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Characterization of microplastic litter from oceans by an innovative approach based on hyperspectral imaging

Silvia Serranti [a,*], Roberta Palmieri [a], Giuseppe Bonifazi [a], Andrés Cózar [b]

[a] *Department of Chemical Engineering, Materials and Environment, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy*
[b] *Departamento de Biología, Facultad de Cc. del Mar y Ambientales, CEIMar, Universidad de Cádiz, E-11510 Puerto Real (Cádiz), Spain*

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ABSTRACT

An innovative approach, based on HyperSpectral Imaging (HSI), was developed in order to set up an efficient method to analyze marine microplastic litter. HSI was applied to samples collected by surface-trawling plankton nets from several parts of the world (i.e. Arctic, Mediterranean, South Atlantic and North Pacific). Reliable information on abundance, size, shape and polymer type for the whole ensemble of plastic particles in each sample was retrieved from single hyperspectral images. The simultaneous characterization of the polymeric composition of the plastic debris represents an important analytical advantage considering that this information, and even the validation of the plastic nature of the small debris, is a common flaw in the analysis of marine microplastic pollution. HSI was revealed as a rapid, non-invasive, non-destructive and reliable technology for the characterization of the microplastic waste, opening a promising way for improving the plastic pollution monitoring.

1. Introduction

The increasing presence of plastic litter in the marine environment is a worrying problem, contaminating oceans at global scale (e.g., Cózar et al., 2014, 2015, 2017). The accumulation of these materials in the environment has dramatically increased with the expansion of plastic products and their improper disposal at their end-of-life (e.g., Andrady, 2017; Barnes et al., 2009; Hidalgo-Ruz et al., 2012). Marine plastic litter comprises a heterogeneous assemblage, including items of a wide range of shapes, size and chemical composition. Yet, there is scientific consensus pointing to plastic litter as the most commonly litter type found on beaches, seafloor, and water (e.g., Pham et al., 2014, Suaria and Aliani, 2014, Munari et al., 2016). Waste polymers usually found in nature are mainly those produced by the industry, as polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS) and polyvinylchloride (PVC) (Rocha-Santos and Duarte, 2015; Suaria et al., 2016).

Plastic particles smaller than 5 mm, the so-called microplastics, are particularly ubiquitous in marine environment (Horton et al., 2017; Cózar et al., 2014, 2015, 2017). Microplastics can be derived from the breakdown of larger objects due to the photo-degradation, oxidation and wave action (Andrady, 2011; Claessens et al., 2013), leading to the generation of abundant small-sized particles (Cózar et al., 2014). Also, plastics manufactured as microscopic sized particles can directly enter the ocean. They are typically used in the cosmetic industry as exfoliants, facial cleaners or "scrubbers", in air-blasting technology or they are virgin plastic pellets, precursors to other products. Microplastics can float at the sea surface when they are less dense than seawater, be suspended in the water column or accumulate in the marine sediments. All these small particles can easily enter the marine food chain and potentially transfer hazardous substances to the biota (Anderson et al., 2016). Because of their small size, microplastic debris are extremely difficult to remove from marine environments (Jambeck et al., 2015).

There is rising international concern regarding the accumulation of microplastics in the marine environments (UNEP, 2016). The Marine Strategy Framework Directive (MSFD) of the European Union established a framework for each Member State to aim the achievement or the maintenance of the Good Environmental Status (GES) for the marine environment by 2020 (Munari et al., 2017). More in detail, MSFD prescribes mandatory microplastic monitoring, categorizing particles according to their physical characteristics including size, shape and polymer type (Gago et al., 2016). All of these three characteristics are closely related to degradation rates, transportation processes, or impacts on the environment (Hidalgo-Ruz et al., 2012). In this perspective, it is fundamental to find a practical tool to simultaneously analyze these microplastic characteristics.

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[*] Corresponding author.
E-mail address: silvia.serranti@uniroma1.it (S. Serranti).

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The polymeric classification of the microplastics or the simple chemical verification of the plastic nature of the small debris is an important limitation of the current studies dealing with marine microplastic pollution. The analytical verification of the microplastics nature is generally limited to a subset of items (e.g., Cózar et al., 2014; Pedrotti et al., 2016; Martí et al., 2017) or even overlooked. This is mainly due to the time required by robust analytical methods such as Fourier-Transform Infrared (FTIR) spectroscopy. FTIR can be problematic regarding the preparation of samples (Crawford and Quinn, 2017). In fact, for example using FTIR as transmission based analytical techniques it is mandatory that samples are transparent to let infrared wavelengths pass into and this condition is not often possible. On the other hand, attenuated total reflection FTIR (ATR-FTIR) requires that the sample is sufficiently in contact with the device and small particles are commonly lost during sample preparation since physical clamping of the samples can be difficult. In addition, FTIR analysis is particularly complex when applied to small and irregular plastics (i.e. textile fibers) samples. Therefore, the visual identification of the microplastics, dependent on experience and skill of the researcher, is often the working method in the analyses of marine microplastic pollution. It is common that pieces that seem to be plastic are recognized as not plastic (Suaria et al., 2016).

From this perspective, the possibility to develop a rapid and reliable procedure for microplastic identification and characterization was explored in this work. HyperSpectral Imaging (HSI) approach represents a powerful solution for characterization, classification and quality control of different materials in several applications fields. For this reason, it has rapidly emerged and fast-grown in many fields in recent years, especially in the plastic waste sector for the identification of different polymers (e.g., Serranti et al., 2011; Hu et al., 2013; Palmieri et al., 2014; Bonifazi et al., 2015a,b; Luciani et al., 2015; Serranti et al., 2015). In the marine litter monitoring field, hyperspectral remote sensing is spreading for large pieces of debris (i.e. derelict fishing gear) detection (Mace, 2012; Veenstra and Churnside, 2012), whereas, concerning marine microplastics, some studies were already addressed to test polymer recognition in seawater filtrates from the Baltic Sea through HSI based tools acting in different wavelengths (Karlsson et al., 2016). Using an extensive sample from seas and oceans worldwide, the present work aims to assess the feasibility of obtaining comprehensive microplastic classifications, combining morphological and morphometrical analyses together with polymer determinations, based on HSI in the Short-Wave Infrared (SWIR) range.

2. Materials and methods

2.1. Marine microplastic waste samples

The analyzed marine microplastics were sampled by using different surface-trawling plankton nets (i.e. neuston and manta nets) in surveys described in previous reports (Cózar et al., 2014, 2015, 2017).

From the source samples, 738 particles (694 fragments and 44 fishing lines), clustered in 7 samples according to their collection site, were analyzed in the present study. For each sample, particles were arranged in lines and they were acquired by hyperspectral imaging system working in the SWIR (1000–2500 nm) range. In total 17 hyperspectral images, representing minimum 21 particles and maximum 105 each, were thus obtained. For each of the 7 samples (Table 1), at least two hyperspectral images were captured, except for two sample sets, coming from Mediterranean Sea (Eastern basin) and Strait of Gibraltar, that were respectively split in 5 (Image 4.1, Image 4.2, Image 4.3, Image 4.4 and Image 4.5) and 3 subgroups (Image 7.1, Image 7.2 and Image 7.3) for HSI acquisition purposes (Table 1).

Since the samples were collected from the sea surface (i.e. floating particles), selected reference polymer samples characterized by a density lower than that of sea water (~1.02 g/cm^3) (Andrady, 2015) were chosen for spectral features comparison with those of the unknown samples, as polyethylene (PE), polypropylene (PP) and polystyrene (PS) (Figs. 1 and 2).

2.2. Hyperspectral imaging system

Hyperspectral imaging acquisitions were carried out at RawMaLab (Raw Materials Laboratory) of the Department of Chemical Engineering, Materials and Environment (Sapienza – University of Rome, Italy). A total of 17 hyperspectral images were acquired using SISUChema XL™ Chemical Workstation (Specim, Finland) (Table 1; Fig. 3) equipped with ImSpector™ N25E imaging spectrograph (Specim, Finland) working in the SWIR range (1000–2500 nm). A 31 mm lens with a field of view of 50 mm was adopted and 256 wavelengths were collected. Chemadaq™ software was

Table 1
Number of microplastic particles belonging to 7 samples collected in different sea and ocean sites and constituting each of the hyperspectral images acquired for every sample.

Sample code	Source site	N° hyperspectral image	Image N° items	Sample N° items
AS	Arctic Ocean	Image 1.1	25	79
		Image 1.2	54	
SAO	South Atlantic Ocean (Subtropical Gyre)	Image 2.1	23	47
		Image 2.2	24	
NPO	North Pacific Ocean (next to Hawaii Islands)	Image 3.1	35	91
		Image 3.2	56	
MS17	Mediterranean Sea (Eastern Basin)	Image 4.1	46	237
		Image 4.2	64	
		Image 4.3	30	
		Image 4.4	38	
		Image 4.5	59	
MS33	Mediterranean Sea (Northwestern Basin)	Image 5.1	27	48
		Image 5.2	21	
NAO	North Atlantic Ocean (next to Cabo Verde)	Image 6.1	25	51
		Image 6.2	26	
SG	Strait of Gibraltar	Image 7.1	38	185
		Image 7.2	42	
		Image 7.3	105	

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