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Seabed litter composition, distribution and sources in the Northern and Central Adriatic Sea (Mediterranean)

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ABSTRACT

Detecting the origin of marine benthic litter is fundamental for developing policies aimed at achieving the Good Environmental Status in European Seas by 2020, as requested by the Marine Strategy Framework Directive (MSFD). The abundance and composition of benthic litter in the Northern and Central Adriatic Sea were investigated at 67 stations with bottom trawl nets. Average density of benthic litter was 913 ± 80 items/km^2, ranking the Adriatic as one of the most polluted basins worldwide. Plastic was dominant in terms of numbers (80%) and weight (62%), and mainly consisted in bags, sheets and mussel nets. Higher quantities of litter were found in coastal areas, especially in front river mouths, coastal cities and mussel farms. In deep waters, litter hotspots were associated with most congested shipping lanes, indicating an additional litter input to the basin. Benthic litter composition resulted to be largely driven by the vicinity to local sources, i.e. mussel farming installations and most congested shipping routes. These findings provide useful insights to set measures to manage marine litter in the Adriatic region, and possibly to minimize this anthropogenic pollution.

1. Introduction

Due to its environmental, economic, safety, health and cultural impacts, marine litter has been recognized as a 21st century global challenge (Sheavly and Register, 2007). Based on the definition from UNEP (2009), marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment". Descriptor 10 of the EU Marine Strategy Framework Directive (MSFD) is focused on marine litter and states that the Good Environmental Status (GES) is achieved when "the composition, amount and spatial distribution of litter on the coastline, in the surface layer of the water column and on the seabed is at the level that does not cause harm to the coastal and marine environment".

The problems generated by marine litter can be attributed both to the amount of debris generated and its nature. Global production of waste (about a half of which represented by non-biodegradable materials) reached 3.4 million tons in 2012 (Ioakeimidis et al., 2014) and it is estimated that 4.8–12.7 million tons of man-made debris enter the world seas every year (Jambeck et al., 2015), persisting in marine environment for years, decades and even centuries. Materials include plastic above all, followed by rubber, glass, metal, processed wood, paper and textile. According to its nature, weight and shape, marine litter can rapidly settle down on the seabed and accumulate in the vicinity of its source or float on sea surface, travel long distances and eventually sink down to the seafloor due either to the increase of its weight for water filling and/or for biological fouling (Lee et al., 2006).

The sources of litter reaching the marine environment can be broadly categorized to whether they are land or sea based (UNEP, 2005). Land-based sources include tourism and recreational uses of the coast, domestic, agricultural and industrial activities, harbors, untreated municipal sewage and improper waste management. Litter from land can enter the marine environment through a series of pathways, including wind-blow, water bodies (e.g. rivers, lakes, ponds, ephemeral streams), municipal drainage systems, sewage inputs as well as natural events, such as flooding, melting of snow, heavy rainstorms, earthquakes and tsunami. Sea-based sources of marine litter include merchant shipping, ferries and cruise liners, commercial and recreational fishing vessels, military

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fleets and research vessels, pleasure crafts, offshore installations such as oil and gas platforms, drilling rigs and aquaculture sites (Galgani et al., 2013a).

Detecting the origin of litter found on the seafloor is the crucial point for developing appropriate policies and regulations at different spatial scale for the sustainable management of the marine and coastal environment. Indicator 10.1.1 of the MSFD consists in "trends in the amount of litter in the water column (including floating at the surface) and deposited on the seafloor, including analysis of its composition, spatial distribution and, where possible, source". However, only occasionally litter can be directly linked to a specific source (e.g. fishing-related items): on most occasions sources can be numerous, with little or no indication available on litter items to easily allow attribution (Ioakeimidis et al., 2014). For example, an unlabeled plastic bottle found on the seafloor could have been discarded at sea by a ship, or transported from inland by a river, as well as abandoned by a tourist on the beach. At present, there is no explicit or widely used methodology that facilitates the sourcing of marine litter (Koutsodendris et al., 2008; Ioakeimidis et al., 2014), due to the usually subjective/local nature of this information.

Tudor et al. (2002) suggested that four main factors might affect the identification of sources: (1) correct item identification (the correct identification of the activity of its origin is critical for source identification); (2) function (that reflects litter item usage); (3) quantity; and (4) associations among items. Other important factors that may be indicative of litter sources include distance from the coast, particularly from large cities and river estuaries, as well as distance from shipping routes and aquaculture/fish-farming installations (Koutsodendris et al., 2008). Misidentifying litter is a common practice among researchers, especially for fragments and damaged items, and this bias can be reduced by photographing the catch (Tudor and Williams, 2001).

Up to date, data on the deposits of macro litter on the seafloor of the Adriatic region derive from voluntary divers (e.g. Ljubec, 2013), submersibles, remote operated vehicles (Galgani et al., 2000), and trawl surveys (Galil et al., 1995; Galgani et al., 2000; Petović and Marković, 2013; Strafella et al., 2015). However, studies specifically addressing the problem of seafloor litter sources in the Adriatic are lacking. Thus, taking into account the urgency of targeted measures toward the achievement of GES by 2020, the present study intends to quantify litter abundance, composition and spatial distribution on the seafloor of the Northern and Central Adriatic Sea, to identify the main sources and to estimate the contribution of different human activities. The final aim is to investigate the role played by main sources occurring in this area in order to provide insights into future approaches to marine litter management.

2. Material and methods

2.1. Study area

The Adriatic Sea is an elongated semi-enclosed basin within the Mediterranean Sea, extending for 138,600 km^2 (Cushman-Roisin et al., 2001). The northern section is very shallow and gently sloping, with an average depth of about 35 m, while the central and the southern are on average 140 m deep, with the two Pomo pits reaching 260 m. The majority of the seabed is located on the continental shelf and is covered by sandy and muddy sediment with different grain size and composition, generally coming from the Italian northwest coast (Russo and Artegiani, 1996). Sediments are largely carried by the large number of rivers discharging into it, i.e. the Po (the most relevant, which drains the industrial centers of large cities, such as Milan and Turin), Adige, Piave, Reno and Brenta.

Two main currents dominate the Adriatic circulation: the West Adriatic Current (WAC) flowing toward South-East along the western coast, and the East Adriatic Current (EAC) flowing North-East along the eastern coast. Two main cyclonic gyres occur, one in the northern part and the other in the South. Bora (from North-East) and Sirocco (from South-East) are the major winds blowing over the Adriatic Sea. In the Northern and Central Adriatic Sea, a vertical thermohaline front, running parallel to the coast and extending throughout the water mass, separates the coastal waters from the open sea ones (Artegiani et al., 1997). This retains the materials that flow from rivers and other water sources within the coastal area.

The Adriatic basin is heavily stressed by many human activities. Intense marine traffic derives from commercial, fishing and recreational activities (Carić and Mackelworth, 2014). It hosts hundreds offshore platforms from the oil and gas industries. Fishery and mussel aquaculture along the Italian coast, and fish farming along the Croatian coast, are crucial economical sources for countries facing the basin. Moreover, the northwestern Adriatic coast is home of a thriving tourism industry (Munari et al., 2015).

2.2. Data collection

Monitoring was conducted in the GFCM Geographical Sub-Area 17 (Northern and Central Adriatic Sea) within the framework of the SoleMon project during fall 2014, by the Institute of Marine Sciences of the National Research Council (CNR-ISMAR, Italy) in cooperation with the Italian National Institute for Environmental Protection and Research (ISPRA, Italy), the Institute of Oceanography and Fisheries (IOF, Croatia), and the Fisheries Research Institute of Slovenia (FRIS, Slovenia). Sampling was performed with a *rapido* trawl (a modified beam trawl) at 67 stations distributed over the area following a depth-stratified random design (0–30 m depth: 39 stations; 31–50 m depth: 17 stations; 51–100 m depth: 11 stations) (Fig. 1a). The number of stations in each stratum is proportional to its surface. For a detailed description of the sampling method, see Strafella et al. (2015).

To evaluate seafloor litter everything that was caught by the *rapido* trawl and that was visible to the naked eye was taken into account. Litter items were separated from the catch, photographed, weighted and classified according to the Master List of categories of the guidance document (TGML/JRC; Galgani et al., 2013b). Litter items were further subdivided considering 6 major categories according to the nature of the material: plastic, metal, glass, rubber, natural and other (Table 1).

2.3. Sources identification

In order to detect major contributions of waste on the seafloor, litter items were classified into three categories based on their source (land, vessels and fisheries) and into six categories related to activity of their origin (recreation, domestic, sanitary, industrial, fishing, aquaculture) (Koutsodendris et al., 2008). The category "mix" was added to both sub-classifications since many litter items (e.g. sheets, plastic bottles, bags) have an uncertain source and may come from multiple activities (Table 1). The number of items and the weight of each litter category found in each haul were standardized to the square kilometer on the basis of the swept area method.

Similarly to previous findings in other areas around the world (Kanehiro et al., 1996; Katsanevakis and Katsarou, 2004; Ramirez-Llodra et al., 2013; Güven et al., 2013; Rech et al., 2014), in the Adriatic Sea it is expected that the majority of marine litter derives from inadequate management of urban solid waste and direct discharge into rivers and coastal waters, dumping from vessels and fishing/aquaculture activities. Therefore, in order to

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