# C.I.P.S

## Report of Environment Vice President Fips-M

Following the untimely death of the president of the Committee on the Environment, Mr Diouf, as a member of the committee and as vice-president of FIPS-m in the same role, I feel it is appropriate to give a brief report on the committee's work on the problem of protecting the marine and river environment.

We have had several contacts with President Diouf, although due to various problems, mainly distance, the commission has remained effectively inactive.

In order to try to embark on a common path, in 2022 and 2023 I sent Mr Diouf a copy of the reports (which I enclose with this document) drafted by me in my capacity as head of the environment at FIPS-M; the goal was to emerge, if he considered it appropriate, even in a small way, from the immobility in which we had been finding ourselves for some time and thus to embark on a constructive path of dialogue, even though we were aware that we could do little on our own, but the essential thing was to begin this journey.

As I had discussed with President Diouf, the Commission for the Protection of the Environment set up within CIPS was to be the final point, where the various problems and observations coming from the commissions set up within the various international federations - Fips-M - Fips Mouche - Eau douce - would converge, so that we could have an overview of the various problems, and try to establish at least behavioural protocols, because to imagine directly influencing highly polluting industrial programmes, or national energy policies (even if only to highlight the main sources of pollution) was utopian.

Clearly, the solution to the world's problems cannot be found by our own efforts, but at a minimum it was important to bring to the attention of our entire environment the risks and damage caused by pollution, to which we also contribute in our sporting activities. The important thing was to start giving accurate information to the base and to try to raise environmental sensitivity.

Unfortunately, this was not followed up in particular due to the death (as already mentioned) of President Diouf; however, I believe that the problem must be tackled decisively and the new commission must set itself precise goals and deadlines to carry out its work properly.

Vice-President of Enviroment Fips-M

Alberto Marchi

My report aims to initiate a shared path, to frame the issue of environmental pollution and provide an overview of the current state of affairs.

The various types of pollution represent a fundamental and extremely serious problem of our time - one for which we must find a solution, even though some of the damage caused by humans is irreversible.

As sea fishing enthusiasts, we must, as much as possible, take actions to limit the discharge of polluting objects into the sea and our rivers, even though we are aware that our efforts are minimal compared to the severity of the situation (but it is the sum of small gestures that leads to significant results).

Let us now proceed with an analysis of the waters of seas and oceans - the natural element where we pursue our passion and spend our leisure time. The seas, in fact, cover the majority of the Earth's surface: 97% of all water is found in the oceans, 2.1% is in polar ice caps and glaciers, and only 0.65% of water (available to all living beings) is found in rivers, lakes, aquifers, and the atmosphere.

Each day, about **2 million tons** of pollutants are discharged into water bodies around the world, most of it ending up in seas and oceans.

The majority of these polluting materials are plastics of all kinds and sizes. A study by the University of Trieste classifies plastics found in our seas (by size) as follows:

1. Macroplastics > 2.5 cm
2. Mesoplastics from 5 mm to 2.5 cm
3. Microplastics from 1 mm to 5 mm
4. Nanoplastics < 100 µm

The first three categories of plastic particles are found at various depths and are generally recoverable. The real tragedy lies with nanoplastics—tiny particles suspended in the water or settled on the seabed. These are virtually unrecoverable and significantly contribute to rising pollution levels.

These micro-deposits, rapidly formed from the fragmentation of plastic products, are suspended in the water or on the sea floor (tests on fish, worms, and mollusks have shown a high concentration of particles in these species; fish analyses in particular reveal that microplastics are transmitted to humans through the consumption of fish and shellfish).

For more detailed information, I have attached two studies conducted by the Marine Biology Institute of Ancona, focusing on species and seafloor in the Adriatic Sea. The first research deals with analyses of the gastrointestinal systems of certain fish species, particularly soles. The second study analyses the structure and weight of marine debris, once again in an Adriatic maritime area. The findings of these studies are concerning and can be considered valid and applicable to all our seas, even though pollution percentages may vary. Reading through these studies (attached) highlights that plastic in all its forms is the main source of pollution.

Having concluded this general introduction, which has helped us understand the topic in simple terms, it is necessary to embark on a shared journey to more meaningfully respect and safeguard the environment.

This brief report (to be shared with all CIPS members) aims to address the issue by asking the member Federations of CIPS to provide a short report on the current measures and actions implemented to protect the environment, or those that will be implemented in the future through regulations, in accordance with national laws. This would give us a global view of the problem and help us find common methodologies and regulations to follow during our activities.

We cannot solve the problem of **PLASTIC**, but we must at least limit it as much as possible.

We hope to receive responses from the federations soon so that we can build something concrete and work effectively together to establish shared rules aimed at reducing the **"self-destruction"** of our seas - caused by the harmful behaviors we have all followed until now.

**For FIPS-M**

The issue of environmental protection has, for several years now, been at the center of global concern- because we are heading toward a point of no return.

As sportspeople who live out our passion at sea, we feel this constant discomfort, worsened by climate change, which is leading to the ongoing degradation of our oceans' quality.

Rivers of words have been spoken to denounce plastic pollution, pesticide residues from agriculture, industrial waste, etc. But beyond the speeches, very few concrete actions have been taken - and yet, the situation worsens year after year.

We, as members of FIPS-M, must acknowledge that we are powerless in the face of this ongoing degradation and that we cannot significantly mitigate what is happening using only our own means.

Certainly, as I've already said, we can each do little individually - but doing nothing at all means doing even less.

In recent years, numerous appeals have been made to our affiliated Federations to collaborate - within our means - and help remedy environmental degradation, but we've seen no real results, no collaborative projects, aside from a few "encouraging words."

It's true that we can do little. But launching a common project, based on clear rules of conduct - even if it has little impact on a global scale - would at least serve to raise awareness of environmentally responsible behavior.

In my opinion, as I've already suggested on several occasions, it would be appropriate to establish a commission (even just through online meetings) that encompasses all fishing disciplines (freshwater, fly fishing, lake fishing, etc.), because the sea is the final repository for pollution coming from the land.

Lakes and rivers - whose waters are increasingly polluted - eventually flow into the sea. Such a commission would allow us to highlight, though not solve on our own, the various issues encountered.

I repeat: a single person cannot tackle these problems.

We must coordinate our efforts across all federations to carry out, as far as possible, at least an awareness campaign for all members about the current issues that, if left unaddressed, will drag us to a point of no return.

However, we cannot remain completely passive.

We must start acting and break this growing inertia.

With this in mind, I propose adopting a set of clear written rules to be applied within the framework of our sporting activities. I've already identified these rules, which I present below:

## Obligations for the Host Nation:

1. Before the start of the competition, the designated competition zones must be cleaned of all plastic and solid waste.
2. Delegates from the various federations must inspect the competition zones before the event begins. If conditions are unsatisfactory, they must inform the organizers. If the situation remains unresolved despite the warning, it must be reported in the delegate's final report. Such behavior may result in the host nation or club being banned from organizing championships for a period of 2 to 3 years.
3. Once the site is deemed compliant, it must be monitored daily throughout the competition. From that point forward, each participant is responsible for leaving their area clean. After each competition round, the sector judge must inspect the participant's area and report any serious infractions.
4. The jury, at the end of each competition day, shall follow up on any reports regarding site cleanliness. The first violation will result in a warning; a second will lead to suspension.
5. After each day of competition, the organizing committee must inspect the venue and clean it, if necessary.

## Technical Measures to Be Adopted:

1. To demarcate competition areas, only biodegradable materials should be used (cardboard, wood, or other biodegradable options).
2. To mark boundaries for "shore competitions," reusable materials like rope should be used instead of plastic tape.
3. Baits, whether provided by the organizers or brought by participants, must be stored in biodegradable or non-synthetic containers, avoiding polystyrene wherever possible.
4. A waste separation bin should be placed for every 15 competitors.
5. At the end of the event, the judge must verify if the participant has left any polluting waste and report this to the organizing committee.
6. In non-catch-and-release competitions, fish to be weighed must be stored in non-plastic nets, not in plastic bags. If this is not possible, bins for triethylamine preservation must be provided.
7. No plastic utensils (cutlery, plates, cups) should be used at any catering points during the competition.
8. For boat competitions, proper waste sorting bins must be available. Containers for baits (e.g., sardine boxes) must not be made of polystyrene, which is one of the most polluting materials and easily ends up in the sea.
9. Already implemented regulation: Smoking is prohibited during competitions, especially because cigarette filters are almost always discarded into the sea (Note: It takes 3 to 4 years to break down a single cigarette filter).

These, then, are the first common measures that could be implemented. It's just a starting point, but the key is to begin.

The guidelines listed under "Technical Measures" must be formally included in the regulations.

Of course, this document marks only the beginning of a broader campaign for environmental protection.

I believe each federation should contribute its own well-considered proposals to help improve the current situation as much as possible.

Our actions are just a drop in the ocean, considering that pollution stems primarily from industrial activity dumping waste into the environment.

But still what matters is starting a united march forward.

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# Spatial pattern and weight of seabed marine litter in the northern and central Adriatic Sea

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ABSTRACT

The present study analyzes spatial distribution and typology of marine litter on the seabed in the FAO Geographical Sub-Area 17 (northern and central Adriatic Sea). Two surveys were conducted during fall 2011 and 2012 and 67 stations were sampled each year. Litter items were collected using the "rapido" trawl, a modified beam trawl commonly used by the Italian fishermen to catch flat fish and other benthic species. Marine litter in the catches was sorted and classified in 6 major categories (plastic, metal, glass, rubber, wood, other). Plastic litter was further subdivided in 3 sub-categories based on its source: fishing nets, aquaculture nets and other. Plastic was dominant in terms of weight followed by metal and other categories. The highest concentration of litter was found close to the coast likely as a consequence of high coastal urbanization, river inflow and extensive navigation associated with the morphological and hydrological features of the basin.



## 1. Introduction

Human activities are responsible for a major decline of the world's biological diversity and environmental degradation. In the oceans, a particular form of human impact is litter, which started to be documented as a major form of pollution in the 1970s (Derraik, 2002; Mifsud et al., 2013).

Litter in the sea is a greatly underestimated component of marine pollution due to the limited geographic extensions of the study areas that make difficult to have a comprehensive understanding of the problem. Although some data on marine litter have been reported in the past, only recently this issue has received serious attention (Katsanevakis et al., 2007; Pham et al., 2014) and marine litter investigation has become an interesting issue for many scientists who focused on its impact on marine life and human activities (Koutsodendris et al., 2008).

Marine litter represents an issue of concern both at global and regional level since the 1970s (UNEP, 2009) and it is one of the descriptors of the Marine Strategy Framework Directive (MSFD) launched by the European Commission (Directive 2008/56/EC).

Marine litter has been defined as any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (UNEP 2009) and may be categorized according to the material type.

The methodologies commonly used in litter investigation on the seafloor are visual investigation and trawl sampling (both on continental shelves and in deep sea) with fishing or research vessels (Galil et al., 1995; Hess et al., 1999; Stefatos et al., 1999; Galgani et al., 2000; Moore and Allen, 2000; Lattin et al., 2004; Pham et al., 2014). Visual investigations may be carried out by divers in shallow water (e.g., Katsanevakis and Katsarou, 2004), through submersibles (e.g., Donohue et al., 2001; Nagelkerken et al., 2001) and remotely operated vehicles (ROVs) in deep water (e.g., Galgani et al., 2000).

Marine litter can be broadly categorized according to its source into land (land-borne sources) and marine-based (sea-borne sources) items. Land-based litter mainly originates from domestic, agricultural and industrial activities and includes items washed out from land during storms and entering the marine environment through rivers, ephemeral streams and sewage inputs, as well as

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from wave action on the coast (Stefatos et al., 1999; Galgani et al., 2000; Moore and Allen, 2000; Katsanevakis and Katsarou, 2004).

Marine-based litter originates from fisheries, recreational boats, shipping, energy production, and science, and includes a large number of different materials of various sizes (Dixon and Dixon, 1981, 1983; Horsman, 1982; Ribic et al., 1992; Galil et al., 1995; Hess et al., 1999; Stefatos et al., 1999; Galgani et al., 2000; Moore and Allen, 2000; Somerville et al., 2003; Ryan et al., 2009; Ramirez-Llodra et al., 2011, 2013). High concentrations of litter are found near shipping lanes, around fishing areas and in oceanic current convergence zones (Galgani et al., 1995a). Early attempts to assess the amount of waste disposed by vessels at sea provided crude estimates of the amount dumped (Pruter, 1987; Dixon and Dixon, 1983; Galgani et al., 1995b; Rees and Pond, 1995). Official data have been reported by UNEP (2009) that estimated approximately 6.4 million tonnes of litter dumped in the oceans each year, 635,000 tonnes of which dumped illegally from ships.

Furthermore, according to its weight and shape marine litter can be divided into two categories: floating litter and sinking litter (Dae-In Lee et al., 2006). There are great differences in the distances that litter can reach from its source, depending on the buoyancy and longevity of the different types of items. For instance, while some plastics may float on the surface travelling great distances before sinking, glass and metal will sink rapidly close to sites where they were initially released (Pham et al., 2014). Floating objects eventually settle down along the shore or sink down to the seafloor due either to the increase of their weight for water filling and/or for the settlement of living organisms on them (Dae-In Lee et al., 2006).

Many studies on benthic litter describe its composition (e.g. plastic, metal, fishing gear, etc.) and origin, calculate its concentrations for each category and estimate its density on the seabed (Stefatos et al., 1999; Galgani et al., 2000; Lee et al., 2006; Pham et al., 2014). Among the various types of litter, plastics make up most of the marine litter worldwide, either on the sea surface, the seafloor and on the beaches (Derraik, 2002; Ryan et al., 2009; Pham et al., 2014). Some plastic debris are transported by wind. However, most land-based litter is carried by water via rivers and storm-water or comes from shipping traffic (Ryan et al., 2009) and it tends to aggregate in response to local sources, hydrography, prevailing winds and bottom topography (Galgani et al., 2000; Moore and Allen, 2000). However, determining the exact source of the litter found on the seafloor is very complex since several factors influence source identification.

Fishing activities are strongly affected by marine debris. Indeed, waste can remain entrapped in the propellers of the fishing vessels and fishermen may experience problems with accumulated debris in nets, they may see their catch contaminated by debris and risk to snag their nets on debris on the seabed. Debris can also reduce set net catch efficiency making them more easily detectable by fish. Moreover, cleaning the nets requires additional costs making the fishing activities less profitable and often forcing the fishermen to change location due to the high concentration of debris (Nash, 1992). The waste caught by fishing nets includes wooden crates, glass bottles, tin cans, cardboard, pieces of netting, plastic bags, bottles and other plastic objects, and food. Conversely, hooks and lines mainly catch plastic bags (Nash, 1992). As most of these materials tend not to be decomposed or destroyed easily, it is not surprising that the 70%, 57%, and 41% of benthic trawls, respectively in the Eastern Mediterranean Sea, the Gulf of Alaska and the Bering Sea, contained litter (Jewett, 1976; Feder et al., 1978; Galil et al., 1995).

On the other hand, fishing also contributes to increase the amount of litter in the oceans. In fact, as fishing nets and other items lost during fishing activities are not easily degradable, they can obstacle bottom trawling and dragnet fisheries causing a decrease of catches and of the overall efficiency of these gears (An et al., 2001; Dae-In Lee et al., 2006). Furthermore, abandoned fishing gears may have numerous negative impacts on marine resources, including ghost fishing and the entanglement of invertebrates (Balazs, 1985; Jones and Ferrero, 1985; Carr, 1987; Laist, 1987; Duguy et al., 1998; Gregory, 1999; Ramirez-Llodra et al., 2011). The impacts of marine litter on marine species, caused by entrapment and ingestion are well documented in the literature

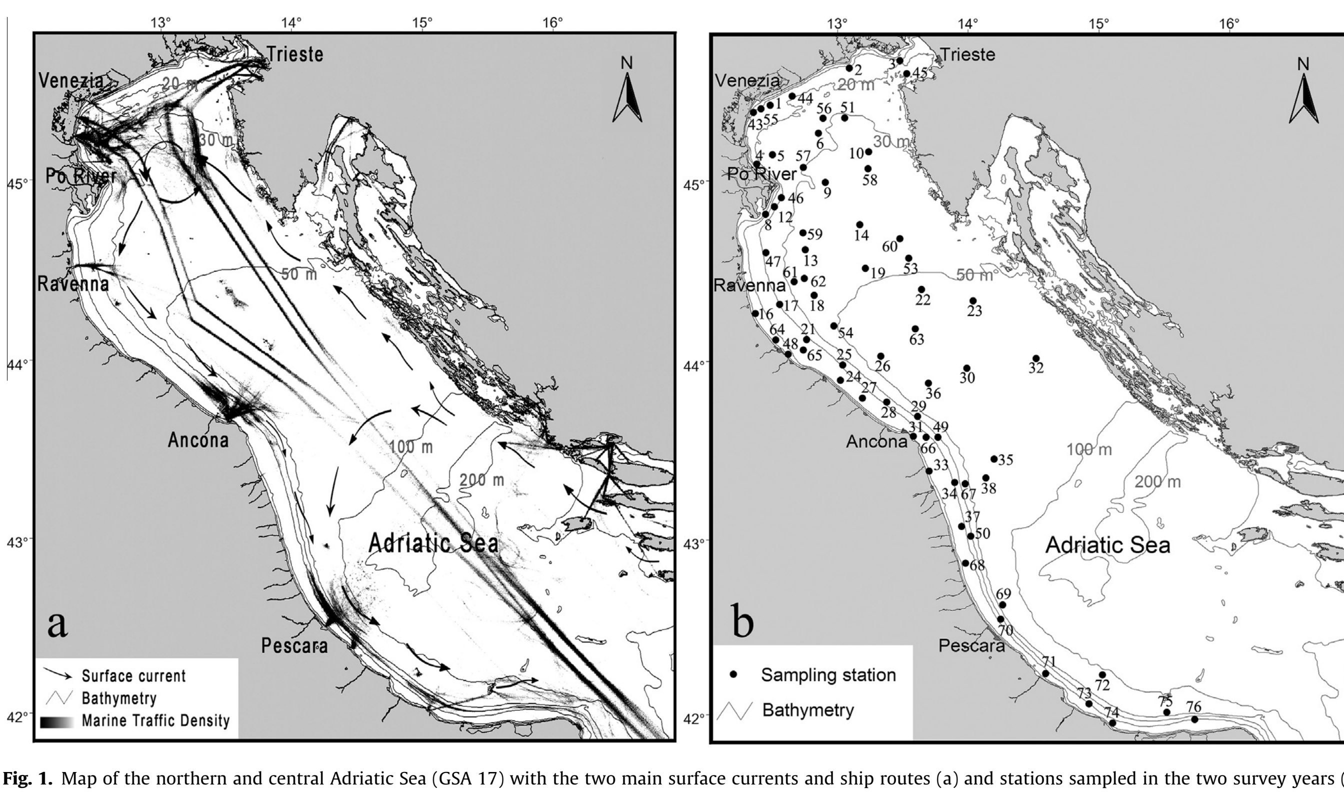


**Fig. 1.** Map of the northern and central Adriatic Sea (GSA 17) with the two main surface currents and ship routes (a) and stations sampled in the two survey years (b).

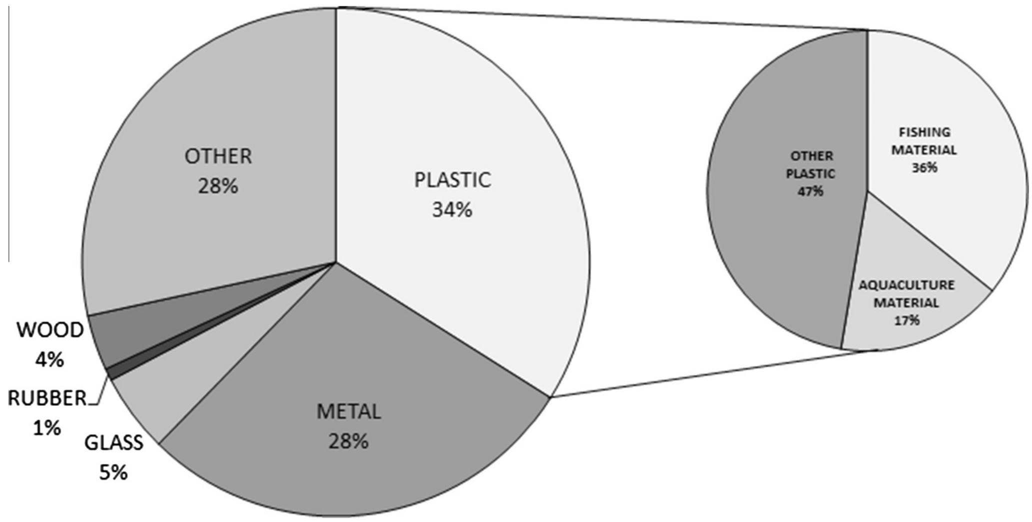


**Fig. 2.** Percentage composition of the marine litter recorded on the seabed during the two survey years. The three sub-categories of plastic litter are reported in detail.

(Ryan and Watkins, 1988; Robards et al., 1995; Spear et al., 1995; Huin and Croxall, 1996; Sazima et al., 2002; Mascarenhas et al., 2004; Boren et al., 2006).

High densities of marine debris have also potential negative interactions with the structure of benthic communities by altering the characteristics of the local biotope and likely contributing to extinctions at species level (CBD, 2012). Indeed, marine litter creates new substrate that can favor the settlement of some species rather than others (Katsanevakis et al., 2007). Moreover, drift debris can increase the distribution range of certain marine organisms and introduce species into an environment where they were previously absent (Winston, 1982; Barnes, 2002; Barnes and Milner, 2005). Barnes (2002) estimated that human litter more than doubles the rafting opportunities for biota, assisting the dispersal of 'alien' species.

Up to date, no coordinated regional or national monitoring programs have been developed for assessing trends and spatial distribution of marine litter in EU waters where only temporally and spatially limited studies have been carried out (Dixon and Dixon, 1983; Bingel et al., 1987; Galgani et al., 1995a, 1995b; Katsanevakis and Katsarou, 2004; Koutsodendris et al., 2008; Ramirez-Llodra et al., 2011; Licitra et al., 2012; Güven et al., 2013; Eryaşar et al., 2014). This is particularly true for deep seafloor litter, due to the high cost involved with sampling the seafloor (Pham et al. 2014).

Taking into account the relatively scarce information available on marine litter and that the marine litter is one of the descriptors of the Marine Strategy Framework Directive (MSFD) launched by the European Commission (Directive 2008/56/EC), the present study reports the data on marine litter collected on the seafloor during two years (2011 and 2012) of survey in the central and northern Adriatic Sea. The aim was to provide, for the first time in the Adriatic Sea, information on the composition, weight and spatial distribution of benthic anthropogenic debris occurring in this area to address the gap in knowledge and to serve as a baseline for future comparisons.

## 2. Materials and methods

### 2.1. Study area

The Adriatic Sea is an elongated basin, with its major axis in the NW-SE direction, located in the central Mediterranean, between the Italian peninsula and the Balkans (Fig. 1a). The northern section is very shallow and gently sloping, with an average depth of about 35 m, while the central one is on average 140 m deep, with the two Pomo Depressions reaching 260 m. Along the Italian coast a large number of rivers discharge into the northern and central parts of the basin, being the Po River the most relevant (Artegiani et al. 1997). River discharge and wind stress are the main drivers of the water circulation. Two main currents dominate the Adriatic circulation: the West Adriatic Current (WAC) flowing toward SE along the western coast, and the East Adriatic Current (EAC) flowing NE along the eastern coast. Two main cyclonic gyres occur, one in the northern part and the other in the South (Fig. 1a). The major winds blowing over the Adriatic Sea are Bora (from NE) and Sirocco (from SE). The former causes free sea surface to rise near the coast intensifying the WAC. The latter can cause flooding events in the shallow lagoons along the Adriatic coast (Marini et al., 2008).

The northern and central Adriatic Sea are also affected by strong annual thermal variations, more consistent in the surface layers (e.g., 5–28 °C) than at the bottom (e.g., 12–17 °C). In winter, the entire water column from the coast as far as 6–7 nm offshore is characterized by low temperature (5–6 °C) and salinity (<37‰), while the offshore waters are warmer (10–12 °C) and ticker (>38‰). A vertical thermohaline front, running parallel to the coast and extending throughout the water mass, separates the coastal waters from the open sea ones. This retains the materials which flow from rivers and other water sources within the coastal area. In summer, a stratification characterizes the water column separating the warmer surface waters with lower salinity from deeper, colder and more saline ones (Artegiani et al. 1997).

The area is subjected to a heavy marine traffic from merchant ships, supplier vessels for offshore activities (e.g., gas platforms), ferry boats, trawl-fishing vessels, and recreational boats (Fig. 1a). It is also the area of intense mussel aquaculture along the Italian coast and fish farming along the Croatian coast.

The study was carried out in the FAO Geographical Sub-Area 17 (GSA 17: northern and central Adriatic). The investigated area has a surface of 36,742 km$^2$ and extended from the Italian coast to the 12 nm limit of the Croatian national waters, and from 8 to 100 m depth (Fig. 1b).

### 2.2. Data collection

Two surveys were conducted in the framework of the Solemon project during fall 2011 and fall 2012, by the National Research Council (CNR-ISMAR, Italy) in cooperation with the Institute for Environmental Protection and Research (ISPRA, Italy), the Institute

**Table 1**
Mean weight densities of the six litter categories found at different depths. The mean weight density of the total litter is also reported. sd = standard deviation.

| Depth | 0–30 m | | 30–50 m | | 50–100 m | |
|---|---|---|---|---|---|---|
| | kg/km$^2$ | sd | kg/km$^2$ | sd | kg/km$^2$ | sd |
| Plastic | 71.31 | 10.51 | 40.54 | 12.33 | 11.58 | 2.87 |
| Metal | 40.52 | 11.21 | 4.92 | 1.84 | 4.99 | 2.63 |
| Glass | 6.58 | 1.29 | 1.45 | 0.52 | 4.16 | 2.25 |
| Rubber | 2.21 | 0.63 | 0.53 | 0.22 | 0.24 | 0.11 |
| Wood | 8.85 | 2.37 | 0.01 | 0.01 | 9.95 | 6.12 |
| Other | 41.18 | 9.79 | 17.91 | 6.66 | 16.95 | 9.40 |
| Total | 170.65 | 35.80 | 65.37 | 21.58 | 47.87 | 23.38 |

of Oceanography and Fisheries (IOF, Croatia), and the Fisheries Research Institute of Slovenia (FRIS, Slovenia). The main objective of the Solemon project is to provide information on benthic and demersal species important to fisheries, however anthropogenic waste data are also gathered.

Litter samples were collected using the rapido trawl, a modified beam trawl commonly used by the Italian fishermen to catch flat fish and other benthic species. The gear consists of a rigid mouth rigged with 46 iron teeth along the lower leading edge. The lower side of the iron frame is provided with 4 skids. The net is made of a polyamide net bag protected in its lower side by a reinforced rubber diamond-mesh net. An inclined wooden board fitted to the front of the iron frame keeps the gear in contact with the seabed acting as a spoiler. The codend was 2.7 m long and had 40 mm mesh size (stretched). The fixed mouth of the gear allows exactly knowing the area surveyed by the gear during each haul.

At each haul the vessel towed two gears simultaneously at an average speed of 5.5 knots. A total of 67 stations were sampled each year (Fig. 1b).

One haul was carried out at each station during daytime. The hauls usually lasted 30 min, while sometimes the towing time was reduced to 5 min to avoid the overloading of the nets. In such cases the haul was repeated and the catches were pooled together. After trawling, litter items were separated from the catch, weighted and classified considering 6 major categories: plastic, metal, glass, rubber, wood, and other according to the nature of the material (Katsanevakis and Katsarou, 2004). Plastic litter was further subdivided in 3 sub-categories based on its source: fishing material, aquaculture material and other plastic (e.g., bottles, plastic glasses, bags). The use of weight instead of numbers was based on the fact that certain litter categories (e.g., plastic and glass) can break into small pieces, impeding the quantification of single items without overestimating abundances (Ramirez-Llodra et al., 2013; Pham et al., 2014).

### 2.3. Data analysis

The weight of each litter category recorded on board in each haul was standardized to the square kilometer on the basis of the swept area. Data of the two years were pooled together and were used to calculate the stratified average weights (± standard

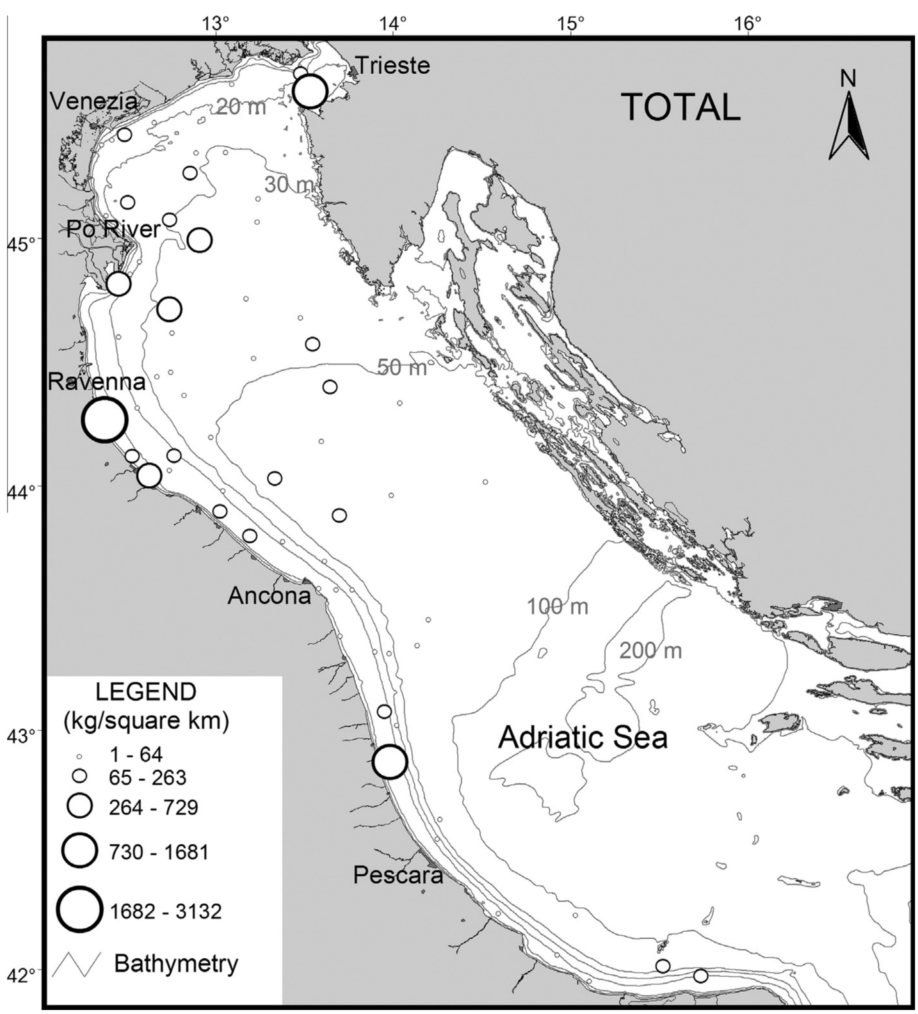


**Fig. 3.** Spatial distribution and weight of the total litter collected on the sea bottom in the two survey years.

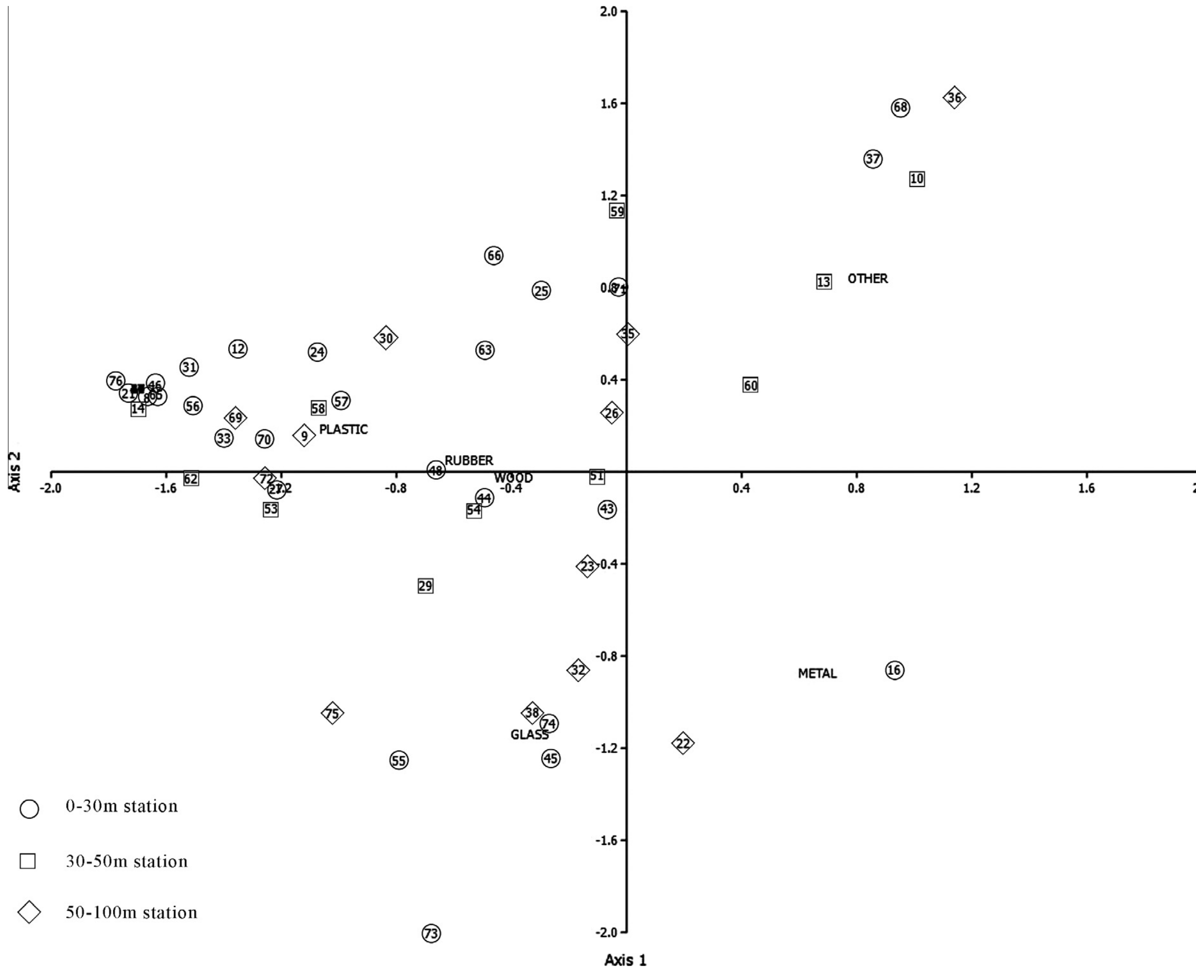


**Fig. 4.** Results of the Canonic Correspondence Analysis (CCA) based on a station/litter items category matrix. The numbers refer to the stations sampled in the two years. The eigenvalues of the first two axes show that almost 80% of the information is explained.

deviation) of litter collected in the two years. The mean weight of litter was compared for each category in three depth ranges (0–30 m, 30–50 m, 50–100 m). The georeferenced haul data were then mapped using ESRI ArcView 3.2 application.

The spatial distribution of the different litter categories was further investigated by means of a Canonic Correspondence Analysis (CCA; Legendre and Legendre, 1998) based on a station/litter items category matrix. CCA is basically a multivariate technique similar to Principal Component Analysis (PCA) or Redundancy Analysis (RDA), except that the Chi-square distance function is used (Zuur et al., 2007).

## 3. Results

Overall, a total amount of 515 kg of litter was collected from 4.3 km$^2$ of seafloor surveyed in the two years. The mean weight of litter recorded was to 85 ± 26 kg/km$^2$.

The average weights of the six litter categories collected in the two years were: plastic 34 ± 4 kg/km$^2$; metal 15 ± 10 kg/km$^2$; glass 4 ± 1 kg/km$^2$; rubber 1 ± 0.1 kg/km$^2$; wood 8 ± 11; other 24 ± 4 kg/km$^2$.

Plastic was dominant, constituting 34% of the total litter collected in the overall sampling period. Metal and other represented the second categories, each corresponding to 28% of the total while rubber, wood and glass made up very small percentages ($\leqslant$5%) (Fig. 2).

Lost fishing nets and other materials deriving from fisheries made up 36% of the overall plastic litter collected in the two years, while aquaculture litter constituted 17%. The sub-category "other plastic" (47%; Fig. 2) comprised a wide range of objects such as garbage bags, shopping bags, cups, bottles, food packaging, and industrial packaging.

Metal and glass litter mainly corresponded to aluminum, cans, jars, glass beverage and bottles; rubber included car tires, rubber strings and parts of winches, while wood mostly consisted of wooden parts of fish-packaging and few other parts of building materials. The category other included sundry material such as pieces of clothes (wool, cotton), cotton wastes, shoes, boots, gloves, etc.

The highest concentration of litter was found in the stations close to the coast within 30 m depth with a mean weight of 171 ± 36 kg/km$^2$, while the lowest amount was recorded offshore between 50 and 100 m (47.87 ± 23.38 kg/km$^2$) (Table 1; Fig. 3).

Plastic was the most abundant category up to 50 m depth, followed by other and metal. Differently, other included most of debris collected between 50 and 100 m depth, followed by plastic and wood (Table 1). These results have been also confirmed by the CCA which separated the different sampling stations on the basis of the relative importance of the litter categories (Fig. 4) with a clear discrimination between samples from inshore and offshore.

Plastic appeared widely distributed with the highest densities in the northern Adriatic Sea, especially in front of the Po river estuary (Fig. 5a).

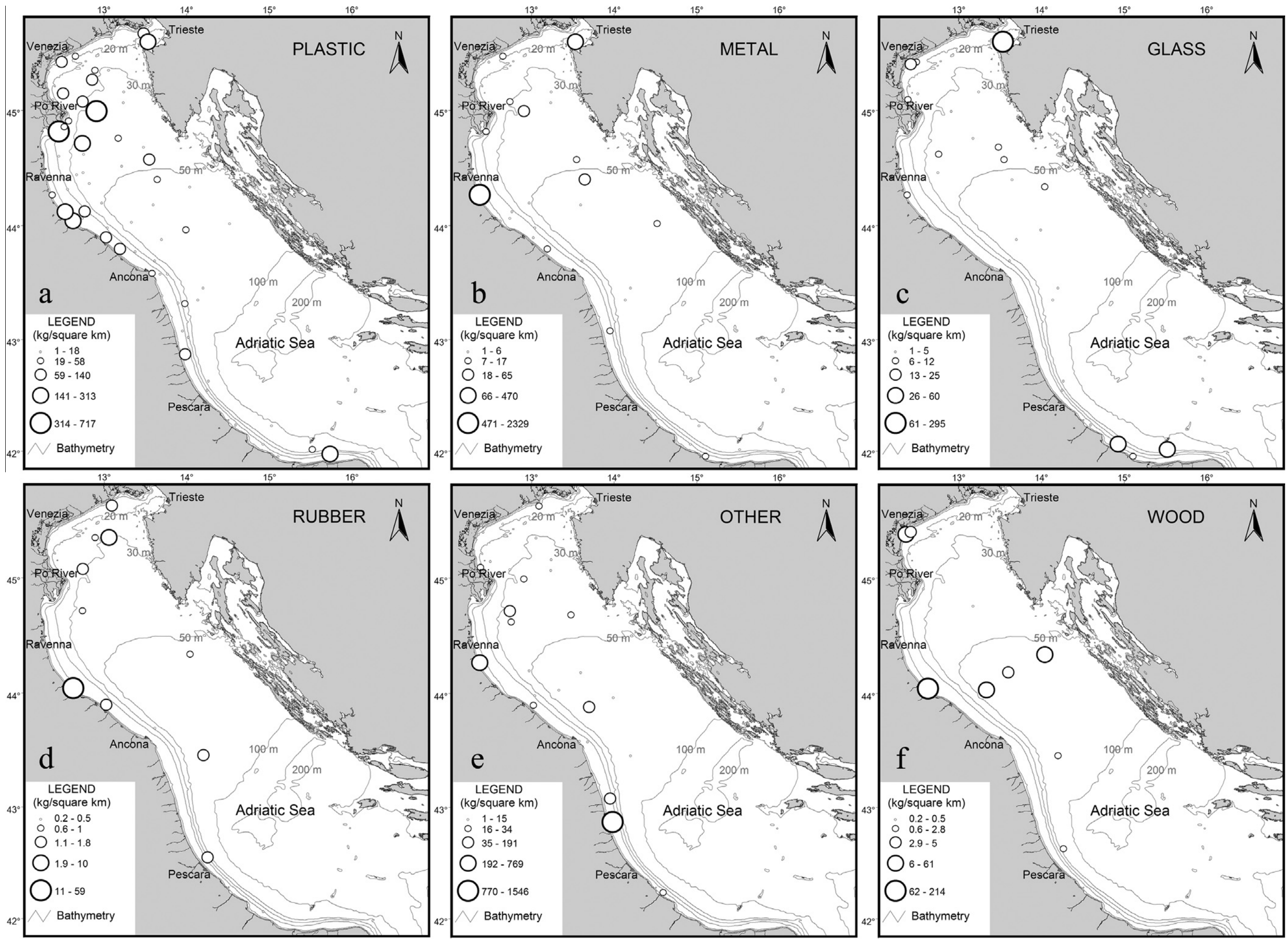


**Fig. 5.** Spatial distribution and weight of the six litter categories collected on the seafloor in the two survey years.

Metal, glass, rubber and other were mainly recorded along the Italian coast (for example in front of Ravenna and Trieste), although high values of the two first categories were also observed close to the Slovenian coast (Fig. 5b–e). Small quantities of metal and glass were also collected along the ship routes in the center of the basin and close the entrance of the main Italian harbours. Wood mainly occurred along a transect between the Italian and the Croatian coast, at South of Istria peninsula, and in front of Venice lagoon (Fig. 5f).

## 4. Discussion and conclusions

Litter represents an increasing anthropogenic factor which has significant environmental and economic impacts in the marine systems, becoming a focal issue for public concern. The recent entering in force of the EC Marine Strategy Framework Directive (MSFD) has highlighted the existing gaps in the knowledge of spatial patterns, weight and typology of marine litter in the European Seas, pushing for the development of coordinated regional monitoring in the EU waters. As a matter of fact, no historical data are available from the northern and central Adriatic Sea for assessing trends in anthropogenic or natural litter, neither specific monitoring programs have been carried out up to date. Thus, this study provides baseline information for future comparisons for instance in the framework of the MSFD implementation.

Several difficulties exist in comparing the results reported in the available literature due to the adoption of different methodologies in data collection, classification and reporting of the marine litter. However, it has been possible to establish that the average amount of litter recorded in the present study in the two sampling years was much higher than those collected during scientific surveys conducted with bottom trawl nets in the northern Tyrrhenian Sea (Licitra et al., 2012) and in the eastern Ionian Sea (Koutsodendris et al., 2008) where the average quantities of litter ranged from 40 to 68 $kg/km^2$ and from 6.7 to 47.4 $kg/km^2$, respectively. However, it is included in the weight range ($60 \pm 40$ to $400 \pm 180$ $kg/km^2$) reported by Ramirez-Llodra et al. (2013) for the Mediterranean Sea. Notwithstanding, it is relevant to highlight that the sampling gear used in the present study may have a different performance from bottom trawl nets in collecting marine waste, being appositely planned to capture demersal resources living at tight contact with the seafloor.

Similarly to what has been reported for other European seas (Galgani et al., 1995a, 1995b, 1996, 2000; Stefatos et al., 1999; Katsanevakis and Katsarou, 2004; Koutsodendris et al., 2008; Eryaşar et al., 2014) higher quantities of litter were found in the coastal areas in respect to the open sea and plastic constituted the main portion of the collected litter. It is worthy to highlight that plastic may be extremely dangerous for the marine ecosystem, being a potential source of toxic chemicals such as PCBs and dioxins (Engler, 2012). Moreover, plastics may degrade in microplastic which, if ingested by organisms, may biomagnify contaminants across trophic levels and may be transferred to humans (Andrady, 2011).

The spatial distribution of the different categories of litter is difficult to explain due to the scarce information on the possible inputs. Moreover, the ability of some materials, such as plastic and wood, to travel long distances before sinking makes extremely difficult to identify their source (Pham et al., 2014). This is especially true for plastic, which remains in the marine environment for long periods. Indeed, this category appeared homogeneously distributed along the Slovenian and Italian coasts as well as throughout the northerner part of the Adriatic Sea. This spatial pattern is likely a consequence of a series of factors such as the high density population, especially during summer period, heavy rivers runoff, extensive navigation (fishing and recreational boats) associated with the morphological features and the water circulation of the basin (Ramirez-Llodra et al. 2013).

Similarly to previous findings in other areas around the world (June, 1990; Kanehiro et al., 1996; Hess et al.,1999; Katsanevakis and Katsarou, 2004; Ramirez-Llodra et al. 2013; Güven et al., 2013), approximately a half of the plastic debris encountered in this study was represented by material coming from fishing and aquaculture according with the intense trawling activity and the high occurrence of mussel farms in the area. Indeed, the Adriatic Sea is one the major fishing ground in the whole Mediterranean basin (Mannini et al., 2004). The remaining portion of plastic litter could be originated from land-based sources including domestic and industrial activities as suggested by Derraik (2002). However, it cannot be excluded a release from shipping as evidenced in this study by the overlapping of plastic distribution and some of the main shipping routes in the central and northern Adriatic. Eryaşar et al. (2014) also reported high concentration of plastic debris in anchorage areas of the Aegean Sea extensively used by international ships.

Metal and glass usually sink rapidly and thus do not travel long distances, so they were probably released by user groups close to the recovery locations. Their occurrence in coastal areas, close to the harbours' entrances as well as along the shipping routes in the middle of the northern and central part of the Adriatic basin, leads to think that they were probably originated from marine-based sources including ferries, merchant vessels and recreational boats according to Whiting (1998); Stefatos et al. (1999); Moore and Allen (2000), Koutsodendris et al. (2008) and Ramirez-Llodra et al. (2013).

Wooden parts of fish-packaging as well as car tires likely indicate a fishery-based source since fishermen employ the latter as fishing boat fenders.

Finally, objects included in the category "other" are not good indicators of litter sources since they might have been originated both from land and marine-based source.

These results confirm that the spatial distribution and weight of seabed litter depend on a number of factors act ing synergistically, which may include, amongst others, abundance and source of litter, its shape, composition, weight and persistence in the water column along with winds, waves, water circulation and bottom topography (Bauer et al., 2008; Mifsud et al., 2013).

Furthermore, once the debris sink to the seabed, there is also the possibility of transport elsewhere, either through anthropogenic activities (e.g., trawling) or through natural processes (bottom currents), especially for materials with very long longevity (Mifsud et al., 2013).

Concluding, the present study represents the first step for a large-scale, standardized assessment of litter accumulation on the seafloor in the northern and central Adriatic Sea and may be used as a baseline to set the necessary measures to minimize such type of anthropogenic pollution. Control of sources of marine litter, producer responsibility, implementation of waste management and recycling programs as well as environmental education activities may represent effective actions to reduce such type of impact at points of origin.

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# Characterization of microplastic litter in the gastrointestinal tract of *Solea solea* from the Adriatic Sea[☆]

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ABSTRACT

Micro-plastic particles in the world's oceans represent a serious threat to both human health and marine ecosystems. Once released into the aquatic environment plastic litter is broken down to smaller pieces through photo-degradation and the physical actions of waves, wind, etc. The resulting particles may become so small that they are readily taken up by fish, crustaceans and mollusks. There is mounting evidence for the uptake of plastic particles by marine organisms that form part of the human food chain and this is driving urgent calls for further and deeper investigations into this pollution issue.

The present study aimed at investigating for the first time the occurrence, amount, typology of microplastic litter in the gastrointestinal tract of *Solea solea* and its spatial distribution in the northern and central Adriatic Sea. This benthic flatfish was selected as it is a species of high commercial interest within the FAO GFCM (General Fisheries Commission for the Mediterranean) area 37 (Mediterranean and Black Sea) where around 15% of the overall global *Solea solea* production originates.

The digestive tract contents of 533 individuals collected in fall during 2014 and 2015 from 60 sampling sites were examined for microplastics. These were recorded in 95% of sampled fish, with more than one microplastic item found in around 80% of the examined specimens. The most commonly found polymers were polyvinyl chloride, polypropylene, polyethylene, polyester, and polyamide, 72% as fragments and 28% as fibers. The mean number of ingested microplastics was $1.73 \pm 0.05$ items per fish in 2014 and $1.64 \pm 0.1$ in 2015. PVC and PA showed the highest densities in the northern Adriatic Sea, both inshore and off-shore while PE, PP and PET were more concentrated in coastal areas with the highest values offshore from the port of Rimini.



## 1. Introduction

Plastic is a multipurpose material that is widely present in everyday life. It is used for example in packaging, building sector, transportation and electronic industry, farming, fashion and sport articles, household and personal detergents. Indeed, characteristics such as durability, malleability, low weight and cost allow its use in the most different applications. The rising demand of plastic items to support societal development has dramatically boosted annual plastic production from 1.5 million tonnes in the 1950s to 322 million tonnes in 2015 (Wright et al., 2013; PlasticEurope, 2014). One of the negative aspects of the plastic revolution is the pollution it creates in the marine environment, with an estimated annual input in the ocean of 9.5 million tonnes of new plastic waste (Boucher and Friot, 2017).

In the literature, distinctions are made between macro-, micro- and nano-plastics, though globally accepted definitions for these terms are yet to be fully established. However, microplastics (MPs), have been described elsewhere and within the context of this present study as plastic pieces having a size range from 1 μm to

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5 mm (Lassen et al., 2015). MPs can be categorized as primary and secondary according to their formation mechanism (Sundt et al., 2014). The formers are originated from direct release into the environment of small plastic particles. These may be added as ingredients in some products (e.g., cosmetic articles) or can come from the abrasion of plastic objects during their production or use (e.g., tyres erosion and washing of synthetic clothing). The latter MPs are instead originated in the marine environment from deterioration of large plastic objects into smaller fragments. This normally occurs through processes like weathering and photodegradation of waste (discarded plastic bags, lost fishing nets, etc.; Boucher and Friot, 2017). MPs distribution is affected by sea currents and other chemical and physical oceanographic conditions (Collignon et al., 2012; Kukulka et al., 2012), as well as by their specific properties. Their partition in the sea may be determined by features like morphology as well as biofouling occurrence on their surface, polymeric formulation and additives (Morét-Ferguson et al., 2010). Plastics with a density exceeding that of ambient seawater sink and therefore tend to accumulate in the sediment (Woodall et al., 2015). On the other hand, low-density particles tend either to float on the sea surface or be carried in suspension in the water column (Fossi et al., 2012; Suaria and Aliani, 2014). The occurrence of biofilms in floating particles may eventually increase the density of originally low-density polymers such as polyethylene and polypropylene (Lobelle and Cunliffe, 2011).

Aquatic organisms, as for example filter-feeding zooplankton and other planktonic organisms, may uptake micro- and nanoplastics by ingestion or through the gills (Lusher et al., 2013; Watts et al., 2014) when they co-occur in the same water mass as their typical food items (Cole et al., 2011; Deudero et al., 2014; Van Cauwenberghe et al., 2015). The consequences of MPs uptake are reflected at physiological and behavioral level since several biological processes like feeding, respiration, reproduction, molecular and cellular interactions may be affected (Gregory, 2009; Avio et al., 2015a,b; Cole et al., 2015).

In addition, microplastic particles may adsorb persistent hydrophobic compounds such as PAHs, PCBs, and pesticides thus facilitating pollutant mobility and distribution in aquatic ecosystems (Bakir et al., 2014). According to their different sizes, MPs have the potential to transport contaminants faster and more effectively through biological membranes and ultimately inside the cells of marine organisms by a Trojan horse like effect. This promotes contaminants' bioaccumulation and biomagnification in the foodweb as well as adverse biological effects ranging from the disruption of key molecular and cellular processes in vertebrate and invertebrate marine organisms to the loss of reproductive output (Cole et al., 2011; Chua et al., 2014; Syberg et al., 2015).

The Mediterranean Sea was recently defined as one of the areas most impacted by plastic pollution in the world (Cózar et al., 2014; Fossi et al., 2014; Suaria et al., 2016) and several studies have been carried out in this basin on the ingestion of plastic particles by marine organisms, ranging from zooplankton to top predators (e.g., Fossi et al., 2012, 2014; Battaglia et al., 2016; Nadal et al., 2016; Romeo et al., 2015; Pedà et al., 2016). More specifically, the central and northern Adriatic Sea has been characterized for the quantification and spatial distribution of litter on the seabed (Strafella et al., 2015; Pasquini et al., 2016; Melli et al., 2017), the sea surface (Liubartseva et al., 2016; Carlson et al., 2017) and the presence of MPs in the Venice lagoon sediments (Vianello et al., 2013). Therefore, since the occurrence of plastic litter has been recorded in the Adriatic Sea, the present aims at verifying the potential entrance of plastic fragments in the food web. by organisms living close to the seabed. MPs occurrence and characterization (size, shape and polymer) were addressed in the gastrointestinal content of wild-caught common sole *Solea solea* (Linnaeus, 1758) collected in the northern and central Adriatic Sea. It represents the first work carried out dealing with MPs content in a finfish species in the Adriatic Sea. Sole use as trophic resource the epipsammon, i.e. the underlying mobile epifauna sedentary or sessile organisms that found on the surface of substrate or in the sediment water interface. Such benthic flatfish was selected for its wide distribution, high ecological and economic value, and its relevance for human seafood consumption. *S. solea* is a species of high commercial interest within the FAO GFCM (General Fisheries Commission for the Mediterranean) area 37 (Mediterranean and Black Sea) where approximately 15% of its global production originates, only second to landings from the north-eastern Atlantic. The 23% of common sole landings of this FAO area comes from the Adriatic Sea (Grati et al., 2013).

## 2. Material and methods

### 2.1. Study area

The Adriatic Sea is a semi-enclosed basin of about 138,600 Km$^2$ extending in the North-West/South-Est direction within the Mediterranean Sea. It consists of three basins characterized by a decreasing depth from the south to the north. An 800 m deep shelf partly separates the southern basin, whose depth is greater than 1200 m, from the Ionian Sea. A second sill, of around 130 m depth, separates the southern basin from the central one where the maximum depth (260 m) is reached in the Pomo Pit. Northward, the seabed gradually rises until it reaches an average depth of approximately 35 m in the northern basin.

The majority of the seabed of the northern and central basins is located on the continental shelf and is characterized by sediments of varying composition and grain size (mostly sand and mud). This material is primarily transported to the basins via the large number of rivers occurring along the Italian north-western coast (Russo and Artegiani, 1996).

The Adriatic circulation is influenced by two main currents: one flows southeastward along the Italian coast (West Adriatic Current, WAC), while the other flows northwestward along the Croatian coast (East Adriatic Current, EAC). There are also several gyres, one of the main two is located in the northern part and the other in the South. The major winds affecting this basin are Bora (blowing from the North-East) and Sirocco (a south to southeasterly wind). A vertical thermohaline front that runs parallel to the coast in the northern and central portions of the Adriatic Sea separates coastal from open sea waters (Artegiani et al., 1997; Strafella et al., 2015).

### 2.2. Field sampling

Individuals of *Solea solea* were sampled in the GFCM Geographical Sub-Area 17 (GSA 17: central and northern Adriatic Sea) in a depth range from 20 to 120 m. Sampling was carried out in fall (November–December) 2014 and 2015 within the framework of the "*rapido*" Trawl Survey SoleMon (Grati et al., 2013). This activity was carried out onboard RV G. Dallaporta by the National Research Council - Institute of Marine Sciences (CNR-ISMAR, Italy) in cooperation with other national (ISPRA - Italy) and international institutes (IOF - Croatia and FRIS - Slovenia). Fish were caught with modified *rapido* trawls (width = 3.69 m, weight = 200 kg, codend stretched mesh size = 40 mm) at 60 of the 67 stations forecasted in the survey in November–December 2014 and 22 stations in the same months in 2015, distributed over the area following a depth-stratified random design into three different depth strata: 0–30 m; 30–50 m and 50–100 m; Fig. 1.

From 2 to 8 individuals were sampled at each station, for a total of 423 soles in 2014 and 110 in 2015. All the fish were "sacrificed" by

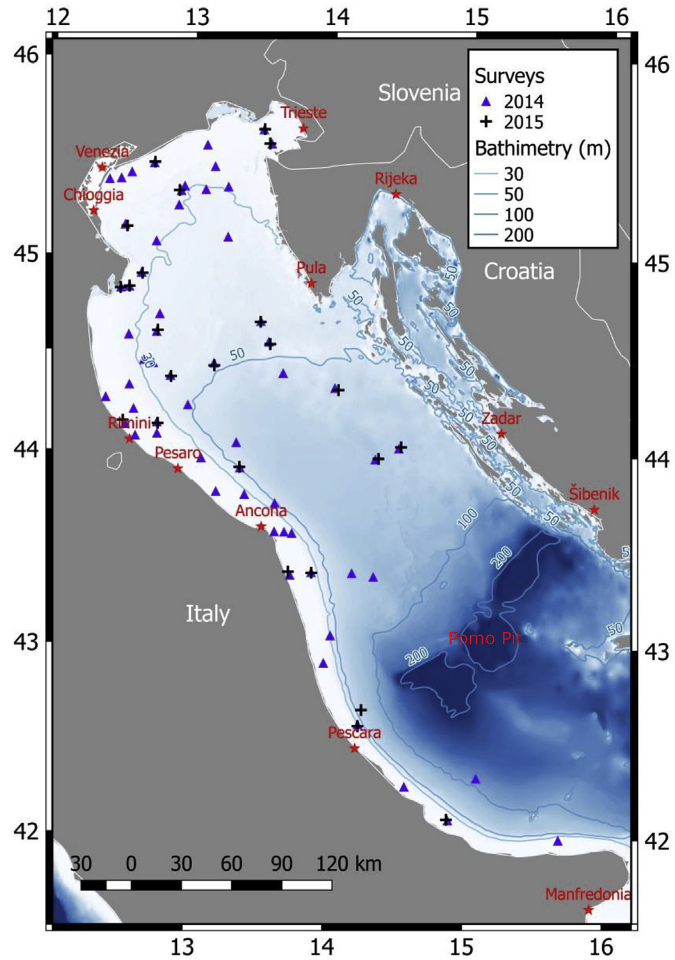


**Fig. 1. Map of the stations sampled during the Solemon surveys in 2014 and 2015.** Bathymetry and major towns and cities are also included.

cervical dislocation, then were measured and weighted, dissected on board and digestive duct samples were collected and frozen at −20 °C until the analyses.

### 2.3. Laboratory analysis

All tools and glassware used for the digestion tests were carefully rinsed with double-distilled water filtered through 1,6 μm GF/A grade glass fiber filters (Whatman, Oslo). Reagents were also filtered with the same GF/A filters. After thawing, the contents of esophagus, stomach, and intestine of each specimen were weighed, put into 250 mL Pyrex bottles and filled with a 10% KOH solution. The volume of KOH added was at least 5 times that of the biological material. Samples were incubated at 55 °C for 24 h. Once the organic material was degraded, the digestates were passed through GF/A filters. Where debris was found in the digestate, a density-based separation step using a sodium iodide (NaI) solution (d ¼ 1.8 g/cm3). In brief, a sodium iodide was added to the digestate (3:1, v/v) immediately after the 36 h digestion. The mixture was then thoroughly stirred for 20 min before being left to settle for 2 h. The supernatant containing the floating plastic particles was subsequently collected and filtered, as previously described. After extraction, the particles were observed and photographed through a microscope. An ocular micrometer was then used to measure them at their largest cross section in order to categorize them into three size classes (<100 μm; 100 μm < X < 500 μm; > 500 μm). Plastic particles were counted per individual fish, and color and shape described. Polymer composition was then determined by μFT-IR spectrometry. Analyses were performed using a Bruker Hyperion 3000 μ-FTIR system which allowed the characterization of MPs larger than 2 μm, $CO_2$ interference was removed to eliminate possible background interferences. The spectral range was set at 4000-675 $cm^{-1}$, with 20-mm spatial resolution at 50 × 50 mm aperture. Blank samples represented by the mixture of reagents involved in the extraction steps were processed under the same extraction condition. No occurrence of MPS was observed excluding any possible contamination during the analituical process.

### 2.4. Data analysis

The mean number of MPs particles (split according to size, shape and polymer composition) per specimen was computed for each sampling station in 2014 and 2015. A fourth root data transformation was performed, and the similarity matrix calculated using the Gower S15 index (Legendre and Legendre, 1998). Gower's index is used to measure how different two records are. Gower's S15 first computes distances between pairs of variables over two data sets and then combines those distances to a single value per record-pair. Statistical difference between 2014 and 2015 in terms of MPs abundances at the stations sampled in both years was investigated by a multivariate analysis using a PERmutation Multivariate Analysis Of Variance (hereafter PERMANOVA, Anderson et al., 2008), A hierarchical cluster analysis, using the same similarity matrix, was carried out and validated through a Principal Coordinates Analysis (PCO), to evidence similarity among stations based on the occurrence of the different MPs polymer per size.

A Principal Component Analysis (PCA), for both years, was also performed to evidence pattern distribution of MPs sizes for each polymer. Since data of 2014 referred to a greater number of samples and a wider geographical coverage in respect to those of 2015, maps showing the spatial distribution of the different polymers as well as of MPs size classes were produced using only 2014 data by QGIS 2.18.4 application. Spearman's rank correlation coefficient was used to check for the presence of a relationship between the length of sole specimens and MPs size.

The same correlation test was performed to highlight eventual correspondences between the occurrence of MPs recorded in 2014 and that of marine litter reported in the same area and year (Pasquini et al., 2016).

All statistical analyses were performed using Primer V6 with the add-on package PERMANOVA+ (Anderson et al., 2008) and R (https://cran.r-project.org).

## 3. Results

MPs were recorded in 95% of the 533 fishes sampled in 2014 and 2015, with more than one MPs item found in around 80% of specimens.

The most common polymers were polyvinyl chloride (PVC), polypropylene (PP), polyethylene (PE), polyester (PET) and polyamide (PA), for a total amount of 4566 microplastic items (3665 in 2014 and 901 in 2015) and an average of 1.73 ± 0.05 MPs items per fish in 2014 (with a peak of 6.30 ± 3.40 MPs found in site# 46) and 1.64 ± 0.1 in 2015 (with a peak of 10.6 ± 1.90 MPs in the same sampling site; Table 1). No statistical difference between years was evidenced in the MPs abundances recorded at the 22 stations sampled in 2014 and 2015 (p-value = .123).

Most of MPs were found as fragments of various size (72%) and the remaining ones as fibers (28%).

No differences were observed in the occurrence of the different

**Table 1**
**Summary table** of sampling carried out in the two years (2014–2015) with the number of station and mean of polymeries per fish.

| year | no of sampling station | no of sampling per strata | MPs mean per fish | Abundance Mean of polymeries |
|---|---|---|---|---|
| 2014 | 60 | 0–30 m → 37<br>30–50 m → 17<br>50–100 m → 6 | 1.73±0.05 | **PVC** 1.45±0.04<br>**PET** 1.74±0.05<br>**PA** 1.76±0.04<br>**PP** 1.85±0.05<br>**PE** 1.85±0.04 |
| 2015 | 22 | 0–30 m → 15<br>30–50 m → 5<br>50–100 m → 2 | 1.64±0.1 | **PVC** 1.5±0.08<br>**PET** 1.61±0.09<br>**PA** 1.65±0.07<br>**PE** 1.71±0.08<br>**PP** 1.72±0.08 |

polymer typologies in 2014, as each of them contributed from 17% to 21% to the overall MPs amount recorded in that year (Fig. 2a). The various polymers showed an average concentration per fish ranging from 1.45 ± 0.04 (PVC) to 1.85 ± 0.04 (PP and PE). Similar values, ranging from 1.50 ± 0.06 (PVC) to 1.72 ± 0.08 (PP) were recorded in 2015.

All polymers were found at almost all stations with the exceptions of stations 30 and 54 where PE and PET were not found, respectively (Fig. 2a). In terms of size, the two smallest dimension classes (<100 and 100 < X < 500 μm) were the most abundant accounting for 50%–85% of the total in most stations (Fig. 2b). Similar percentages were observed in 2015 (Fig. 3a and b).

Multivariate analysis and maps applied to 2014 data showed a spatial subdivision of the different kinds of MPs (Figs. 4–6). PVC and PA followed similar distribution patterns with the highest densities in the northern Adriatic Sea, both inshore and off-shore. PE, PP and PET were more concentrated in coastal areas with the highest values offshore Rimini (Fig. 5).

MPs smaller than 100 μm were more concentrated in coastal waters with a tendency to decrease either as spatial range and in quantitative terms from North towards South. Those greater than 500 μm were homogeneously distributed from the coast up to around 40 Km offshore with a peak in the middle of the Adriatic Sea, while MPs included in the size class 100–500 μm and fibers showed a uniform pattern on the overall investigated area (Fig. 6).

The Spearman test applied to 2014 data showed a significant result only for MPs <100 μm (p-value = .027; ρ = −0.0478), highlighting an abundance decrease with the increase of sole dimension, expressed as total length (TL). Finally, no significant relationship was evidenced between the spatial distribution of MPs and that of marine litter (p-value = .064).

## 4. Discussion

Plastic fragments tend to accumulate in biota and their quantification and characterization in the digestive tracts of marine organisms indirectly reflect their occurrence in the aquatic environment. The identification of ingested MPs could serve as a starting point in assessing marine biota exposure to MPs and ultimately determining their potential effects in fish.

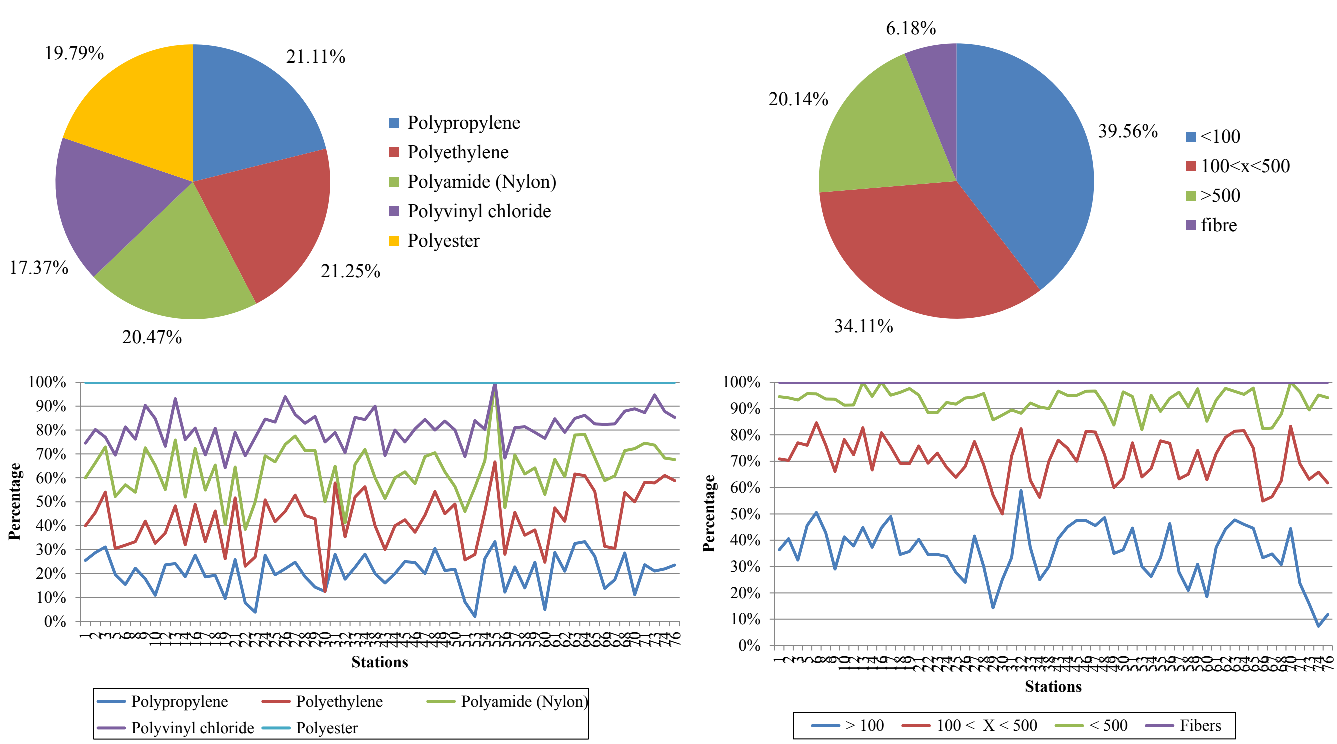


**Fig. 2. Percentage microplastic concentration in 2014**. a) Pie chart showing the percentage concentration of MPs typologies, and below a stacked bar chart showing distribution by station; b) Pie chart showing the distribution of MPs size classes and below a stacked bar chart showing distribution by station.

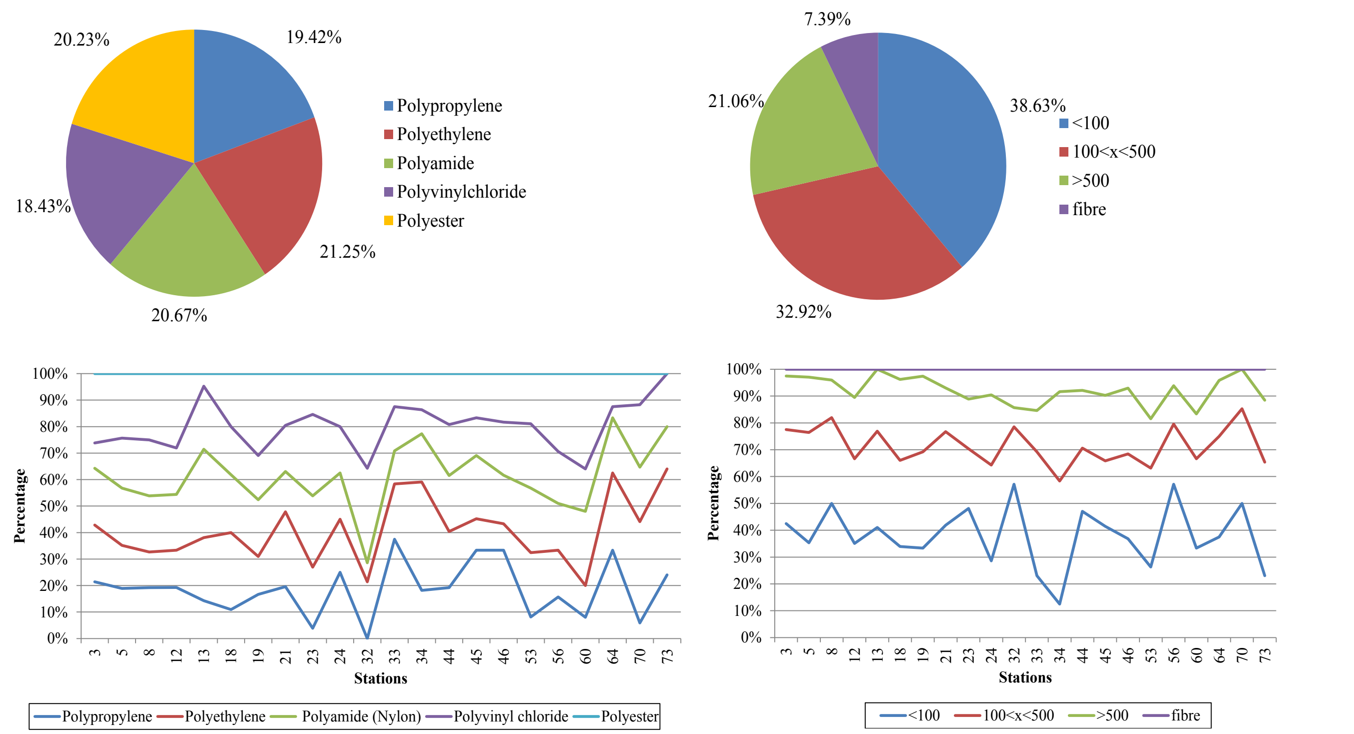


**Fig. 3. Percentage microplastic concentration in 2015**. a) Pie chart showing the percentage concentration of MPs typologies, and below a stacked bar chart showing distribution by station; b) Pie chart showing the distribution of MPs size classes and below a stacked bar chart showing distribution by station.

The occurrence of small plastic particles on beaches and in coastal waters was first reported in southern New England in the 1970s (Carpenter et al., 1972). However, in European seas the interest towards these pollutants and their possible transfer into the marine food chains strongly increased after the Marine Strategy Framework Directive (MSFD) entered into force in 2008 (EC, 2008). Specifically, of the 11 descriptors listed in Annex I of the MSFD for determining of Good Environmental Status (GES), Descriptor 10 has been defined as “Properties and quantities of marine litter do not cause harm to the coastal and marine environment”.

In this work, MPs were found in 95% of the 533 specimens of *S. solea*, representing a higher percentage in respect to those reported for other fish species, e.g., 35% for five mesopelagic and one epipelagic fish in the North Pacific Gyre (Boerger et al., 2010); 100% in several different species collected in the Río de la Plata estuary (Pazos et al., 2017); the estuarine species 36.5% for pelagic and demersal species in the English Channel (Lusher et al., 2013); 67.7% for *Boops boops* around the Balearic Islands (Nadal et al., 2016).

Due to the trawl cod-end mesh size (46 mm) used in the SoleMon surveys, it was very unlikely that the MPs detected resulted from contact within the net and subsequent ingestion.

In addition, differently from what reported by other works focusing on the occurrence of MPs in the digestive tract of a few fish species (Boerger et al., 2010; Lusher et al., 2013), the majority of plastic particles were not fibers.

Previous studies related MPs ingestion by fish to feeding strategies (Anastasopoulou et al., 2013; Romeo et al., 2015). However, in the present study the MPs occurrence in the sole digestive tract did not appear strictly related to the feeding strategy of the species. The negative correlation between MPs <100 μm concentration and the sole size can be explained with the match of spatial distribution of this species in the Adriatic Sea. In fact, juveniles mostly concentrate along the Italian coastal waters up to 30 m depth and from the northerner part of the basin to South of the Po river mouth where this MPs size was recorded. The absence of a correlation for the other MPs categories, even though the diet shifts towards greater size prey as the soles grow (Molinero and Flos, 1991; Stergiou and Karpouzi, 2002a,b), appears to confirm the hypothesis that the main reason of the MPs presence or absence in the gastrointestinal tract of this species is the MPs spatial distribution and abundance.

The occurrence of low density polymers such as PP and PE in the gastrointestinal contents of soles indicates that these MPs were present in the sediment. Indeed, as already demonstrated by other studies (Lobelle and Cunliffe, 2011), the occurrence of biofilms on floating MPs particles may increase their sinking properties thus favoring their deposition on the seabed.

PE, PP and PET spatial distribution could be mostly explained by the Adriatic Sea hydrodynamic circulation, especially the near-shore currents and gyres and it may be difficult to identify original sources of plastics. Also, PVC and PA distribution are surely affected by the hydrodynamic features of the basin but, in this case, their high concentration near the Po Delta and at South of the Venice Lagoon could be linked to the high occurrence of mussel farms in those areas (Strafella et al., 2015). In fact, plastics are used in all stages of bivalve mariculture including PA ropes for line culture plastic crates and frames for bottom culture and PVC pipes and buoys (Beveridge, 2008). However, as our study also showed that no correlation exists between the concentration of marine litter and that of MPs in the investigated area, it is reasonable to hypothesize possible different dispersion flows by currents due to the smaller dimensions of MPs with respect to large marine litter items.

The findings of this study and the maps produced can assume a relevant role to provide appropriate responses to the MSFD 2008/56/EC criteria 10.1.3 (“… trends in the amount, distribution and, where possible, composition of microparticles, in particular microplastic”) and 10.2.1 (“… trends in the amount and

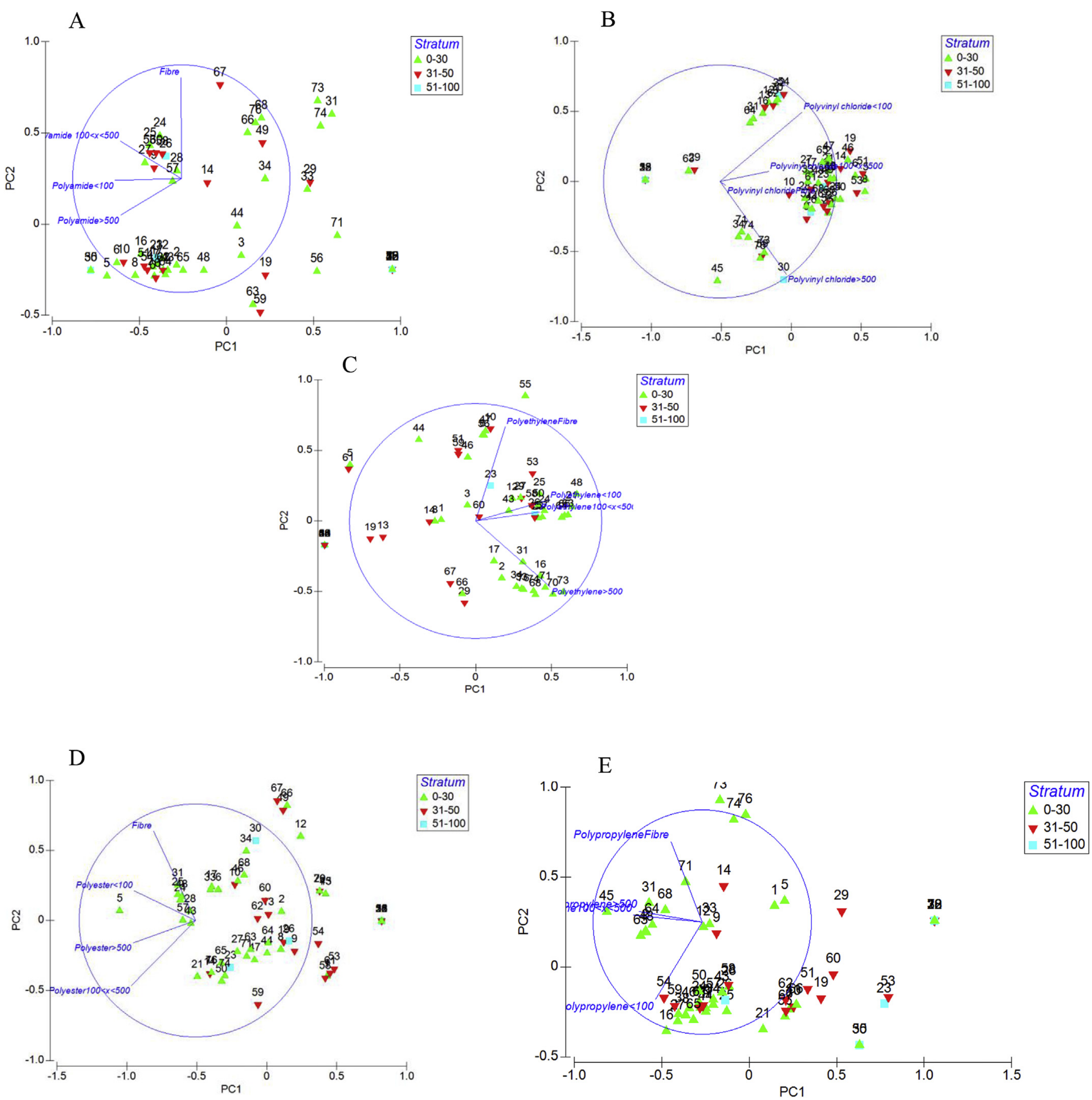


**Fig. 4. Principal component analysis (PCA) of MPs in 2014**. The straight line represents the different MPs size classes; the station was divided by three bathymetric layer (0–30 m, green; 31–50 m, red; 51–100 m, light blue). Polyamide (A), Polyvinyl chloride (B), Polyethylene (C), Polyester (D), Polypropylene (E). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

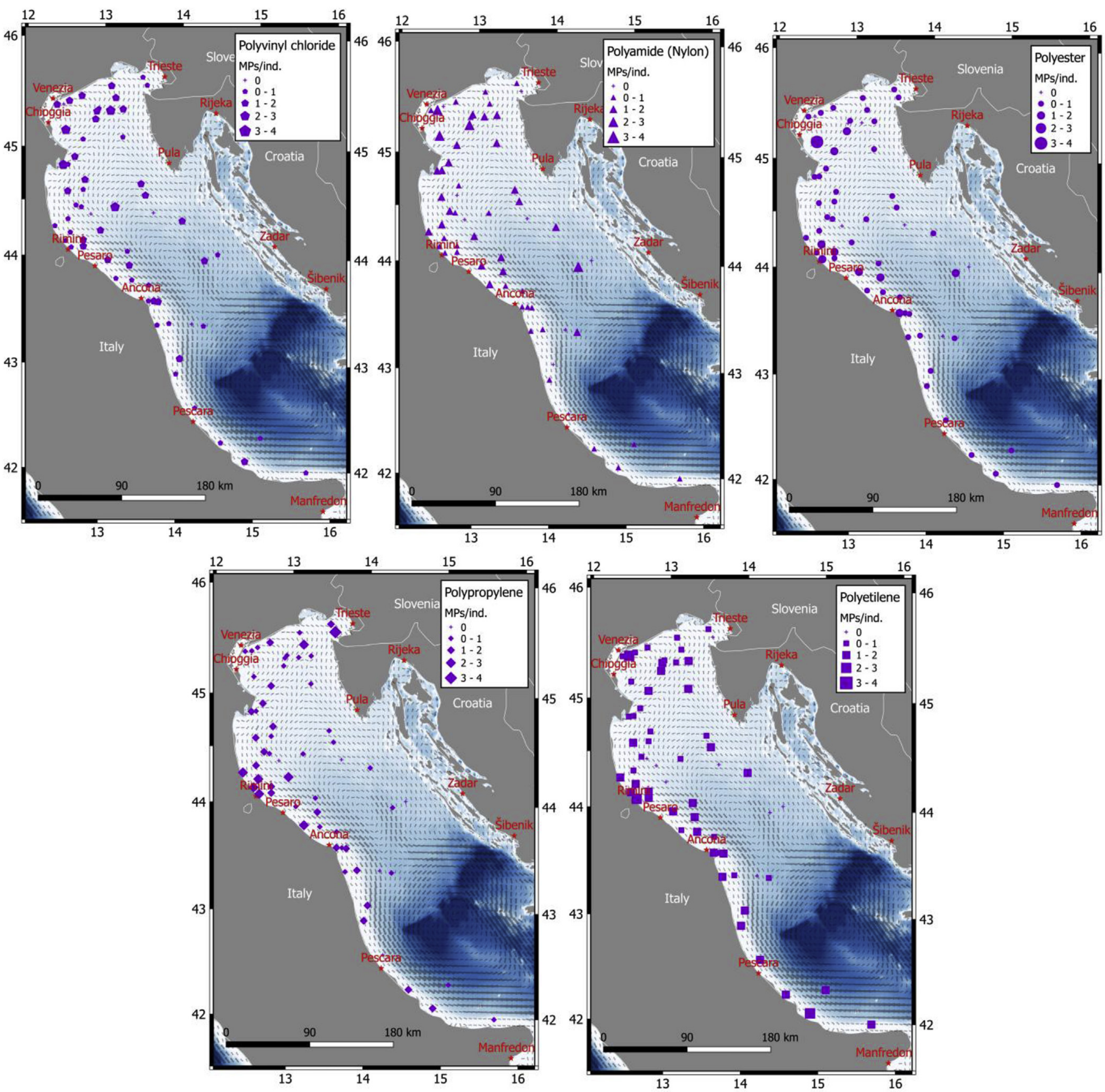


**Fig. 5.** Maps of spatial distribution of the different polymers. Every symbol represents the average MPs concentration per fish in each station. The arrows identify the current pattern and the main city were also reported.

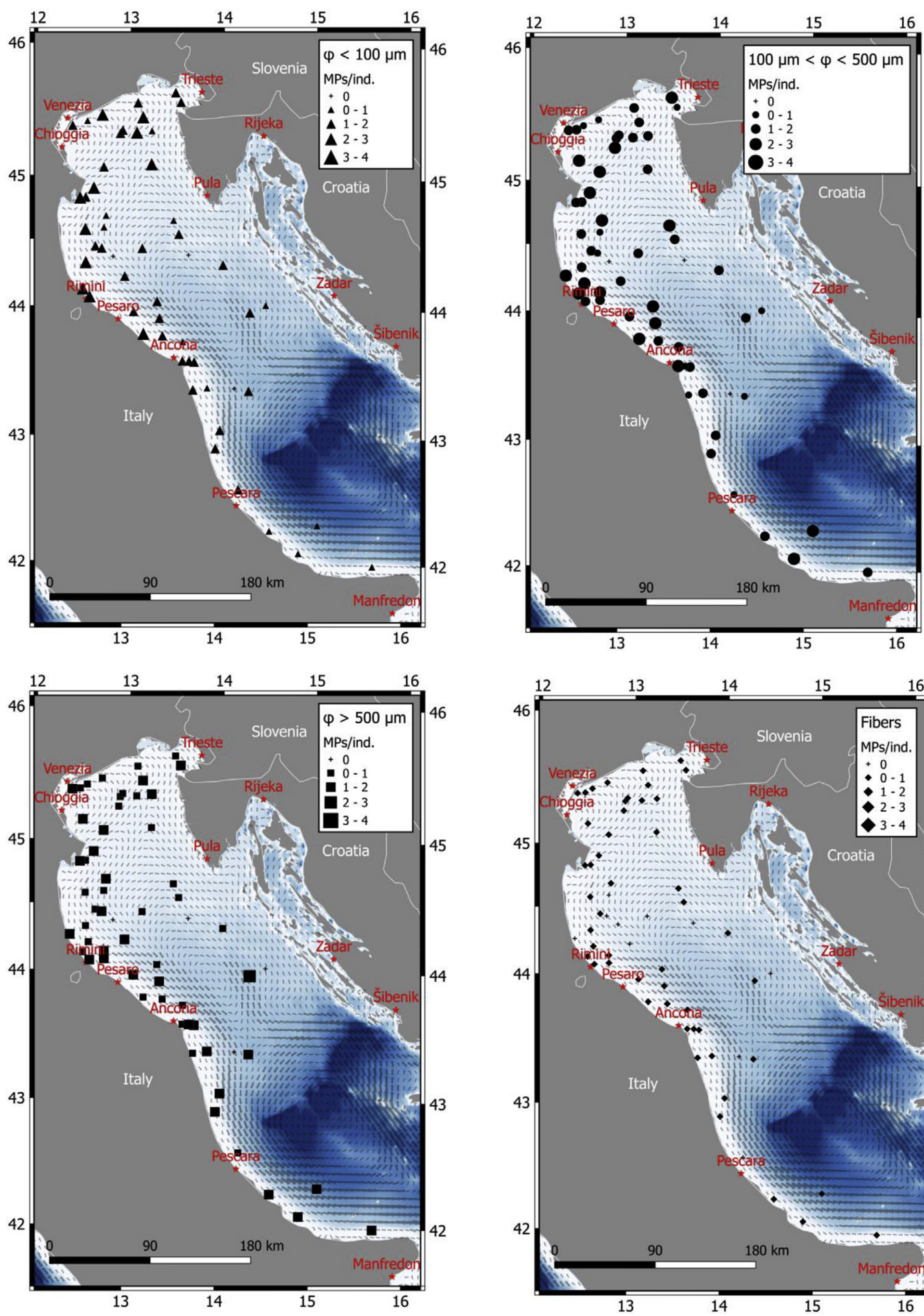


**Fig. 6. Maps of spatial distribution of the different size.** Every symbol represents the average MPs concentration per fish in each station. The arrows identify the current pattern and the main city were also reported.

composition of litter ingested by marine animals, e.g. gastrointestinal analysis"). Moreover, these results represent a further step in the investigations on MPs contaminant transfer across the food web in order to understand the possible ecological and biological consequences for humans. Indeed, taking into account the results of a few studies about MPs translocation from gastrointestinal tract to other body parts in bivalves and terrestrial mammals (Hussain et al., 2001; Carr et al., 2012; Van Cauwenberghe and Janssen, 2014), it is conceivable that the same might also happen in fish entering consequently in the human diet.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2017.12.038.

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