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Microplastic detection and Lagrangian modelling in the Tyrrhenian Sea

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***Abstract* – In recent years the presence of microplastic (MP) in oceans is getting more and more attention due to its impacts on these environments. A major concern is represented by closed and densely populated basins, like the Mediterranean Sea. In this work, an assessment of MP concentrations in the Tyrrhenian Sea, a sub-basin of the Mediterranean Sea, is performed by means of numerical simulations. A Lagrangian stochastic model of dispersion, which requires hydrodynamic fields and MP sources as inputs, is employed. The hydrodynamic fields are supplied by the Copernicus Marine Environment Monitoring Service (CMEMS), while the MP sources are estimated by means of a novel method based on the population density. The results agree well with field data derived from Goletta Verde sampling campaign and highlight the importance of a correct estimation of the sources. Both the numerical results and field data show the presence of high polluted areas.**

I. INTRODUCTION

The attention of the scientific community regarding the impact of plastic waste in the marine environment is growing since the beginning of the present century [1].

Thanks to their buoyancy and durability properties [2], plastic debris entering the marine compartment persists and accumulates, forming areas known as garbage patches. In semi-closed and densely populated basins like the Mediterranean Sea, see e.g. [3], plastic pollution is recognized as a critical issue [2], [4]. In recent years, microplastic (MP), i.e. the fraction of plastic litter with dimension smaller than 5 mm [1], has attracted further attention. MP, which can be of primary, if released directly into the sea, or secondary origin, if generated by the fragmentation of larger debris, represents an important environmental problem [5]. Several studies have shown that MP can be ingested by marine organisms, entering the food chain, and contaminate the benthic zone. Another critical question is also represented by the fact that microplastic, floating both on the sea surface and in the water column, is carried by currents, waves and wind, even far from sources. Consequently, MP distribution can be investigated using stochastic models of dispersion [6-8]. Moreover, in recent years the availability of data from sampling campaigns [4], [9] allows us to understand the characteristics of the phenomenon of microplastic pollution, in terms of distribution, concentration, transport mechanisms and residence times and validate numerical models.

In the present work, the MP spatial distribution in the Tyrrhenian Sea is investigated through a stochastic dispersion model. The numerical results are compared with experimental data derived from the Goletta Verde sampling campaign carried out in 2015 [9]. In the proposed model, a new method to estimate microplastic sources, based on the population density, is used.

II. MATERIALS AND METHODS

A. Goletta Verde campaign

In order to have actual data concerning MP pollution along the Italian coast, Legambiente association planned a sampling campaign, from June to September 2015, using the Goletta Verde vessel. The major Italian river mouths, which are supposed to be highly polluted, as well as minor islands, i.e. sites presumably far from MP sources [9], were chosen as sampling locations (Fig. 1).

Samples of water and microplastics were collected on board of the Goletta Verde by means of two different gears, a Manta Trawl (MA) and a Plankton net (WP2), both lined with a 333 μm mesh net.

In each site, the vessel travelled two linear transects at 2 knots for 20 minutes. MA sampling was conducted

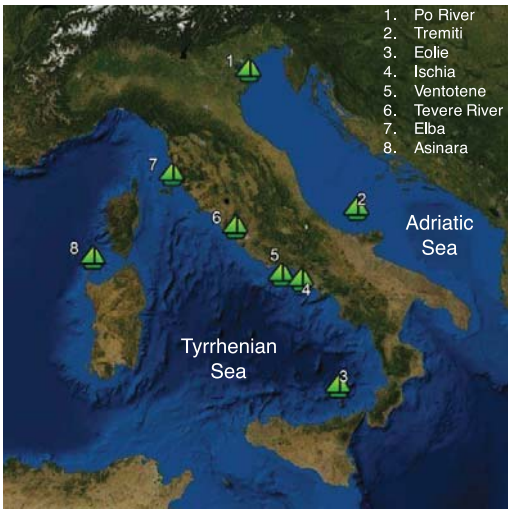

Fig. 1. Goletta Verde 2015 sampling locations.

collecting MPs from the sea surface to a depth of 25 cm, while the WP2 sampled a portion of the water column 20 m high, starting from the sea surface.

After the campaign, plankton and other organic matter were separated in order to analyse the collected samples. MPs were measured under a 7-120x binocular stereoscope (AxioCam ERc5s for image analysis, Carl Zeiss Micro-imaging Gmbh) [9]. This analysis allows to classify them upon their shape, e.g. synthetic filaments, plastic films, fragments and spheres, and colour.

The MP density, or item concentration, was determined and expressed as items/m^3, considering that the volumes of the filtered seawater were 2800 m^3 and 2956 m^3 for the MA and WP2 samplings, respectively [9].

B. *Source estimation method*

In this study, a primary MP source estimation method was developed, considering that the amount of MPs entering into the sea could be proportional to the population density [10]. The domain studied includes the Italian regions facing the Tyrrhenian Sea and Sicily and Sardinia islands.

River mouths and coastal cities were considered as inputs of MP. River inputs (RI) and coastal city inputs (CCI) - unevenly spaced along the coast - are quantified assuming a MP amount proportional to the population. River MP contribution is related to the total residential population, which is estimated by overlapping the water basin map (source: ISPRA, Italian Institute for Environmental Protection and Research database) with that of the residential population in the same area (source: ISTAT, Italian National Institute of Statistics, 2011 database) in every water basin. Therefore, the so estimated MP amount is related only to the population responsible of its production while it does not depend on the volumetric flow rate of the river that carries it. RI were considered constant during throughout the simulation period, being therefore continuous sources of MP. Besides, population living both in coastal cities and surrounding areas are considered for CCI. Also coastal cities contribution was considered constant during the period between 2007 and 2016.

The MP charge was assigned to the rivers and the coastal city, considering that every inhabitant is responsible of 270 g of MP per year [11].

C. *2D Lagrangian simulation*

MP pollution in the Tyrrhenian Sea has been studied analysing paths, concentration and accumulation zones. Since a large part of the primary MP tends to float on the sea surface, it was considered plausible the use of a 2D Lagrangian stochastic model (LS) model to simulate MP transport and diffusion phenomena in this sub-basin. This LS model was developed by the authors and requires as input the hydrodynamic fields of the considered domain. Hence, daily mean surface velocity fields were provided by the Copernicus Marine Environment Monitoring Service (CMEMS) [12], [13]. The domain of the simulations is composed of 166x142 cells with 1/16° spatial resolution. Horizontal diffusivity was set to 30 m^2/s [14].

III. RESULTS

D. *Goletta Verde MP measurements*

MP concentrations measured during the campaign in each sampling area are reported in Tab. 1. In total, 1578 items were collected, by means of the Manta Trawl and the WP2 FAO net, in 5639 m^3 of seawater sampled, with an average value of 0.3±0.04 items/m^3. The concentration of MP floating on the sea surface, sampled with the Manta, resulted higher than that found in the water column, analysed with the net, in almost every sampling point.

Goletta Verde samplings by means of MA upheld that the area close to the Tevere and Po river mouth is, as expected, significantly polluted. However, the greatest concentration of MP was found near Ischia island (0.706

Table 1. MP concentration measured during Goletta Verde campaign (20/07/2015-07/08/2015) with Manta Trawl and WP2 FAO net.

Sampling points	Manta Trawl Density (items/m^3)	WP2 FAO net Density (items/m^3)
Tremiti	0.134	0.197
Eolie	0.288	0.248
Ischia	0.706	0.280
Ventotene	0.263	0.142
Elba	0.326	0.129
Asinara	0.174	0.064
Po river	0.641	
Tevere river	0.362	

items/m^3). On the other hand, the lowest density among the eight sampling locations was measured in the waters surrounding the Tremiti islands (0.134 items/m^3).

E. Tyrrhenian MP estimated inputs

The proposed method allowed us to estimate 136 MP sources, subdivided into 71 RIs and 65 CCIs (Fig. 2).

The total population living in the area surrounding the Tyrrhenian Sea is equal to 25,524,864 inhabitants. Considering 270 g of MP produced per inhabitant per year, a total of 6891 tons per year entering the Tyrrhenian Sea, 4764 tons of them due to the river inputs and 2127 tons due to the coastal city inputs. was estimated.

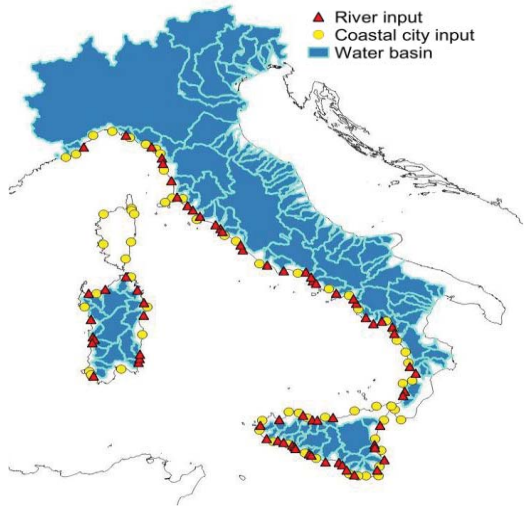

Fig. 2. River input locations (yellow dots) and coastal city inputs (red triangles) facing the Tyrrhenian Sea.

F. MP dispersion simulation

The phenomenon of MP dispersion has been simulated considering a period of 10 years, from 2007 to 2016. In the numerical simulation, more than $4 \cdot 10^6$ particles per year were released from the estimated sources.

Paths, concentration and accumulation zones of MP were identified analysing both daily and averaged output of the simulations. Daily MP concentration map and surface velocity vector fields regarding 01/01/2015 and 01/08/2015, are depicted in Fig. 3a and 3b, respectively.

A strong spatial variability of the MP concentration is apparent for the whole simulation period. Fig 3a shows a typical winter situation in which the currents are faster and directed towards the coast; the MP tends to remain confined to the coastal areas giving rise to higher concentrations. In contrast, the currents move towards the open sea during typical summer conditions (Fig. 3b). In this case the MPs are carried away from the sources and accumulate in offshore stable vortices.

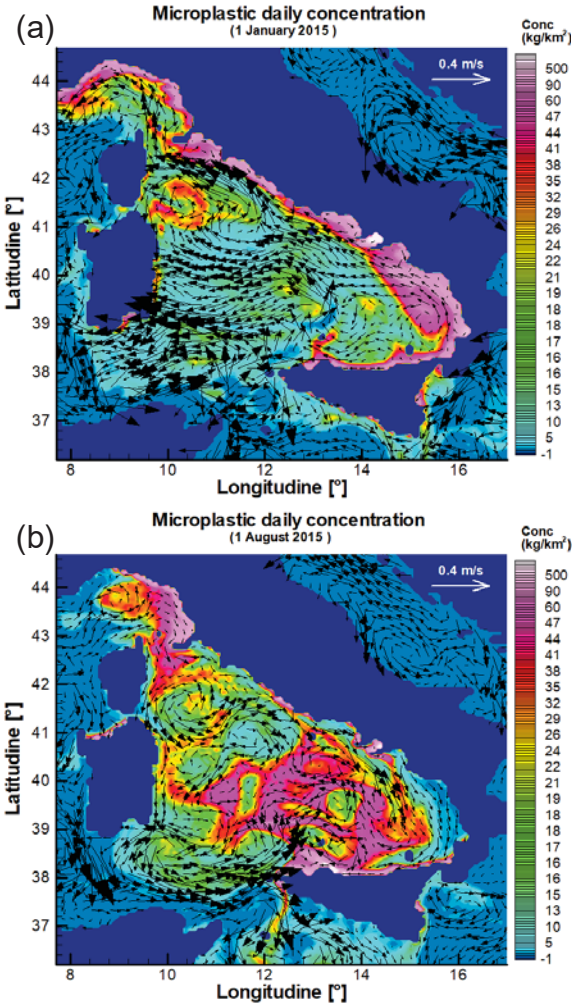

Fig. 3. MP daily concentration and surface velocity vector field. 01/01/2015 (panel a) and 01/08/2015 (panel b)

In order to identify critical high concentrations and accumulation zones for the different periods of the year, the monthly outputs averaged over a 10-year period (2007-2016) have been calculated. Figure 4 shows the 10-year average referred to the months of July. Higher concentrations are visible in the near-shore waters, particularly in the areas of Naples and Liguria, excluding the Calabria coasts.

In the first case, the high concentration is due to the large MP load introduced in the Gulf of Naples, both in terms of MP source numbers and of MP charge due to the population density. On the other hand, in the Ligurian Gulf the northward transport of MP introduced in the central Tyrrhenian Sea, for example that associated with the Tiber and Arno rivers discharges, is crucial. Furthermore, this contribution is added to that of the coastal city of Genoa.

Another main feature is the high MP concentration occurring along the northern coast of Sicily. This fact is

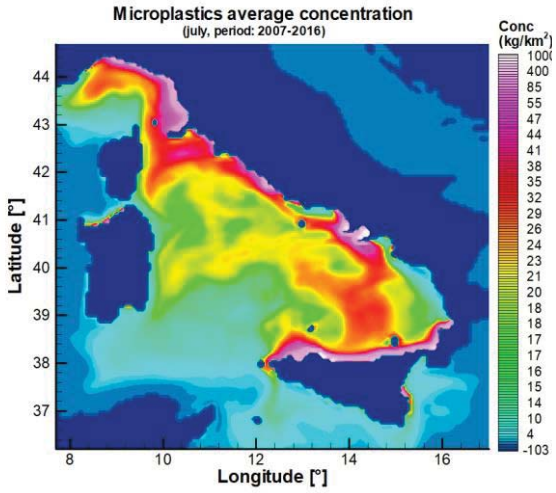

Fig. 4. MP 10-year monthly averaged concentration map (July, 2007-2016)

associated with the offshore transport of MPs introduced by the sources of the Gulf of Naples, which tend to remain confined to the southern Tyrrhenian basin. Note that in the centre of the domain the MP concentration falls in the range 10-20 kg/km^2.

To validate the proposed model, the numerical results were compared with the experimental data, i.e. Goletta Verde MP measured density, expressed as items/m^3. It is necessary to underline that different measurement units were used concerning measured (items/m^3) and simulated MP concentrations (kg/km^2). The comparison between the two was deemed acceptable considering that the MP sampling realized with the Manta Trawl explores 25-50 cm from the sea surface and the Lagrangian model solves the 2D dispersion using surface velocity components. Hence, even though measured and simulated concentrations have different units, the comparison allows us to make qualitative considerations and to analyse the spatial distribution of MP.

As shown in Tab. 2, simulated and measured MP concentrations agree reasonably well. The ratio between the two varies within a narrow range. Ischia resulted the most polluted location among those analysed in this paper, in terms of both measured and simulated concentrations.

In order to investigate the temporal variability of the dispersion phenomena in the sampling locations, the MP concentration time series concerning July 2015 have been analysed. Fig. 5 shows that in this period (from Julian day 3104 to 3135) the MP concentration is considerably small compared the monthly average value.

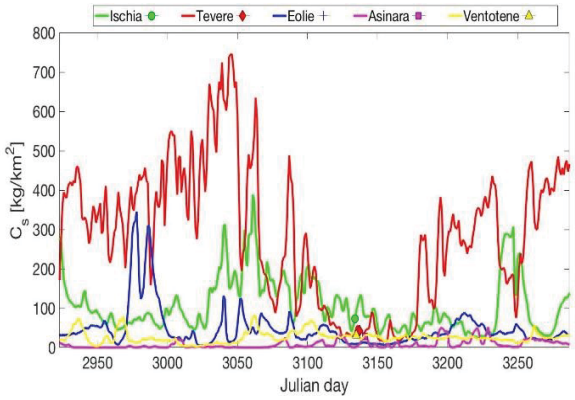

Fig. 5. Time series of simulated MP concentration from 01/01/2015 to 31/12/2015.

IV. DISCUSSION/CONCLUSION

In this work, MP dispersion in the Tyrrhenian Sea, is investigated. Numerical simulations were carried out with a 2D Lagrangian stochastic model which uses CMEMS mean surface velocity fields and implements a new MP source estimation method proposed by the authors.

The comparison between the measured concentrations during the Goletta Verde campaign and the numerical results is rather good. This fact suggests that both the hydrodynamic field and the source estimation method were sufficiently accurate. For the sake of simplicity, a constant amount of MP was considered during the simulations as input data. Therefore, to improve the accuracy of the proposed method, it could be useful to take into account the seasonal variability of the population in the coastal vacation spots.

Table 2. Comparison between MP concentration measured during Goletta Verde campaign (20/07/2015-07/08/2015) and simulated with the Lagrangian stochastic model.

Sampling location	**Sampling Date**	**Measured concentration (items/m^3)**	**Simulated concentration (kg/km^2)**	**Week - averaged simulated concentration (kg/km^2)**
Eolie	20/07/2015	0.288	23.321	25.21
Ischia	31/07/2015	0.706	72.587	78.13
Ventotene	01/08/2015	0.263	30.920	30.04
Tevere river	03/08/2015	0.362	42.734	43.75
Asinara	07/08/2015	0.174	28.829	10.92

Besides, in the Tyrrhenian Sea the dispersion of MP presents a great spatial and temporal variability. The average concentration is 30 kg/km^2 and increases in near-shore waters. Ischia Island resulted the most polluted location. It was noticed a direct relationship between the population density and the amount of MP found in the sea waters, as observed off the coasts of Lazio and Campania. On the other hand, it was found high MP concentrations even in the waters facing Sicily and Liguria, which are far away from the main MP sources. Furthermore, the fundamental role of Tyrrhenian Sea circulation in determining the general MP dispersion and the formation of accumulation zones was confirmed.

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