Monitoring, simulation and dissemination: the European SPlasH! project strategy to face up the microplastic problem in commercial port environment

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Abstract

Purpose: The European SPlasH! project aimed to obtain detailed information on microplastic (MP) pollution and dynamics in the peculiar marine environment of commercial harbours, disseminate the results to different categories of stakeholders and raise public awareness of the problem of MP pollution.

Methods: The study area is represented by the harbours of Genoa (Italy), Olbia (Italy), and Toulon (France). Several actions were carried out in the project: two campaigns per harbour for the sampling of different matrices; application of diffusion modelling and tank tests to understand particle dynamics and trajectories in water column; field activities with students for plastic wastes collection from beaches; results dissemination by different information tools.

Results: Differences in MP concentration in the different sampling periods and in polymeric composition between the ports were noted, with a higher variability for the Port of Genoa. MPs dispersion outside the basin of Genoa varied under specific weather and sea conditions, resulting in the worst scenario with strong

Conclusions: Results obtained from SPlasH! Projects are important tools for improving management of MPs environmental issue and to spread awareness especially to the younger generation.

Keywords: microplastics; marine port environment; environmental monitoring; dispersion models.

1. Introduction

Harbours, especially commercial ones, have the potential to produce environmental impacts on their surrounding marine environments. Therefore, sustainable development of ports is an issue that all commercial and non-commercial port managers have to face on a daily basis [1]. Since seaports are both

receptors of contaminants, from the cities and territories they overlook and from discharges and rivers flowing into their basins, and sources of impacts, due to the presence of several commercial and industrial activities, they must adopt managing actions that limit the potential negative effects on the external marine environment [2]. In this scenario, port management policies are constantly evolving and are looking for the development of environmental-friendly practices. For this purpose, legislative instruments have been developed on a large scale such as the European Water Framework Directive [3] or the ESPO Green Guide of the European Sea Ports Organisation (ESPO) [4]. This context includes the issue of plastics and microplastics (MPs) management and monitoring in the marine environment for which the European Commission has, for example, codified and established specific descriptors and criteria [5].
The European SPlasH! "Stop to plastics in H_2O!" project is one of the many projects that have been devised in recent years for the study, monitoring and management of MPs in marine environments, but the only one (at its start) with ports as the target environment. SPlasH! is a project funded by the Interreg Italy-France Maritime 2014-2020 Programme (**Fig. 1**) and was developed from March 2018 to September 2020 (http://interreg-maritime.eu/web/splash). The project is a collaboration between three partners, namely the University of Genoa (Italy), the University of Toulon (France) and the European Research Institute (Italy). In this paper, the strategy on which the project was based, and some results of monitoring, simulation and dissemination obtained in the ports of Genoa, Olbia and Toulon are presented.

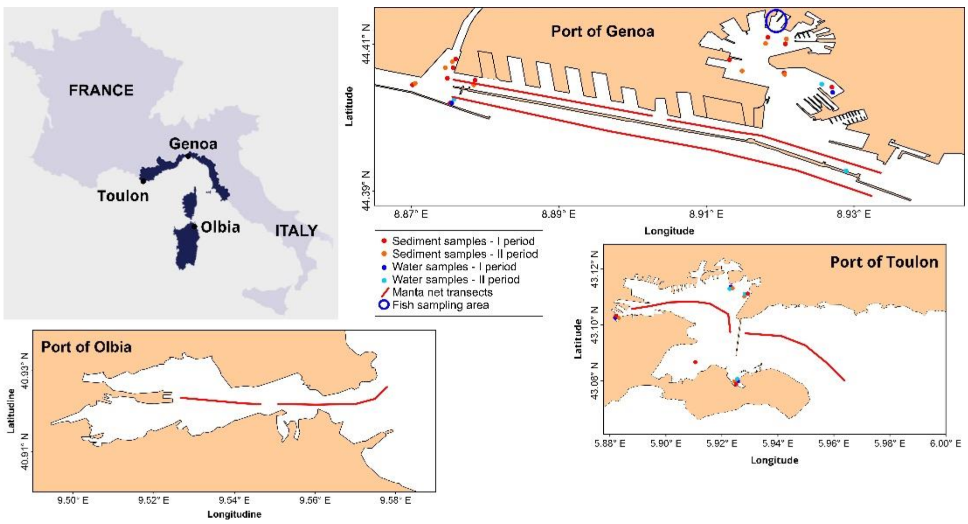

Fig. 1 Map of France and Italy highlighting the Maritime Programme area (in blue), and maps of the Port of Genoa, the Port of Toulon, and the Port of Olbia with the sediment and water sampling points (coloured dots), the Manta net transects (red lines), and the fish sampling area (blue circle)

2. The SPlasH! project

The SPlasH! project aimed to analyse the presence, origin and dynamics of MPs in commercial ports in the north-western Mediterranean Sea (**Fig. 1**) for the first time, and the harbours involved in the project were Genoa, Toulon and Olbia. The project was divided into three main tasks: monitoring, simulation and dissemination. The three sections and the interactions between them are reported in the scheme in **Fig. 2**.

Monitoring campaigns dealt with the sampling of MP floating on the sea surface, along the water column, trapped and accumulated in the bottom sediment, and ingested by fish. Monitoring also included the study of all the instruments available for sampling MPs in the marine environment, and the selection of those most suitable for port areas [6]. Following this in-depth study, the project also included the design, implementation and first field tests of prototypes for sampling MPs along the water column. The aim of the monitoring was to collect as much information as possible on the presence and type of MPs in port environments to try to understand their origin and identify their sources. All the results obtained by the monitoring activities were useful for the implementation of dispersion models and also for the stakeholders to understand the state of the port environment in terms of MP contamination.

The study also addressed the settling velocity in the water column of MPs exposed to wave action performing a series of laboratory experiments and MP dispersion under the influence of weather and sea forcing by the application of mathematical models.

All the collected data and the obtained results were then disseminated to both scientific and social community by participation to international conferences, laboratories with Master and PhD students, meetings with schools [7], and photographic exhibitions. The dissemination part also included the design, production and dissemination of a social game, with the purpose to raise awareness on plastic pollution.

The ultimate aim of the project was to provide useful information to port managers, public administrators and environmental agencies to enable them to implement measures and actions to reduce the impact of plastics on port and outside waters.

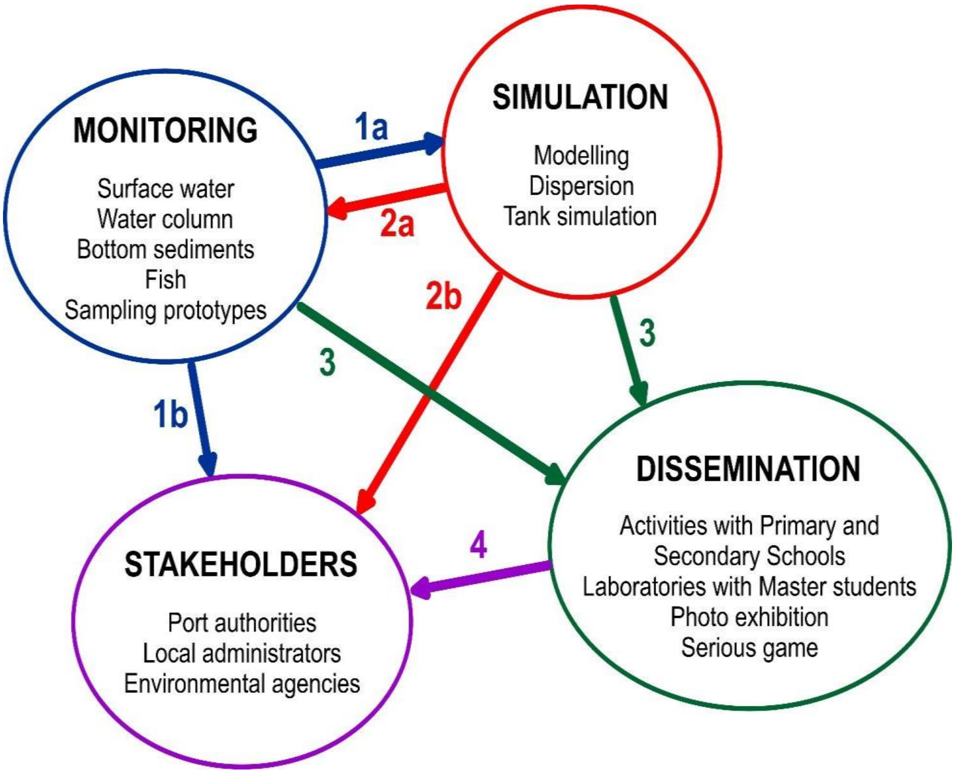

Fig. 2 The strategy of the SPlasH! Project to face up the MP problem in commercial port environment. Colours represent the different activity categories addressed by the project; numbers indicate the time order in which the activities were carried out within the project

3. Materials and methods

3.1 Sampling strategy and methods, and sample analysis

The project monitoring plan included 4 campaigns between winter 2018-2019 and spring 2019 during which different matrices were sampled, namely bottom sediments (using a Van Veen grab), surface water (by a Van Dorn bottle), surface material (by a Manta net), and fish (caught with a purse seine with the help of a professional fisherman). Sample number and sampling period and ports are reported in **Table 1**. The distribution of the sampling stations is shown in **Fig. 1**.

Table 1 Project ports, sampling periods, and number of samples for each sampling matrix (sediment, water, surface material and fish)

Port	Period	Sediment samples	Water samples	Surface material samples (manta net transect)	Fish samples
Genoa	12/2018	11	2	3	-
Genoa	05-06/2019	10	3	2	21*
Toulon	03/2019	4	3	2	-
Toulon	06/2019	4	3	2	-
Olbia	11/2019	-	-	2	-

* 21 fish were also sampled in a natural fishpond in Sardinia (Italy) to compare a heavily impacted environment with a natural one.

Materials and methods, and related results, of surface material and MP content in fish stomachs are presented by [8] and [9], respectively. The following is the methodology used for sediments and surface water sampling and analysis. Sediments were sampled using a 5-L Van Veen grab and stored in new glass jars. Surface water was sampled with a 5-L Van Dorn bottle and store in 10-L glass bottles. Measures to avoid secondary contamination of samples were taken at all stages of sample handling (sampling, laboratory treatment and analysis) using glass and metal instruments, pre-washing with micro-filtered water, wearing cotton clothes and working under a hood [6]. A portion of 50 mL of each sediment sample was placed inside a beaker and mixed with 200 mL of a NaCl saturated solution (density of 1.2 g cm^{-3}) to extract microlitters from sediment by density separation. The details of the procedure followed for the microlitter extraction and filtration on GF/F glass microfiber filters is reported in [10]. Water samples were filtered by a vacuum pump into GF/F filters with diameter of 47 mm and porosity of 0.7 µm. Each 10 L water sample was divided into 5 different filters (2 L for each filter) to facilitate sorting under the microscope. Particles derived from sediment and water samples, and retained on the filters were observed, measured and catalogued with a Leica Z16 microscope and photographed with a Leica Application Suite software. Microparticles were classified according to their shape, size and colour [11]. Afterwards, 20% of microparticles for each sample were analysed with Raman spectroscopy (Xplora™ Plus Raman spectrometer using a 785 nm-laser, with

Confocal Raman Microscope using a 100x lens, Horiba) to identify MP polymers. Particle composition has been classified using the Bio-Rad KnowItAll Raman Spectral Library. Only spectra with correspondence > 70% to the reference spectra were accepted and considered in results [11]. Microparticles have been classified as minerals, natural organic particles and MPs.

3.2 Simulation

A series of laboratory experiments was performed with the aim of measuring MP trajectories under different wave conditions and according to different MP characteristics, in order to quantify the inertial effect and suggest a new analytical formulation for the settling velocity. Methodology and results of laboratory experiments are presented in [12]. In addition, marine circulation and MP dispersion process were studied. For the numerical simulations, the FLOW module of DELFT3D was used to simulate the multidimensional hydrodynamics, calculating the non-stationary circulation and transport phenomena, forced by the meteorological marine conditions identified with clustering techniques (tide, wind, waves and pressure fields) [13]. The computational domain was discretised within the port and its vicinity with a curvilinear mesh. The evolution of the horizontal velocity generated on the surface of the domain and the evolution of the MP concentration were then obtained. The MP release was simulated into the Polcevera stream (western part of the port) and in the inner part of the port and follows a flood hydrogram starting 24 hours after the beginning of the simulation. Then, the MP concentration is evaluated, which is the maximum concentration reached at each point according to the different meteocean scenario. The cumulative transport was evaluated through the different inlets of the port. The results of manta net sampling in the Port of Genoa [8] were used to assess the distribution of MP concentration in the water body and return quantitative values.

3.3 Dissemination

Activities with schools took place from September 2018 to February 2019, and from March 2019 to May 2019. The activity with the students included different types of activities: interactive, with videos, photos, graphs and dissemination materials, and laboratory with the administration of a questionnaire before and after the practical activity; at the end of this path a field trip/cleanup was planned, observing and cataloguing the type of objects found. Dissemination included the organisation of a photo exhibition and posters summarising the project achievements: numbers from the sampling of the different matrices investigated, and the processing of the data and the results were considered and posters explaining the numbers achieved by the project were produced and shown to the public in an exhibition that was replicated in Genoa and Toulon. A social game was also chosen as a public awareness tool, i.e. a video game in which informative messages appear during the game. As regards scientific dissemination, SPlasH! researchers have participated in international conferences and produced scientific publications, as well as participating in scientific dissemination events open to the public. Master's degree students and graduate researchers were involved in theses and research fellowships, respectively, centred on the project themes: a specific problem was given to each student/researcher, and they were engaged both in the field and laboratory activities, and in the data processing and results discussion.

4. Results and discussion

Regarding the results of water and sediment, differences were found between both the considered matrices and the ports (Genoa and Toulon). In fact, the polymeric composition of the MPs found in the water samples was more heterogeneous than in sediments (10 and 4 polymers, respectively) and, similarly, the MP composition of samples taken in Genoa was more varied than in Toulon samples for both matrices (**Fig.3**). Prevalent presence of polyester can be highlighted in water, while sediment samples show a major content of polypropylene particles in both sites. Water and sediment samples from the Port of Genoa were generally richer in MPs than those from Toulon. Inside the ports, MP distribution obtained by sampling analysis depends on both sampling area and time. This variation in MP distribution, which does not depend on a change in the analysis methodology, is therefore evidence of the variability of the port marine environment, which is affected by both natural and anthropic forcings, such as weather and sea parameters (wind, currents, wave and rain), river inputs and port activities (propeller action on the seabed, dredging activities, city discharges, etc.). For example, in the Port of Genoa in the first sampling campaign, the highest MP concentration (431 MP L^{-1}) was found in sediments of the inner part of the basin (where the ferry and cruise ship terminals are located), while in the second campaign, the highest concentration (60 MP L^{-1}) was lower and found in the western sector of the port off the mouth of a torrent. On the contrary, in the waters of Toulon, the second campaign showed higher concentration than the first campaign (2.8 and 0.7 MP L^{-1}, respectively). All these results agree with the greater variability of port environment already found by other studies [8, 14-15], and also with the greater complexity of the Port of Genoa compared to Toulon, in terms of number and different types of port activities, morphology of the basin, presence of rivers, quantity of maritime traffic, etc. [16]. Moreover, the Port of Genoa is frequently subjected to dredging activities that involve moving bottom sediments from areas where it is necessary to increase or maintain the bottom depth for navigability to unconfined storage areas within the port basin [17-18], and these movements can alter the MP concentration of sediments [19] and can partially justify the differences found between the first and the second sampling campaigns. In addition, in the inner port areas, where the sea bottom is shallow, the action of the propellers of ferries and cruise or container vessels affects the sea bottom resuspending the bottom sediment [20] and thus putting any MPs present in it back into suspension in the water column.

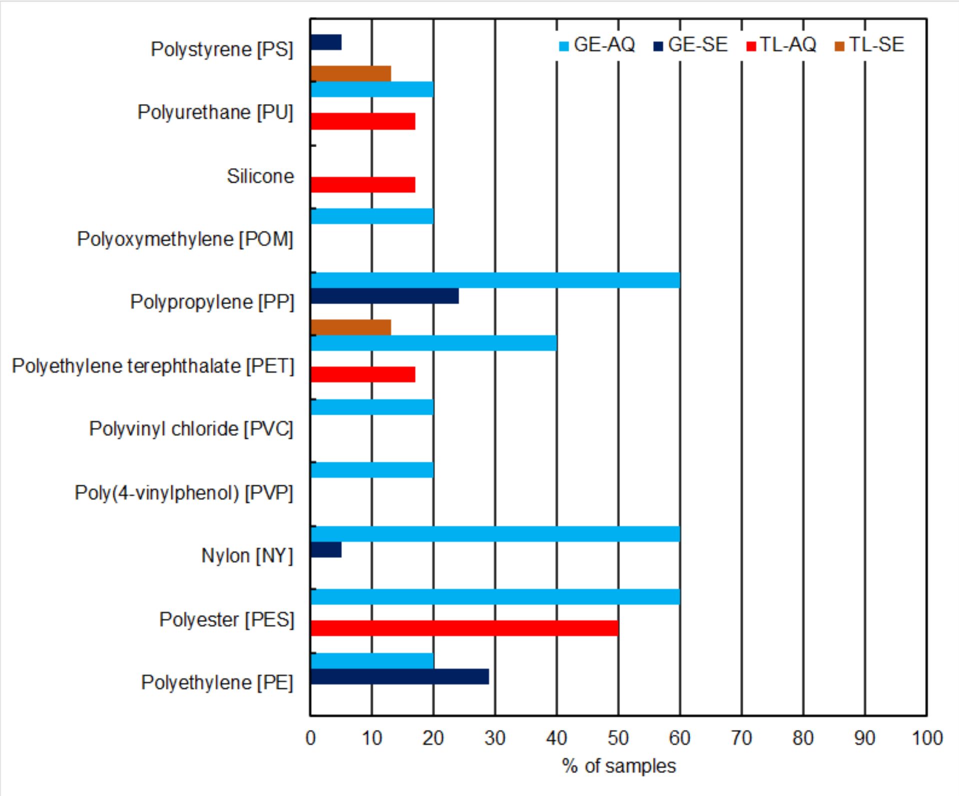

Fig.3: Overall percentage in the two monitoring campaigns of water and sediment samples from Genoa (light blue and blue, respectively) and Toulon (red and orange, respectively) containing the polymers listed on the *y*-axis

All scenarios obtained from the simulation of MP dispersion in the Port of Genoa show a mass spillage from the port area, even if with relatively low MP concentration. However, the worst scenarios are those in which there is a northern wind that invariably tends to lead to an increase in the amount of material released from the port, resulting in significant dispersion in the surrounding area (**Fig.4**). The port area is not very affected by the contribution to coastal circulation due to sea waves mainly because the surf zone in the proximity of the Genoa harbour is quite narrow and it does not let the development of significant longshore currents. The protected are of the port is obviously really well protected from the waves and the currents inside the harbour are mainly controlled by urban streams flowing inside the commercial harbour waters. The main forcing for the currents, hence, results to be the wind that is able to exert a drag force on the sea surface and trigger local circulation. Being a semi enclosed basin, the action of the wind is able to produce a net flow at the harbour entrances, making them a sort of control section for the exchange of mass between the internal part of the harbour waters and the coastal are close to the port itself. It is necessary to stress out how harbours represent at the same time a sink of pollution from MP because they can collect all the litter from inland waters and drainage systems, and a source of pollution for the coastal environment, because under specific meteocean conditions the accumulated litter can be delivered in the areas nearby the port itself. Nearby all the three harbours involved in the project are located areas of high environmental value corresponding as well to marine protected areas (Portofino, Porquerolles, Tavolara).

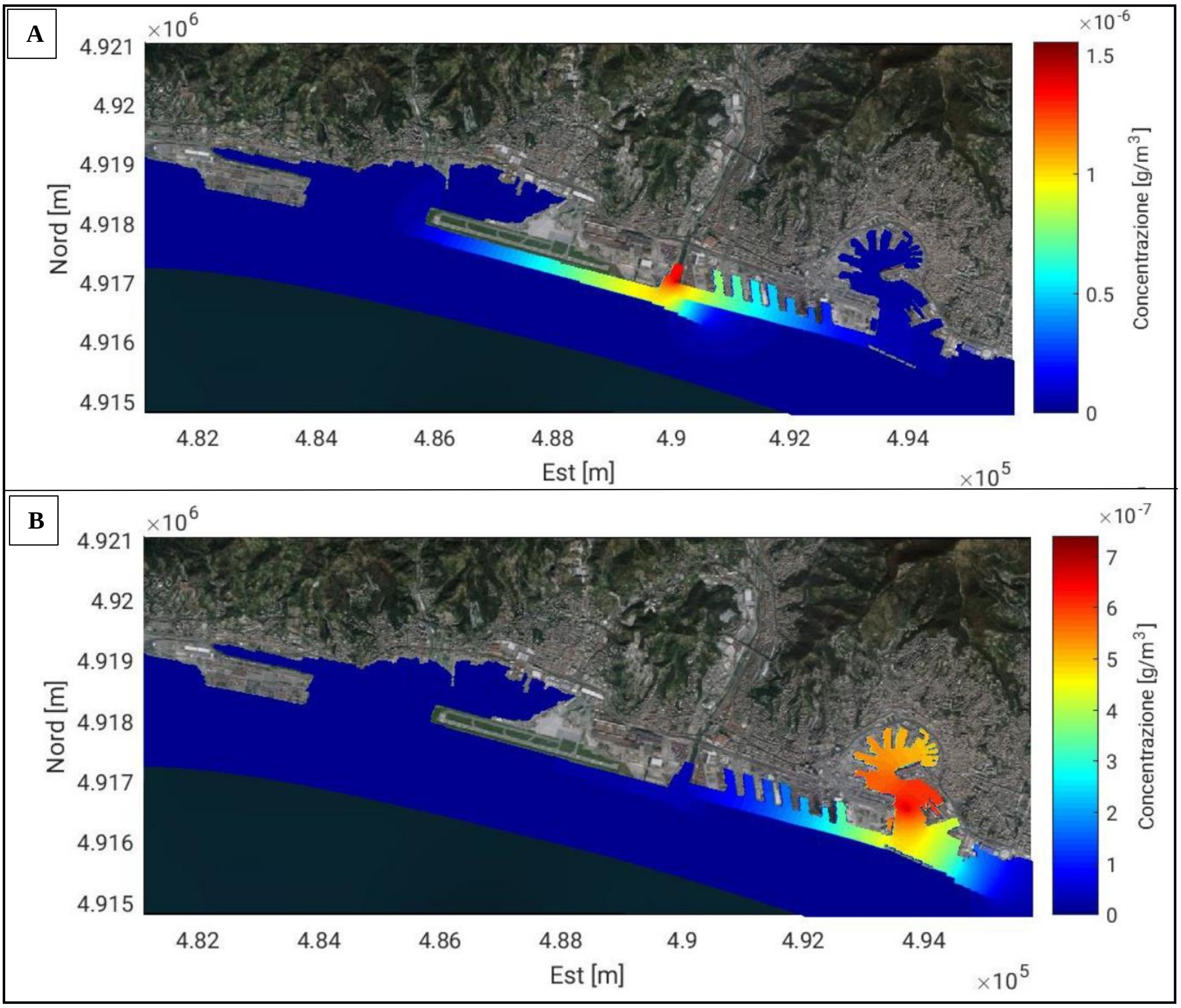

Fig. 4: Results of the evolution of the maximum concentration of tracer released at different points in the port area under different wind conditions during the winter season: a) release point at the mouth of the Polcevera stream with N wind; b) release point in the inner part of the port with N wind

Scenarios obtained were used to identify areas of accumulation of MPs based on meteorological and marine forcing, and thus to identify areas where monitoring should be concentrated or where containment actions by management authorities should be implemented.

The involvement of schools in the project area produced the numbers of students and classes showed in **Fig.5** making it possible to collect and catalogue plastic materials of different types (cigarette butts, cotton buds and plastic waste) in the quantities shown in **Fig.5**. Moreover, 11 three-year or master theses and 1 PhD thesis were realised, and 6 papers were published in international scientific journals [6, 8-9, 12-13, 21-22]. Finally, 6 research contracts were awarded to carry out the project activities.

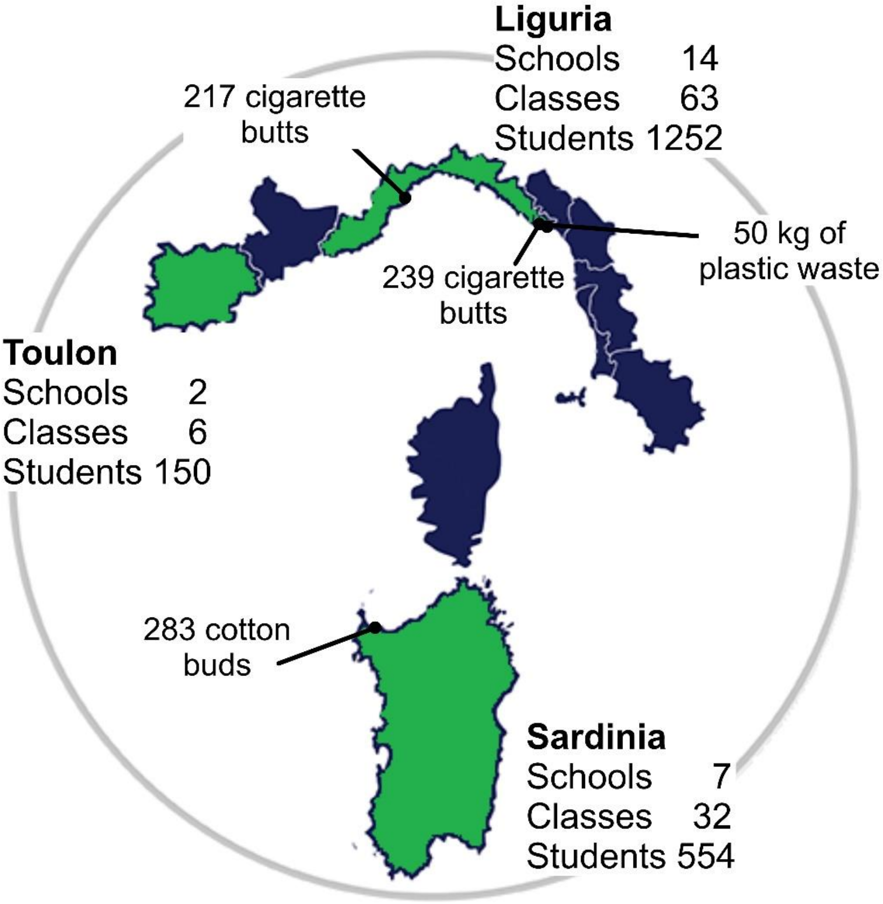

Fig.5: Results of dissemination activities: numbers of schools, classes and students involved in the activities in Toulon, Ligurian and Sardinia regions, and numbers of plastic items collected by students on beaches

The social game (https://www.europeanresearchinstitute.eu/splashseriousgame/) has been realised in Italian and French (the Maritime program languages), and also in English for its maximum dissemination. In order to interest as many people as possible and to broaden the vision of the problem of plastic pollution, the game was set in three different environments typically frequented by tourists: beach, sea and mountain (**Fig.6**).

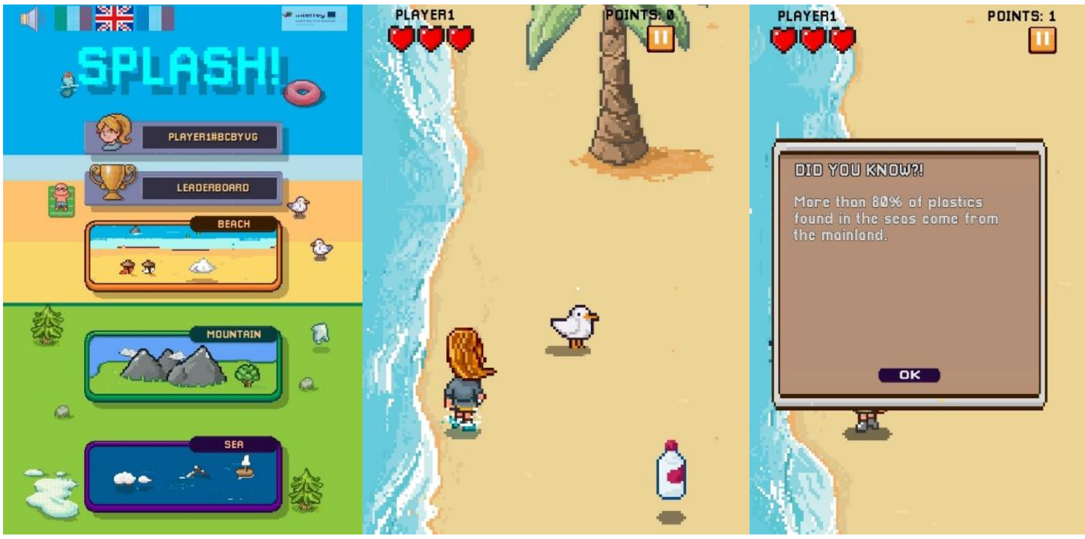

Fig.6: On the left, homepage of the social game of SPlasH! in which the player must start playing from the beach and then, can play in the other two available environments (mountain and sea); on the centre, a moment of play in the beach environment; on the right, an example of informative message that appears during the game

5. Conclusion

The "SPlasH!" Project provided useful information to better understand the degree and variability of MP contamination in marine port environments and the main physical processes governing their dispersion in harbour and nearby areas; furthermore, some simplified experiments revealed specific characteristics of MP dispersion under the action of sea waves. The obtained results, combined with the use of dispersion models, can be exploited by Port Authorities to improve the management of this environmental issue and to improve water quality. Further sampling campaigns will be held to increase knowledge and awareness on this environmental threat during the next SPlasH & Co "Stop to plastics in H2O in the time of Covid" Project that is started on February 2022.

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