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The first assessment of marine debris in a Site of Community Importance in the north-western Adriatic Sea (Mediterranean Sea)

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ABSTRACT

At present, few studies have investigated the marine litter abundance, composition and distribution on rocky bottoms due to sampling constraints. We surveyed by means of the ROV imaging technique a system of biogenic rocky outcrops classified as a Site of Community Importance in the Adriatic Sea. A mean density of 3.3 (±1.8) items/100 m^2 was recorded, with a strong dominance of fishing- and aquaculture-related debris, accounting for 69.4% and 18.9% of the total, respectively. The abundance of litter over the rocky bottoms was significantly higher than that on soft substrates, and its spatial distribution proved to be related to hydrographic factors. Litter-fauna interactions were high, with most of the debris (65.7%) entangling or covering benthic organisms, in particular habitat constructors such as the endangered sea sponge *Geodia cydonium*. Unless appropriate measures are undertaken to address this problem, the abundance of marine litter in the area is likely to increase.

1. Introduction

Every year, millions of tons of solid waste is estimated to enter marine ecosystems worldwide (UNEP, 2016), making this issue one of the fastest growing threats to the ocean's health. These wastes are derived from every type of human activity and, after escaping management procedures, end up in the environment. Commercial and recreational shipping, fishing activities, aquaculture, river discharge, urban and industrialized areas, legal and illegal dumpsites close to the shoreline, recreational use of the coast and ports are all recognized as important sources of marine litter (Sheavly and Register, 2007). As a result, marine litter has become ubiquitous in the world's oceans, from the shorelines to the deepest areas (Thompson et al., 2009).

Great concern has recently been shown for how this huge amount of waste may affect the marine environment; thus, the issue was introduced as one of the descriptors of the Marine Strategy Framework Directive (MSFD) launched by the European Commission (Directive 2008/56/EC). A reduction in the litter already present in the marine environment and the prevention of further inputs are expected to be achieved by 2020, in conformity with the overall goal of reaching a Good Environmental Status (GES) in European waters. Consequently, it is now of crucial importance to identify the main areas of accumulation and the most threatened habitats to define a strategy for limiting the amount of marine litter and restoring natural ecosystems.

On the seabed, accumulation occurs in areas of complex geomorphology and under favourable hydrodynamic conditions (Galgani et al., 2000; Watters et al., 2010). Once settled on the seabed, the debris may alter the surrounding habitats by providing a previously absent hard substrate, potentially covering large portions of the settled communities (Saldanha et al., 2003), preventing gas exchange, causing chemical and physical pollution (Brown and Macfadyen, 2007), and interfering with life on the seabed (UNEP, 2016). However, despite their vulnerability to marine litter, at present, few hard-bottom environments have been investigated in terms of litter distribution. The main reason for this lack of investigation is the methodology commonly used for litter investigation on the seafloor, i.e., trawl sampling with fishing or research vessels (Galil et al., 1995; Galgani et al., 2000; Moore and Allen, 2000; Pham et al., 2014), which is a technique that is not viable on rocky substrates.

Recent studies have addressed this gap in knowledge using visual investigations: scuba divers in shallow coastal and/or coral reef

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environments (e.g., Donohue et al., 2001; Bauer et al., 2008; Abu-Hilal and Al-Najjar, 2009), submersibles (e.g., Galgani et al., 1996; Watters et al., 2010) and remotely operated vehicles (ROVs) in deep waters (e.g., Schlining et al., 2013; Angiolillo et al., 2015; Oliveira et al., 2015). These studies highlight the role of rocky substrates as accumulation points, with densities ranging from 0 to 600 items/100 m^2. Contrary to the global data, which identifies the marine litter as mostly land-sourced, in these environments, derelict fishing gear (DFG) often contributes up to 60–90% of the total amount of litter (Chiappone et al., 2005; Bauer et al., 2008; Abu-Hilal and Al-Najjar, 2009; Watters et al., 2010; Angiolillo et al., 2015; Oliveira et al., 2015). Moreover, the number of DFG - nets, lines, traps, and other recreational or commercial fishing equipment that has been lost, abandoned, or deliberately discarded (Sheavly, 2007) - is increasing in the ocean (Macfadyen et al., 2009; Morishige and McElwee, 2012; Bilkovic et al., 2014; Angiolillo et al., 2015; Wilcox et al., 2015).

Among all types of litter lying on the sea bottom, DFG is probably the major cause of benthic mechanical degradation (Chiappone et al., 2005; Bilkovic et al., 2014). In particular, in rocky environments, DFG tends to remain entangled on the rocks or on the habitat-forming species, abrading, breaking and suffocating the organisms that live on the substrate (e.g., corals, sponges, bryozoans) (Chiappone et al., 2005; Bauer et al., 2008; Bo et al., 2014; Angiolillo et al., 2015). Furthermore, before being colonized by epibiontic organisms, DFG can result in ghost fishing by catching a large spectrum of organisms for a long time (Matsuoka et al., 2005; Brown and Macfadyen, 2007). DFG also covers natural crevices, reducing the habitat complexity (Orejas et al., 2009; Bo et al., 2014; Fabri et al., 2014). DFG may further entangle divers and swimmers and damage the propellers and rudders of boats and vessels, representing a danger for recreational activities.

Because the majority of fishing gear is now made of non-biodegradable synthetic fibres, they may persist in the marine environment for decades (Macfadyen et al., 2009). Indeed, because solar radiation and thermal oxidation are the primary factors that influence the degradation of plastics, the degradation rate on the seafloor is extremely low (UNEP, 2016). Unfortunately, DFG removal is often prohibitive due to both high costs and the risk of provoking further mechanical impacts on the benthic community (Antonelis et al., 2011).

The present study aimed to assess and quantify the occurrence, abundance and composition of marine litter in the EU Site of Community Importance (SCI) "*Tegnùe* of Chioggia" (Natura 2000 Italian network - IT3250047), an area in the north-western Adriatic Sea (Mediterranean Sea) characterized by coralligenous biogenic rocky outcrops. We investigated the distribution of marine litter by using the ROV-imaging technique. The visible effects of marine litter on the benthic community, with a particular focus on DFG, are also described.

2. Materials and methods

2.1. Study area

The study area is located in the north-western Adriatic Sea, along the coast of Chioggia, Italy (Fig. 1). Despite its otherwise homogeneous seabed, mostly made of mobile, silty-sandy sediments (Russo and Artegiani, 1996), the north-western Adriatic Sea hides a unique system of rocky outcrops that host rich communities of large suspension-feeders and an associated high biodiversity of fish and invertebrates (Casellato and Stefanon, 2008; Ponti et al., 2011; Falace et al., 2015). The presence of rich benthic macroinvertebrate populations is favoured by the unique physical, morphological and oceanographic characteristics of the northern Adriatic Sea (Zavatarelli et al., 1998; Ponti et al., 2011).

These subtypes of coralligenous habitats were historically referred to by fishermen as "*Tegnùe*" (which means in the local dialect "hold") because of their property of entangling the nets. They are scattered from 5 to >40 km offshore along the Italian coasts, from the Gulf of Trieste to the River Po delta (Brambati et al., 1983). These formations are elevated up to 2–3 m over the seabed and extend from a few to several hundreds of square metres (Gabriele et al., 1999). Some outcrops are characterized by large horizontal surfaces, whereas others are composed of scattered conglomerates of small rocks (Falace et al., 2015).

The most extended system of outcrops is located off the coast of Chioggia and has been protected by both recreational and commercial fisheries since 2002, first as a No-Take Zone (NTZ) and then, in 2011, as an SCI (Habitats Directive 92/43/EEC). The protected area includes four sub-areas: a wider one (Area 1) located between 6 and 10 km from the coast, with a surface of 22 km^2, and three small areas (Areas 2–4) between 13 and 15 km offshore, accounting in total for 4.5 km^2 (Fig. 1).

2.1.1. Oceanography of the northern Adriatic Sea

The northern Adriatic Sea is a semi-enclosed basin characterized by shallow waters (15–40 m depth), intense seasonal thermohaline variability and considerable freshwater inflow, originating mainly from the Po and the other rivers along the Italian coast. Two main currents dominate the northern Adriatic Sea, sustaining a general cyclonic circulation. Riverine input generates the intense Western Adriatic Current (WAC), which flows south-eastward along the Italian coast, whereas the compensating Eastern Adriatic Current (EAC), which is saltier and warmer, flows north-westward along the Croatian coast (Poulain et al., 2001).

The rivers located along the Italian coast are the major source of nutrients of the Adriatic Sea and their significant productivity characterizes the WAC frontal system, which is the most eutrophic area of the basin (Solidoro et al., 2009). The WAC also transports the materials carried by the rivers along the coast. These conditions, on the one hand, might favour the development of benthic communities and, on the other hand, make this coastal area particularly prone to the accumulation of marine litter.

2.1.2. Sources of marine litter

Both urban and industrial areas are concentrated along the Adriatic coast as well as many maritime activities (aquaculture, fisheries and recreational activities). Potential litter inputs from land include river discharge, with the Po being the most relevant followed by the Adige (Fig. 1), and a thriving tourism industry (Munari et al., 2016). The heavy marine traffic is derived from both commercial and recreational activities. In particular, its richness in fishery resources makes the northern Adriatic Sea the most exploited area of the Mediterranean Sea (Mazzoldi et al., 2014). The port of Chioggia, located in the southern part of the Venice Lagoon, hosts the most important fishing fleet in the basin, with all the different métiers well represented and a total of 213 active fishing boats in 2016, according to the EU Fleet Register. Moreover, the area hosts 37 mussel farms with an annual production of approximately 11,096 tons, nearly 15% of the national mussel culture production (Prioli, 2008).

2.2. Surveys

The data on marine debris were collected during two expeditions performed in May–June 2014 and July 2015 on board the R/V *Astrea* of the Italian National Institute for Environmental Protection and Research (ISPRA). All 4 sub-areas of the SCI were surveyed; however, due to their different extensions and conformations, different monitoring schemes were applied: Area 1, flat and widespread, was investigated through straight transects constituting a grid. As no previous information on the marine litter distribution was available in the area, the positions of the transects in the grid were defined randomly. The number of transects was determined with the goal of maximizing the extent of the area surveyed while maintaining the high detail needed to detect

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