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Marine biofouling organisms on beached, buoyant and benthic plastic debris in the Catalan Sea

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ABSTRACT

Plastic debris provides long-lasting substrates for benthic organisms, thus acting as a potential vector for their dispersion. Its interaction with these colonizers is, however, still poorly known. This study examines fouling communities on beached, buoyant and benthic plastic debris in the Catalan Sea (NW Mediterranean), and characterizes the plastic type. We found 14 specimens belonging to two phyla (Annelida and Foraminifera) on microplastics, and more than 400 specimens belonging to 26 species in 10 phyla (Annelida, Arthropoda, Brachiopoda, Bryozoa, Chordata, Cnidaria, Echinodermata, Mollusca, Porifera and Sipuncula) on macroplastics. With 15 species, bryozoans are the most diverse group on plastics. We also report 17 egg cases of the catshark *Scyliorhinus* sp., and highlight the implications for their dispersal. Our results suggest that plastic polymers may be relevant for distinct fouling communities, likely due to their chemical structure and/or surface properties. Our study provides evidence that biofouling may play a role in the sinking of plastic debris, as the most abundant fouled plastics had lower densities than seawater, and all bryozoan species were characteristic of shallower depths than those sampled. More studies at low taxonomic level are needed in order to detect new species introduction and potential invasive species associate with plastic debris.

1. Introduction

Plastics are synthetic organic compounds produced by polymerization of petrochemicals. Due to its mechanical properties and durability, plastic debris accumulates and persists in the environment over long time. Since the mid-XX century, production and disposal of plastic has increased dramatically, and nowadays plastic debris is ubiquitous in the marine environment. The accumulation of marine litter and plastics has been reported on beaches and shorelines (Lots et al., 2017; Andrades et al., 2018; Van der Mheen et al., 2020; Ferreira et al., 2021), the sea surface (Cózar et al., 2014; Van Sebille et al., 2015), as well as the deep sea (Woodall et al., 2014; Van Cauwenberghe et al., 2013). It has been estimated that 4.8–12.7 million metric tons of plastic waste enters the oceans every year (Jambeck et al., 2015) with more than five trillion plastic pieces floating at the surface (Eriksen et al., 2014), while an unknown amount ends up on the seafloor. Recent studies also suggest that a significant amount of plastic is trapped for several years, or even decades, in the coastal zone, stranded or settled on its way to offshore waters (Lebreton et al., 2018; Onink et al., 2021).

As the different plastic polymers have different density and buoyancy, there is heterogeneity of plastic types in different marine environments (e.g. sea surface, seafloor): plastic less dense than seawater such as polyethylene and polypropylene (density 0.85–0.98 g cm^{-3}) may float, while higher density polymers such as polyester or polyamide (density 1.1–1.4 g cm^{-3}) sink. However, colonization and biofouling of low-density floating plastic debris may decrease its buoyancy causing it to sink (Kaiser et al., 2017; Kooi et al., 2017). Biofouling communities include a variety of organisms from bacteria to algae, barnacles, bryozoans, molluscs and polychaetes (Oberbeckmann et al., 2015; Flemming and Wuertz, 2019; see review in Póvoa et al., 2021), and may also include macro-organisms that may use plastic debris for laying their eggs (e.g. cephalopods) (Gündoğdu et al., 2017).

The impact of plastic debris on marine wildlife through ingestion, entanglement and suffocation (Gregory, 2009; Capillo et al., 2020; Mancia et al., 2020) is well documented, as it is the release and transfer of organic pollutants and heavy metals (Nakashima et al., 2016; Cole et al., 2011). However, plastic debris also provides long-lasting substrates, allowing diversity of organisms to disperse widely (Barnes and

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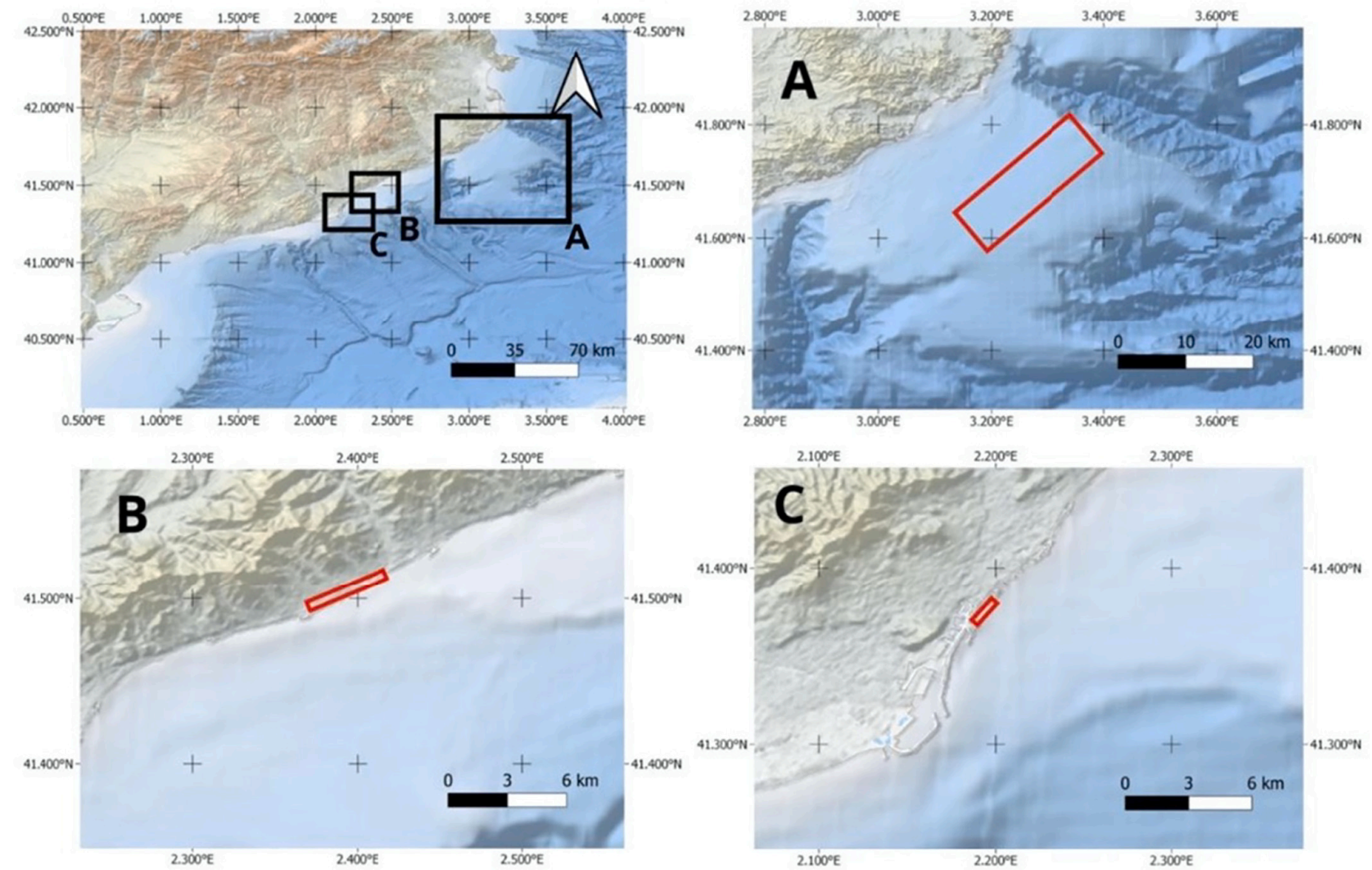

Fig. 1. Map of the study area showing the location of sampling areas for: A) Benthic plastic debris; B) beached plastic debris; C) buoyant plastic debris.

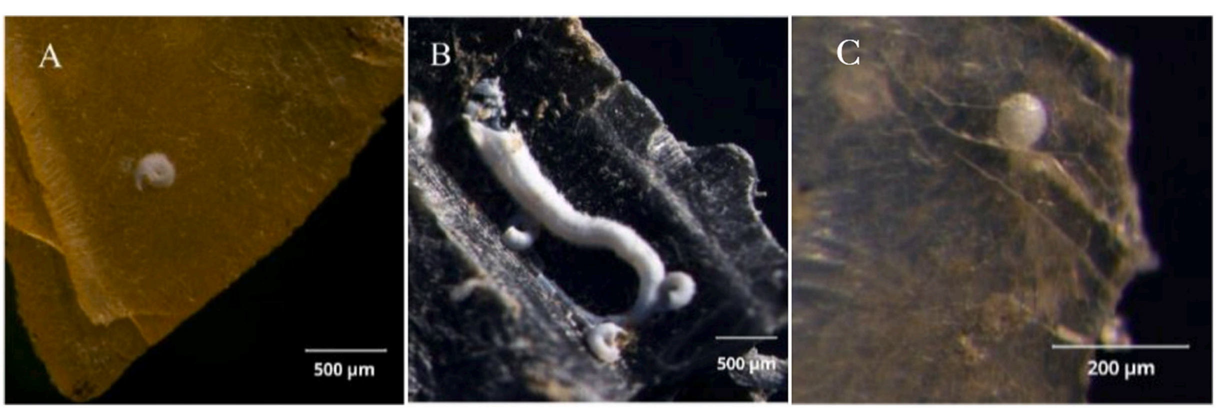

Fig. 2. Stereo-microscope images showing polychaete species attached on diverse floating plastic debris. A) The spirorbid species forming closely coiled tubes (referred here as *Spirorbis* sp. 1); B) coiled tubes of *Spirorbis* sp. 1 and a tube of another spirorbid species (*Spirorbis* sp. 2) and C) the benthic foraminifer *Tretomphalus* sp.

Milner, 2005; Masó et al., 2003; Lastras et al., 2016). Therefore, rafting species have the potential of widening their original distributional ranges, and become non-native or even invasive species (Aliani and Molcard, 2003; Barnes et al., 2009; Rech et al., 2016). While the role of floating plastics as artificial substrates has been extensively documented (Aliani and Molcard, 2003; Bravo et al., 2011; Reisser et al., 2014), the role of seafloor plastic litter is still largely unexplored (Katsanevakis et al., 2007; Galgani, 2015; Masó et al., 2016; Miralles et al., 2018; García-Gómez et al., 2021; Mancini et al., 2021). This may be particularly important as benthic plastic debris substrates may have the potential to change biodiversity and structure of benthic communities (Aliani and Molcard, 2003; Katsanevakis et al., 2007; Ramirez-Llodra et al., 2012; Sánchez et al., 2013). In addition, only a few studies have identified the fouling organisms to species level, and even less have characterized the plastics on which these organisms were attached (Póvoa et al., 2021).

Here, we report on biofouling communities of beached, buoyant and benthic plastic debris, including micro- (<5 mm) and macroplastics (>5 mm), collected in the NW Mediterranean. The aim is to decipher whether there is any specific interaction between the plastic debris, based on size and composition (polymer type), and the biofouling community assemblage.

Table 1
Summary of the number of specimens found for each phylum, and the number and percentage of benthic and beached plastic debris encrusted by each phylum. The percentages do not sum to 100% because there are numerous plastic debris colonized by more than a phylum.

Phylum	Number of specimens	Number of benthic debris	Percentage of benthic debris (%)	Number of beached debris	Percentage of beached debris (%)
Bryozoa	>100	21	47.7	5	71.4
Annelida	>100	21	47.7	4	57.1
Chordata	100	19	43.2	–	–
Brachiopoda	77	13	29.5	–	–
Cnidaria	23	7	15.9	–	–
Mollusca	8	4	9.1	–	–
Echinodermata	4	4	9.1	–	–
Arthropoda	3	1	2.3	1	14.3
Porifera	1	1	2.3	–	–
Sipuncula	1	1	2.3	–	–

2. Materials and methods

2.1. Plastic debris sampling

Floating plastic debris was collected along five transects positioned at a distance between 100 and 200 m from the shoreline off the beach of Sant Sebastià (Barcelona, Spain) on the 14th and 17th of October 2020 (Fig. 1C). NE–SW oriented, Sant Sebastià is the longest beach in the city of Barcelona (660 m long × 89 m wide). The beach is bordered by the harbour breakwater to the SW and the gas breakwater to the NE. It is one of the most crowded beaches in the city, and marine litter easily accumulates on the breakwater of the harbour (Camins et al., 2020). Plastics were sampled using a manta trawl adapted to be towed from light boats (kayak and paddle surf) following the methodology described in Camins et al. (2020). Each transect was 500 to 1000 m long and followed a coast-parallel course. After each transect, the manta trawl was rinsed thoroughly with freshwater to ensure that all plastic debris ended up into the collector bag.

Benthic plastic debris was collected offshore Palamós by the vessel “La Perla de Palamós”, a 23-meter length trawler fishing vessel, in December 2020 (Fig. 1A). Depths of collections ranged from 100 to 366 m, and the transects were performed parallel to the shoreline and perpendicularly to the La Fonera submarine canyon, habitat of the valuable red shrimp *Aristeus antennatus* (Risso, 1816).

Beached plastic debris was collected after storms in the wrack line (i.e. line of debris left on the beach by high tide) of the Llevant Beach, located in Premià de Mar, and the Ponent Beach, located in Vilassar de Mar (Fig. 1B), on the 11th and 22nd of January 2021. Both beaches are contiguous and NE–SW oriented; the Llevant Beach is 595 m long × 88 m wide, and the Ponent Beach is 1160 m long × 55 m wide. These beaches are bordered by the Premià de Mar harbour to the SW and the Astillero Beach, located in Vilassar de Mar, to the NE.

All samples with biofouling organisms were preserved in 70% ethanol for the posterior identification.

2.2. Species identification and plastic characterization

Floating plastic debris, which was mostly microplastics, was filtered through a 1 mm stainless steel sieve and disposed on a 90 mm Petri dish to be observed and photographed on a white background scale, using a Nikon SMZ1000 stereo-microscope coupled with a DS-Fi2 camera to detect any biofouling organisms. Fouling organisms attached to macro- and mesoplastics were identified to the lowest taxonomic level possible, using the same stereo-microscope. Scanning electron microscopy (SEM) was conducted on an uncoated specimen of each bryozoan species using a Hitachi TM4000plus Tabletop at the Natural History Museum in Oslo.

All plastic debris with biofouling organisms was chemically characterized using a Perkin Elmer Frontier Infrared Spectrometer (FT-IR) at the Scientific and Technological Centres of the University of Barcelona (CCiTUB). FT-IR spectroscopy allowed the identification of the polymer composition of each item, based on the well-known infrared absorption bands that represent the presence or absence of specific functional groups in the material. Each spectrum was compared with known spectrums using the Systematic Identification of Micro PLastics in the Environment (SIMPLE) program developed by Aalborg University (Denmark) and the Alfred Wegener Institute (Germany) (Primpke et al., 2019).

2.3. Statistical analysis

To analyse the difference among fouling communities of the three sampling areas and the eight polymer types, Bray-Curtis similarity indices were calculated for all samples and visualized by non-metric multidimensional scaling (nMDS) based on species presence/absence data. All statistical analyses were performed using the R package Vegan (Oksanen, 2020) in R version 3.5.0 (R Core Team, 2018).

3. Results

3.1. Fouling organisms

In the five transects performed, only four floating microplastics were encrusted by biofouling organisms, with a total of 14 specimens in two phyla (Annelida and Foraminifera). In three microplastics, 12 specimens of the polychaete worm *Spirorbis* sp. were found (Fig. 2A–C), while the remaining piece was encrusted by two benthic foraminifera, one specimen identified as *Tretomphalus* sp. (Fig. 2C).

More than 400 specimens belonging to 26 species in 10 phyla (i.e. Annelida, Arthropoda, Brachiopoda, Bryozoa, Chordata, Cnidaria, Echinodermata, Mollusca, Porifera and Sipuncula) were found in beached and benthic plastic debris (Tables 1 and 2; Figs. 3–5). Annelida and Bryozoa were the most abundant phyla, both present with >100 specimens in 47.7% of the benthic biofouled plastics (Table 1), and >100 specimens of Annelida and 14 specimens of Bryozoa found in the 57.1% and the 71.4% of the biofouled beached plastic debris, respectively.

The most common benthic fouling species were: the annelid *Spirobranchus triqueter* (Linnaeus, 1758) (45.5%), the brachiopod *Novocrania* sp. (29.5%), the bryozoan *Chorizopora brongniartii* (Audouin, 1826) (23.1%), the chordate *Scyliorhinus* sp. (22.7%), the bryozoans *Arbopercula tenella* (Hincks, 1880) (19.2%), *Cryptosula pallasiana* (Moll, 1803) (11.5%), ?*Annectocyma* sp. (11.5%), *Fenestrulina malusii* (Audouin, 1826) (11.5%), and *Aetea sica* (Couch, 1844) (11.5%), the chordate *Phallusia mammilata* (Cuvier, 1815) (9.1%), the echinoderm *Ophiotrix fragilis* (Abildgaard, 1789) (6.8%), and the mollusc *Barbatia barbata* (Linnaeus, 1758) (4.5%). These taxa represented also the 45.2% of all species (Table 2). Fifteen out of the 26 species identified (61.5% of the total) were shallow-water bryozoans (Figs. 4 and 5), the 87.5% of which belongs to the order Cheilostomatida and the 12.5% to the order Cyclostomatida.

Specimens belonging to Annelida, Brachiopoda, Bryozoa and Chordata were found at all depths. Chordates were the most abundant at 350

Table 2
Summary of the number of specimens or colonies (bryozoans) found for each species, number of benthic debris found with that species attached and percentage of plastics with each species attached. The percentages do not sum to 100% because there are numerous plastic debris colonized by more than a phylum.

Phylum	Species	Number of specimens or colonies	Number of debris	Percentage of plastics with each species (%)
Annelida	*Spirobranchus triqueter* (Linnaeus, 1758)	>100	20	45.5
Brachiopoda	*Novocrania* sp.	74	13	29.5
Bryozoa	*Chorizopora brongniartii* (Audouin, 1826)	68	6	23.1
Chordata	*Scyliorhinus* sp.	19	10	22.7
Bryozoa	*Arbopercula tenella* (Hincks, 1880)	22	5	19.2
Bryozoa	*Aetea sica* (Couch, 1844)	4	3	11.5
Bryozoa	?*Annectocyma* sp.	5	3	11.5
Bryozoa	*Cryptosula pallasiana* (Moll, 1803)	7	3	11.5
Bryozoa	*Fenestrulina malusii* (Audouin, 1826)	4	3	11.5
Chordata	*Phallusia mammillata* (Cuvier, 1815)	4	4	9.1
Echinodermata	*Ophiothrix fragilis* (Abildgaard, 1789)	4	3	6.8
Mollusca	*Barbatia barbata* (Linnaeus, 1758)	4	2	4.5
Bryozoa	?*Aplousina* sp.	1	1	3.8
Bryozoa	*Copidozum tenuirostre* (Hincks, 1880)	1	1	3.8
Bryozoa	*Escharella variolosa* (Johnston, 1838)	2	1	3.8
Bryozoa	*Hagiosynodos latus* (Busk, 1856)	1	1	3.8
Bryozoa	*Myriapora truncata*? (base) (Pallas, 1766)	1	1	3.8
Bryozoa	?*Plagioecia* sp.	1	1	3.8
Bryozoa	*Reptadeonella violacea* (Johnston, 1847)	1	1	3.8
Bryozoa	*Schizomavella cornuta* (Heller, 1867)	4	1	3.8
Bryozoa	*Schizoporella dunkeri* (Reuss, 1848)	1	1	3.8
Cnidaria	*Alcyonium palmatum* (Pallas, 1766)	14	1	2.3
Cnidaria	*Eunicella verrucosa* (Pallas, 1766)	1	1	2.3
Arthropoda	*Lepas anatifera* (Linnaeus, 1758)	3	1	2.3
Cnidaria	*Leptogorgia sarmentosa* (Esper, 1789)	1	1	2.3
Mollusca	*Neopycnodonte cochlear* (Poli, 1795)	2	1	2.3
Total	**26**	**>300**	**44**	

and 366 m depths, while bryozoans and annelids at 100 and 293 m depths (Table 3). Cnidaria and Mollusca were found at 100 and 350 m depths, while Arthropoda were only found at 293 m depth; Echinodermata, Porifera and Sipuncula were only found at 100 m depth.

3.2. Plastic characterization

Benthic and beached plastic debris colonized by organisms was composed of different polymers including polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), chlorinated polyethylene (CPE), polystyrene (PS), polyurethane (PU), polyvinyl chloride (PVC) and polyamide (PA) (Table 4). PE debris was the most abundantly found, representing the 47% of the samples. The remaining samples were composed of PP (13.7%), PET (11.8%), CPE (9.8%), PS (7.8%), PU (3.9%), PVC (3.9%), and PA (2.0%). Plastic composed of PET, PE and PS showed the highest diversity of biofouling organisms, with nine, eight and seven phyla, respectively (Table 4). Annelid specimens were found attached to each plastic type except for PA.

3.3. Variations in the fouling communities

Non-metric multidimensional scaling (nMDS) showed that fouling communities grouped separately according to the sampling area (Fig. 6). PET/PS and PU/PVC fouling communities had a similar grouping, while all other fouling communities grouped separately according to the polymer substrate type (Fig. 7).

4. Discussion

In this study, we have found a diverse range of phyla (i.e. Annelida, Arthropoda, Brachiopoda, Bryozoa, Chordata, Cnidaria, Echinodermata, Mollusca, Porifera and Sipuncula) attached on floating, benthic and beached plastic substrates ranging in size from a few mm to 40 cm. This adds to the growing body of evidence that plastics function as substrates for colonization by a great number of marine organisms, and therefore can act as potential vector for their dispersion (Barnes, 2002; Masó et al., 2003; Zettler et al., 2013).

Some of the phyla and the species identified in this study have been already reported on benthic plastic debris in the Mediterranean Sea. This is, for example, the case of the annelid *Spirobranchus triqueter*, the arthropod *Lepas anatifera*, the bryozoan *Arbopercula tenella*, the chordate *Phallusia mammillata*, the cnidarians *Alcyonium palmatum* and *Eunicella verrucosa*, the mollusc *Neopycnodonte cochlear*, and the phylum Porifera (Hincks, 1880; Rosso, 1994; Thessalou-Legaki et al., 2012; Angiolillo et al., 2015; Gündoğdu et al., 2017; Ferrario et al., 2018; Crocetta et al., 2020; Carugati et al., 2021). This study adds three new phyla to the previous records, i.e. Brachiopoda, Echinodermata and Sipuncula.

Only in a few studies bryozoans on plastics are identified to species level (Hincks, 1880; Rosso, 1994; Thessalou-Legaki et al., 2012; Sokolover et al., 2016; Ferrario et al., 2018), likely due to the lack of taxonomic expertise. It is in fact representatives of the phylum Bryozoa the most commonly found attached to plastic debris, being the most species-rich and the most abundant in specimen number, as resulted in this study. This is expected as bryozoans are abundant and diverse worldwide (>6000 living species; Bock and Gordon, 2013), including the Mediterranean (>550 species; Rosso and Di Martino, 2016), almost exclusively sessile and ubiquitous, being present from the tropics to the poles and from the intertidal to the deep sea (e.g. Figuerola et al., 2012, 2018; Almeida et al., 2021). Previous studies also confirm bryozoans as ubiquitous organisms on plastic and other floating debris in the sea (e.g.

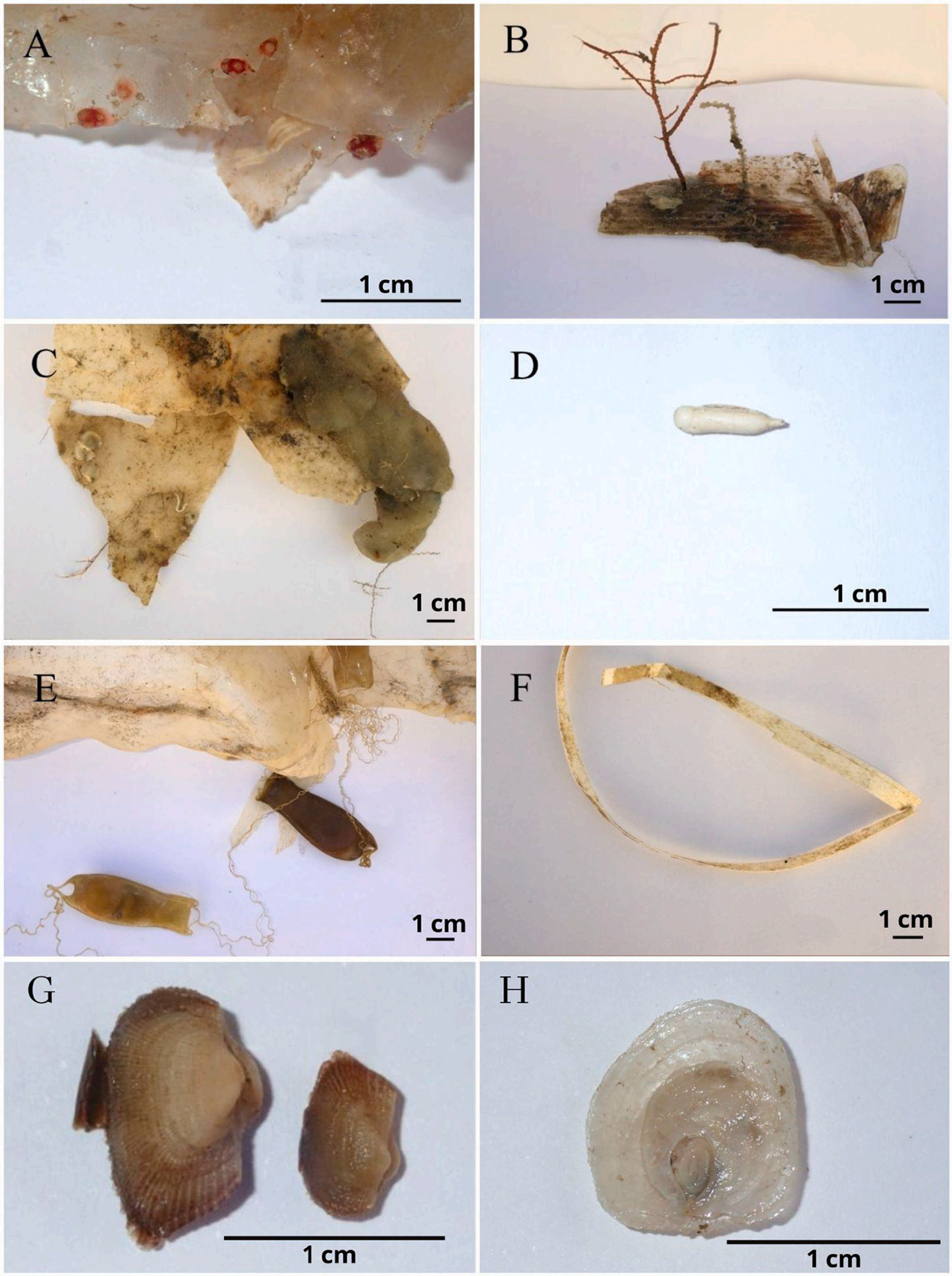

Fig. 3. Images showing diverse biofouling organisms found on benthic and beached plastic debris A) the cnidarian *Alcyonium palmatum* (juvenile); B) the gorgonians *Leptogorgia sarmentosa* and *Eunicella verrucosa*; C) the ascidian *Phallusia mammillata*; D) unidentified species belonging to the phylum Sipuncula; E) egg cases of the catshark *Scyliorhinus* sp.; F) bryozoan colonies of *Arbopercula tenella* (brown coloured area); G) the bivalve *Barbatia barbata*; H) the brachiopod *Novocrania* sp. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Watts et al., 1998; Thiel and Gutow, 2005; Ferrario et al., 2018; Rech et al., 2018). For instance, 49 bryozoan species were reported on 317 objects that drifted across the N Pacific Ocean after the Tsunami of 2011 (McCuller and Carlton, 2018). Here, we have also found a non-indigenous bryozoan species (*A. tenella*), that was previously reported on plastics in other sectors of the Mediterranean Sea (Hincks, 1880; Rosso, 1994; Thessalou-Legaki et al., 2012; Thessalou-Legaki et al., 2012; Ferrario et al., 2018; Orfanidis et al., 2021). Our findings thus suggest that the increasing introduction of plastic debris might increase the chances for the introduction of non-indigenous species in different sectors of the Mediterranean, an issue that needs to be addressed for instance increasing the number of surveys that characterize biofouling organisms at species level. Specifically, in the case of *A. tenella* further future sampling should be promoted to confirm its establishment on natural and/or artificial habitats. In the current study, we did not find any invasive species although other studies worldwide reported some invasive species belonging to different phyla (Annelida, Bryozoa, Cnidaria, Mollusca and Porifera) on a variety of different floating

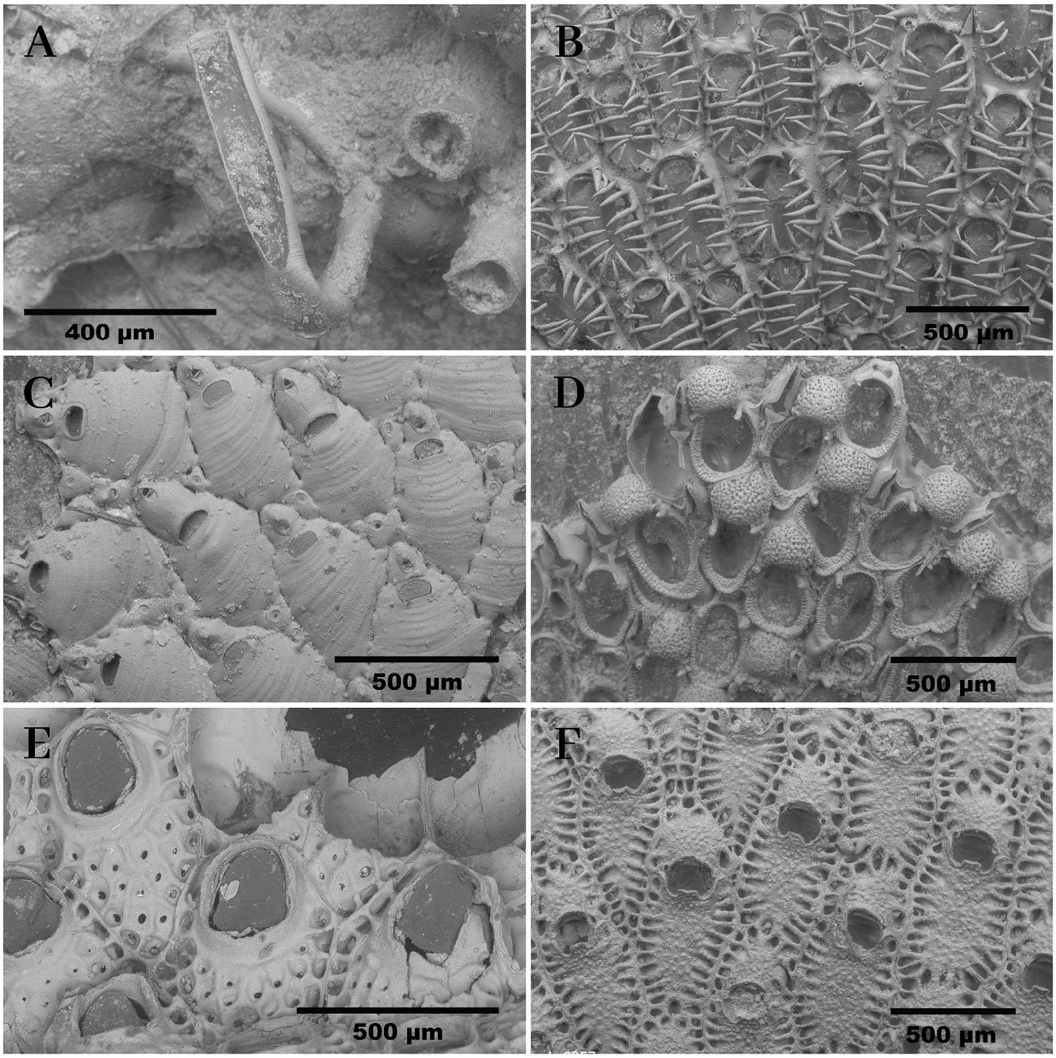

Fig. 4. SEM micrographs of some bryozoan species found encrusting benthic plastic debris. A) *Aetea sica*; B) *Arbopercula tenella*; C) *Chorizopora brongniartii*; D) *Copidozum tenuirostre*; E) *Cryptosula pallasiana* and F) *Escharella variolosa.*

substrates, including macroalgae (e.g. Avila et al., 2020) and plastic items (e.g. Barnes, 2002; Kiessling et al., 2015).

It is known that biofouling can be influenced by the size and composition (polymer) of plastic debris apart from season, geographic location (proximity to propagule sources), water temperature, nutrient levels and the velocity and turbulence of the surrounding water flow (Becker and Wahl, 1991; Melo and Bott, 1997; Callow and Callow, 2002; Kerr and Cowling, 2003). Based on our data, we found a clear separation of fouling communities according to the sampling area, as expected from previous studies. The limited number of species found on floating plastic debris, probably due to the limited colonization surface available given to to the size of microplastics, explains part of the difference in the fouling composition between sampling areas. In addition, the high proportion of egg cases of *Scyliorhinus* sp. found attached to the benthic plastic debris (22.7%) partly explain the difference between the benthic plastic fouling communities and those on beached and floating plastics. We highlight that this finding may have implications for egg transportation and dispersal, but further research is needed to assess the possible impact on the geographical and habitat distribution of this catshark species.

Biofouled plastic debris were mostly composed of PE > PET>PP. However, PET>PE > PS seems to favour the colonization by a greater variety of organisms (Table 4). Regardless of the polymer type, most plastics in our study shared the most abundant species [e.g. the non-indigenous bryozoan *A. tenella* (PE, PP); the bryozoan *Chorizopora brongniartii* (PET, PS, CPE); the brachiopod *Novocrania* sp. (PE, PP, PET, PS, PU, PVC), and the annelid *Spirobranchus triqueter* (PE, PP, PET, PS, CPE, PVC)], suggesting that these particular species have no substrate preference for a plastic type. However, our results also suggest that plastic polymers may be relevant for distinct fouling communities except for some specific polymers (PET vs PS and PU vs PVC), likely due to their chemical structure and/or surface properties, as seen in microbial assemblages in PS vs PE and PP (Vaksmaa et al., 2021). A more exhaustive assessment is, however, needed to confirm that specific polymers have a role in selecting for a specific fouling community.

The most abundant benthic and beached plastic debris found colonized by organisms were made of polymers with lower densities than seawater (Table 4), suggesting that biofouling may play an important role in the transport of plastic debris to the seafloor. This is also supported by the fact that all the bryozoan specimens found attached to benthic plastic were shallow-water species but were instead found at depths of 100 m or more. Therefore, the deposition of low-density plastic debris in the benthic environment may be facilitated by biofouling, which increases the density of plastic debris (and decreases buoyancy), and thus forces them to sink below the surface (Kowalski et al., 2016). This sinking may not be immediate, as when fouled debris sink, changes

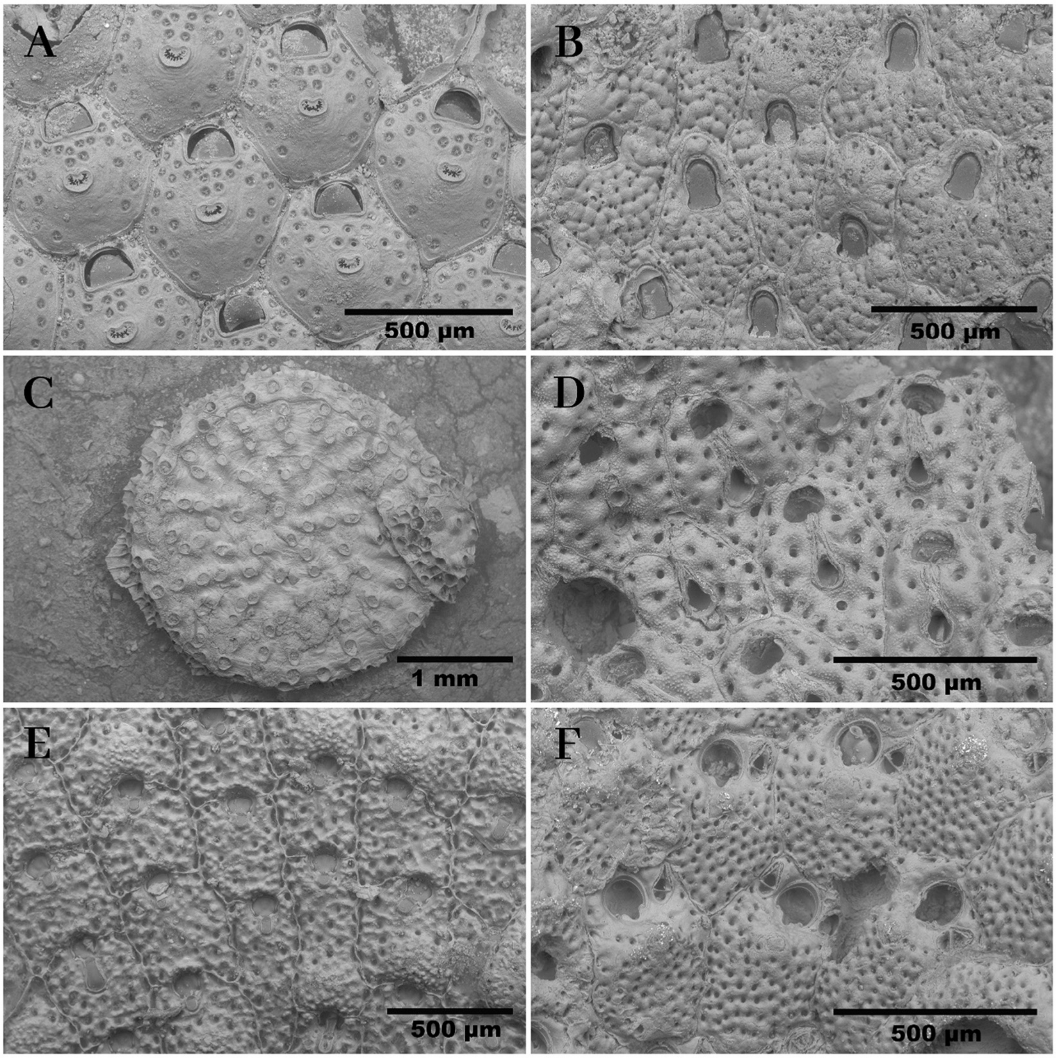

Fig. 5. SEM micrographs of some bryozoan species found encrusting benthic plastic debris. A) *Fenestrulina malusii*; B) *Hagiosynodos latus*; C) ?*Plagioecia* sp.; D) *Reptadeonella violacea*; E) *Schizomavella cornuta* and F) *Schizoporella dunkeri*.

in the fouling community caused by predation or a lack of light below the euphotic zone may cause plastic to drift up and down in midwaters (Ye and Andrady, 1991; Andrady, 2011). Eventually plastic debris may be fouled so heavily that their density is sufficient to remain on the seafloor (Ye and Andrady, 1991; Andrady, 2011; Ryan, 2015; Fazey and Ryan, 2016a, 2016b). The differences found here in the fouling composition between sampling areas reinforces the existence of these community changes during sinking or transport of plastic debris. Our data also suggest that this deposition is not permanent. The presence of several species (e.g. *S. triqueter*) in biofouled beached plastic debris obtained from the wrack line suggest that plastic debris in coastal environments are resuspended by bottom currents and transported and beached during storms. This supports the idea of a significant amount of plastic entering the ocean being temporary trapped in the coastal zone (Lebreton et al., 2018; Li et al., 2020), though may be eventually funnelled to the deep sea when high energy downslope hydrodynamic processes occur (Tubau et al., 2015; Dominguez-Carrió et al., 2020).

5. Conclusions

Our findings show that buoyant and benthic plastic debris provides habitat for a diverse range of marine organisms. The high number of bryozoan species identified, including a non-indigenous species, attached to plastic debris highlights the need for further studies of fouling communities at the lowest taxonomic level possible in order to detect non-native and invasive species, confirm their establishment on natural and/or artificial habitats and, consequently, changes of their distributional range. Our findings also suggest that the transport of low-density plastic debris (i.e. PE and PP) to the seafloor, and their posterior deposition in benthic environments, may have been facilitated by the biofouling. In addition, the species found attached to beached plastic debris also suggest that these debris may move to deeper areas due to bottom currents, or even return to the shoreline as a result of wave action during storms. Biofouling may thus be one mechanism responsible for the substantial proportion of the plastic that is 'missing' from the ocean surface. With an increasing arrival of plastic waste in the ocean in

Table 3
Trawl depth, phyla and species found, and number of plastic debris with that species.

Trawls	Average depths (m)	Phyla	Species	Number of debris
Trawl 1	366	Chordata	*Scyliorhinus* sp.	4
		Bryozoa	*Arbopercula tenella*	1
			Copidozum tenuirostre	1
		Annelida	*Spirobranchus triqueter*	1
		Brachiopoda	*Novocrania* sp.	1
Trawl 2	350	Chordata	*Scyliorhinus* sp.	5
		Annelida	*Spirobranchus triqueter*	2
		Bryozoa	Unidentified species	2
		Brachiopoda	*Novocrania* sp.	2
		Cnidaria	Unidentified species	1
		Mollusca	Cephalopoda eggs	1
Trawl 3	293	Bryozoa	*Arbopercula tenella*	3
			Indeterminate species	1
		Annelida	*Spirobranchus triqueter*	4
		Brachiopoda	*Novocrania* sp.	3
		Chordata	*Scyliorhinus* sp.	1
		Arthropoda	*Lepas anatifera*	1
Trawl 4	100	Annelida	*Spirobranchus triqueter*	14
		Bryozoa	*Aetea sica*	3
			?*Annectocyma* sp.	3
			Arbopercula tenella	1
			Chorizopora brongniartii	6
			Cryptosula pallasiana	1
			Escharella variolosa	1
			Fenestrulina malusii	3
			Myriapora truncata? (base)	1
			?*Plagioecia* sp.	1
			Schizomavella cornuta	1
		Chordata	*Phallusia mammillata*	4
			5 indeterminate species belonging to Ascidiacea	5
		Cnidaria	*Alcyonium palmatum*	1
			Eunicella verrucosa	1
			Leptogorgia sarmentosa	1
			3 indeterminate species belonging to Hydrozoa	3
		Brachiopoda	*Novocrania* sp.	7
		Echinodermata	*Ophiotrix fragilis*	4
		Mollusca	*Barbatia barbata*	2
			Neopycnodonte cochlear	1
		Porifera	Indeterminate species	1
		Sipuncula	Indeterminate species	1

Table 4
Number of benthic and beached debris of each plastic type, and phyla found. CPE = chlorinated polyethylene; PA = polyamide; PE = polyethylene; PET = polyethylene terephthalate; PP = polypropylene; PS = polystyrene; PU = polyurethane; PVC = polyvinyl chloride. Annelida (1); Arthropoda (2); Brachiopoda (3); Bryozoa (4); Chordata (5); Cnidaria (6); Echinodermata (7); Mollusca (8); Porifera (9); Sipuncula (10).

Plastic type	Number of benthic debris	Number of beached debris	Density (kg/m^3)	Phyla
PP	6	1	850–920	1, 3, 4, 5, 6
PE	21	3	890–980	1, 2, 3, 4, 5, 6, 7, 8
CPE	4	1	930–960	1, 2, 4, 5, 6
PU	2	0	960–1260	1, 3, 4
PS	4	0	1040–1080	1, 3, 4, 5, 6, 7, 8
PA	1	0	1120–1160	5
PET	5	1	1380–1410	1, 3, 4, 5, 6, 7, 8, 9, 10
PVC	1	1	1380–1410	1, 3

the coming years, plastic debris will become progressively a more common substrate for marine organisms. Therefore, these phenomena have considerable ecological ramifications and consequences that deserve further research.

CRediT authorship contribution statement

Arnau Subías Baratau: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Anna Sanchez-Vidal:** Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Emanuela Di Martino:** Investigation, Methodology, Writing – review & editing. **Blanca Figuerola:** Conceptualization, Data curation, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

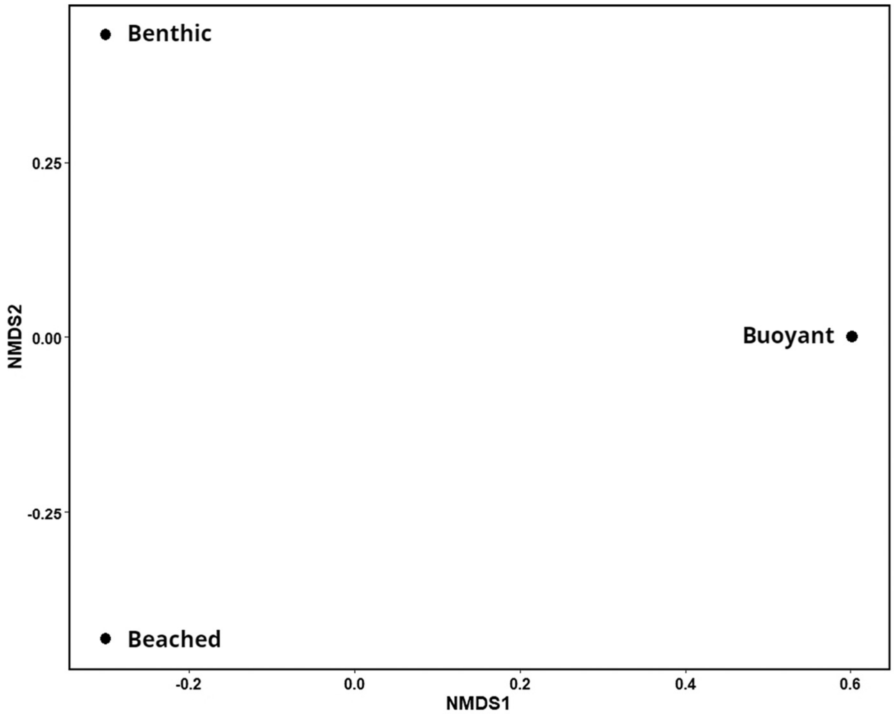

Fig. 6. Non-metric multidimensional scaling (nMDS) visualizing Bray-Curtis similarities of fouling communities from all sampling areas based on presence/absence data (stress value = 0).

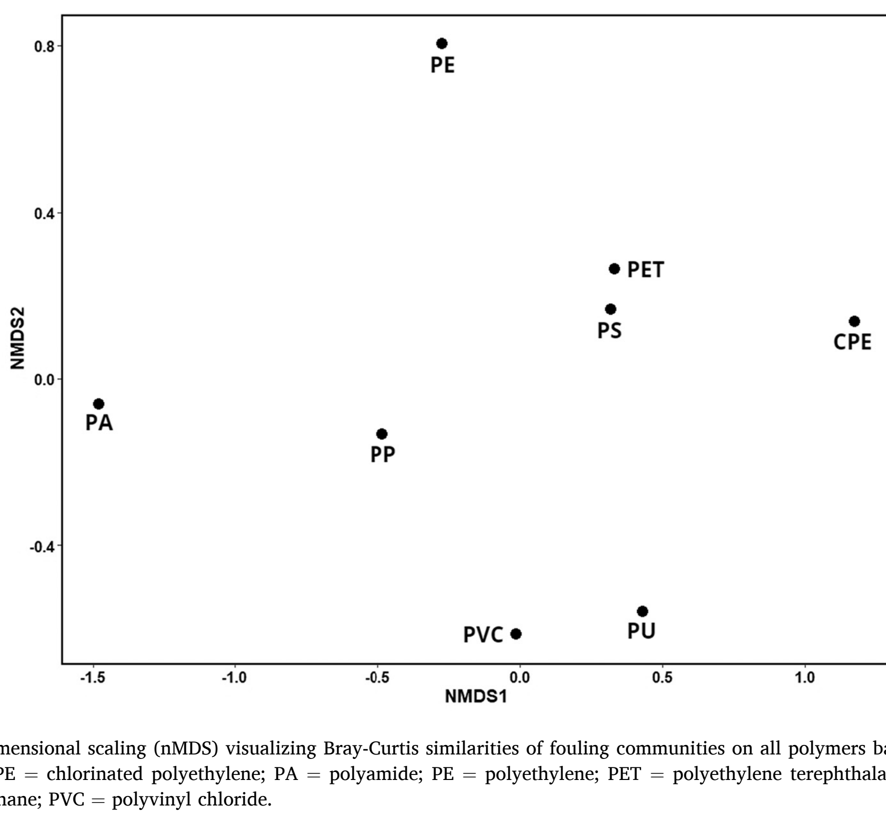

Fig. 7. Non-metric multidimensional scaling (nMDS) visualizing Bray-Curtis similarities of fouling communities on all polymers based on presence/absence data (stress value = 0.0447). CPE = chlorinated polyethylene; PA = polyamide; PE = polyethylene; PET = polyethylene terephthalate; PP = polypropylene; PS = polystyrene; PU = polyurethane; PVC = polyvinyl chloride.

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