, providing in this way, a powerful inexpensive tool for large-scale monitoring of debris accumulation patterns (Ryan, 2013b).

2. Methods

2.1. Shipboard sighting surveys

Visual surveys of floating debris were carried out during three different research cruises aboard R/V Urania between May and October 2013. The Adriatic Sea was surveyed during the CoCoPro13 cruise (8–21 May 2013) while the central and western parts of the Mediterranean Sea were covered during the cruises Venus2-ArgoIT (5–25 June 2013) and Ichnussa13 (20–29 October 2013).

Observations were all made by the same observer during regular navigation of the ship at a speed of $\sim$10 knots. The observer scanned the sea surface from the bearing deck of the research vessel ($\sim$5 m above sea level and $\sim$30 the bow) and recorded UTC time, GPS coordinates, size and type of all macro-debris items ($>$2 cm) sighted off the starboard side of the track-line. Sightings were all performed during daylight hours, by naked eye and only under good weather conditions (Beaufort sea state $<$5). 7×50 binoculars were used to clearly identify more distant objects. Data collected in poor visibility conditions (i.e. wind >21 kts and wave height >2 m), when the detection probability within the transect width was severely compromised, were removed from the dataset and were not considered in further analysis. Meteo-marine data such as wind speed and direction, sea surface temperature and salinity, were automatically recorded by the ship's data logger. The survey effort was split into 30-min transects (mean length: 9.21 ± 1.05 km) in order to standardize fatigue for the observer, enhance the number of replicates and better account for the patchy distribution of debris at sea. The exact distance covered during each transect was calculated from GPS start and stop positions using the haversine formula (Sinnott, 1984).

After being recorded, every item was allocated to one out of four size classes (<10, 10–50, 50–100, >100 cm) and to one of two major type categories: Anthropogenic Marine Debris (AMD) and Natural Marine Debris (NMD). AMD was further subdivided into styrofoam (expanded polystyrene), plastic (mainly fragments, plastic bags, bottles and containers) and others (e.g. manufactured wood, aluminum cans, rubber strips, glass bottles, paper and cardboard), while NMD was classified as wood (mainly logs, trunks, branches and canes), algae (mainly branches of *Cystoseira* spp. and *Sargassum* spp.) or others (e.g. *egagropili* of *Posidonia oceanica*, cuttlebones, bird feathers, sponges or pumice).

The survey area was subdivided into 14 sectors (Fig. 1) following the METEOMED™ subdivisions of the Mediterranean Sea for marine weather forecasts: Central Adriatic (A), Southwestern Adriatic (B), Southeastern Adriatic (C), Strait of Otranto (D), Northwestern Ionian Sea (E), Sicilian Sea (F), Strait of Sicily (G), South Tyrrhenian Sea (H), Central Tyrrhenian Sea (I), Corsica Channel (M), Sea of Sardinia (K), Balearic Sea (L), Algerian Basin (M) and Sardinia Channel (N). The number of surveyed transects per sector varied from 3 to 38, mainly due to different weather conditions, navigational schedules and operational needs during the cruises. Location of all transects and sectors is reported in Fig. 1.

2.2. Abundance estimates

A simplified distance sampling technique was used to estimate AMD and NMD densities taking into account the decrease in litter detectability with increasing distance from the observer. In order to do so, during the last cruise (Ichnussa13) the perpendicular distance of all sighted objects was estimated by knowing that the distance from an item when abeam, equals the distance traveled