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ESA Discovery and Preparation – OSIP

Campaign on Remote Sensing of Plastic Marine Litter



Tackling the plastic debris challenge at its source – Linking EO data with multi-source in-situ data for modelling debris pathways from source to sink

Executive Summary

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CONTRACT REPORT

The work described in this report was done under ESA contract.

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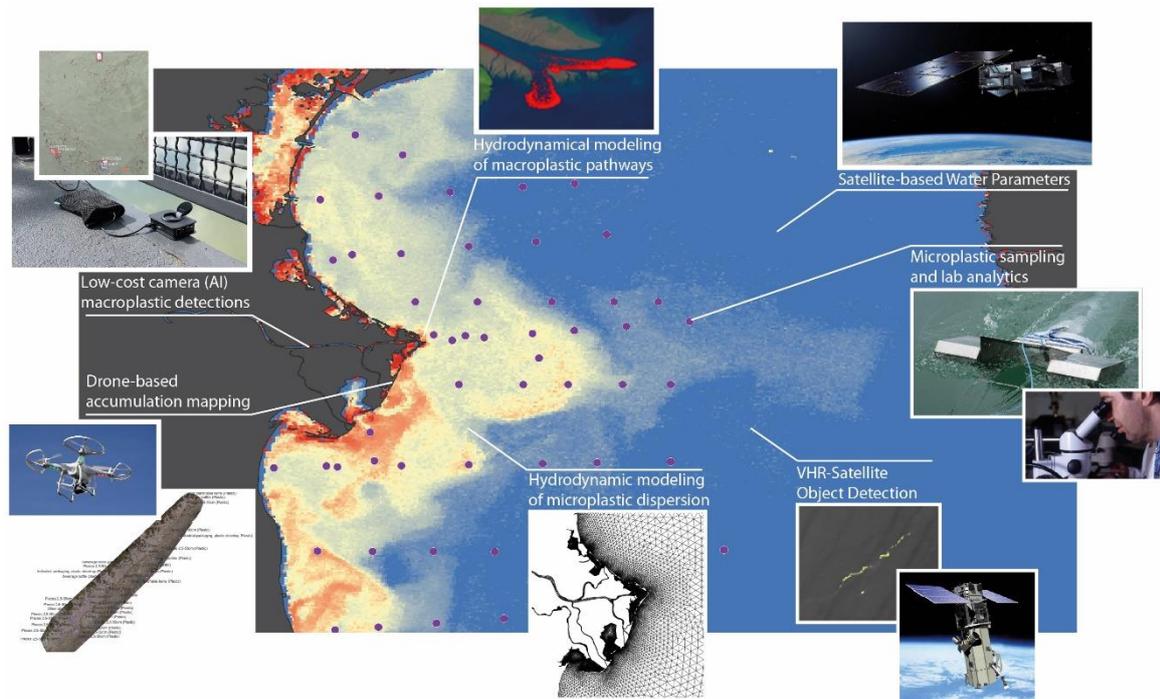
1 Aim of the document

This executive summary provides a brief description of the topics that have been addressed by the project “From source to sink”, which was an activity funded by the Discovery Element of the European Space Agency’s Basic Activities in the framework discovery campaign on Remote Sensing of Plastic Marine Litter. The project was coordinated by Remote Sensing Solutions GmbH (Germany) and realized together with six other European partners, namely Consiglio Nazionale delle Ricerche Istituto delle Scienze Marine (CNR ISMAR) from Italy, HYDROMOD Service GmbH from Germany, Asociación Española de Basuras Marinas (AEBAM) from Spain, Carl von Ossietzky Universität Oldenburg in Germany, Universidade de Coimbra in Portugal and University of Bayreuth in Germany. The innovation project started in August 2020 and was completed in September 2022.

This document summarizes the major findings of each research component and also provides future recommendations for monitoring concepts of plastic litter, based on the outcome of the project activities that were taking place in the study area located in the Po river and its delta.

2 Overall project logic

Monitoring areas closer to plastic marine litter sources that can be very well targeted, such as rivers and estuarine systems, has the potential to improve mitigation strategies. Since the area to be monitored is much smaller, mitigation strategies can be spatially focused and even clean-up activities can be more efficient (more targeted). Recent studies showed that floating plastics emitted from the coast depict a much greater chance to rapidly return to land with most litter stranding within a short distance of the river mouth. Our knowledge about the source, amount and spatial variability of both macro- and microplastic in aquatic ecosystems is still limited, partially due to analyses being based solely on in-situ point measurements. In-situ data are an important component for monitoring plastic debris, but these data alone cannot capture highly complex source-sink relationships. Field data taken in a highly dynamic water system that is influenced by processes such as wind, currents and waves, are only representative for a particular sampling location and time. However, regularly sampled in-situ data can be the input for hydrodynamic models that predict the spreading into coastal waters.



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Upscaling in-situ point data of litter with Earth Observation (EO) and hydrodynamic models was the central concept of the project. From source to sink (from river - to ocean - to coast), a wide range of technologies were for the first time tested together, starting with **low-cost camera systems** operated from bridges above the Po river, in order **to identify floating macroplastic particles** in the images using artificial intelligence (Faster-RCNN). The number of observed particles were used **as input to seed the macroplastic transport model** “HYDROMOD-Tracer”, which provides **transport pathways** for the particles. In addition to the macroplastic, the **in-situ microplastic data collected via manta trawls** in the river itself as well as in transects in the open ocean along the coastline, **could calibrate and validate the hydrodynamic model** (Regional Ocean Modelling System, ROMS) and the Lagrangian model **to simulate the dispersion pathways** of microplastics (ICHTHYOP). The collected *in-situ microplastic samples* that have been **analyzed using FTIR** (Fourier Transform Infrared) spectroscopy, allowed us not only to **quantify the abundance of microplastic and define the plastic type**, but also to **identify near-shore fronts** with a high abundance of microplastic debris. The locations of these fronts have also been **proved by the use of satellite-based total suspended matter** information. Along the further transportation pathway, **drones were used at potential hotspots of accumulation zones** with expected high rates of beached plastic particles. With the acquired drone imagery, microplastic particles were automatically classified to quantify the abundance of plastic litter along the shoreline.

3 Major project achievements per technology

3.1 Camera-based macroplastic monitoring in rivers

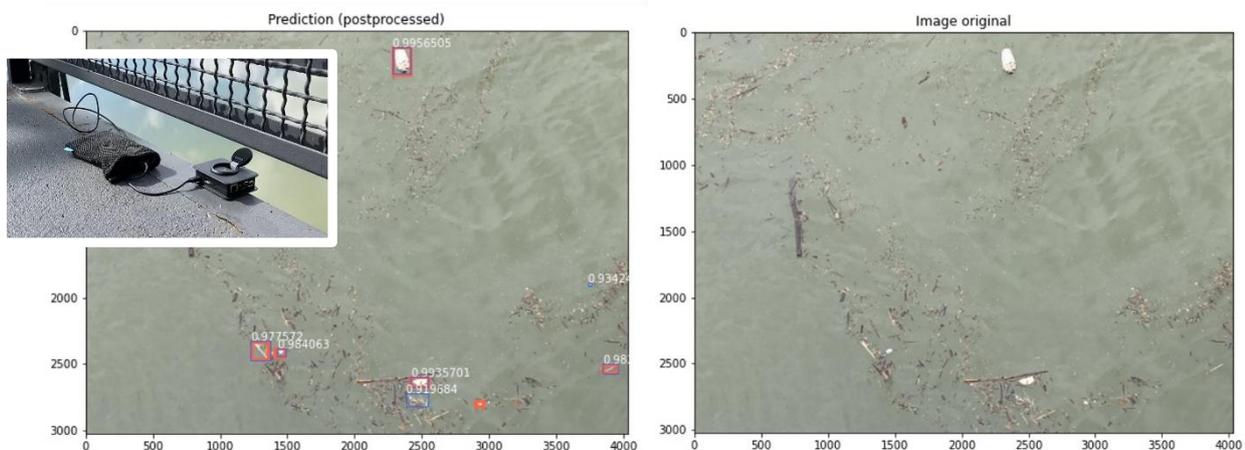


Figure 1: Example of an original image (right) and the predicted detections of macroplastic particles. Particles with a blue and a red box indicate correct detections, areas with a blue or red box only indicate false positive or false negative detections, respectively.

The project setup a low-cost camera system that can be automatically operated from bridges or features above the river surface, as well as a deep learning approach to identify macroplastic particles in the images. We decided to not consider expensive cameras, as these are not feasible from an operational perspective. Simple Raspberry Pi Cameras V2 were assembled with Raspberry Pi Controllers and power banks for the experimental tests. A user interface for accessing the camera settings via mobile phones was programmed. In total, 18,848 images were collected in the study area, of which 3,526 images were labelled in regard to macroplastic particles. These labelled images were then used to train and test a deep neural network (Faster-RCNN) for an automated plastic particle detection in images. Application of the final model to the Po River dataset resulted in an Average

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Precision score of 0.61, which are slightly lower scores than achieved by previous studies using expensive hyperspectral cameras. Besides these promising results, further development is needed if this technology is meant to be used in an operational monitoring. It would need to be extended by an object tracing algorithm.

3.2 Satellite remote sensing

Satellite data time series from the Copernicus Programme as well as very high-resolution satellite images were used for deriving information on river plume extent, the identification of ocean- and water-fronts and for identifying larger potential plastic objects offshore. Total suspended matter (TSM) is an indicator of river plumes and it plays an important role in the identification of potential plastic litter. We used the ready-to-use TSM product from Sentinel-3 and also developed a new machine learning based approach for generating high-resolution (10m) TSM maps based on Sentinel-2 data. River plume extents could be continuously monitored and potential fronts (where water from the river pushes against sea water) being identified.

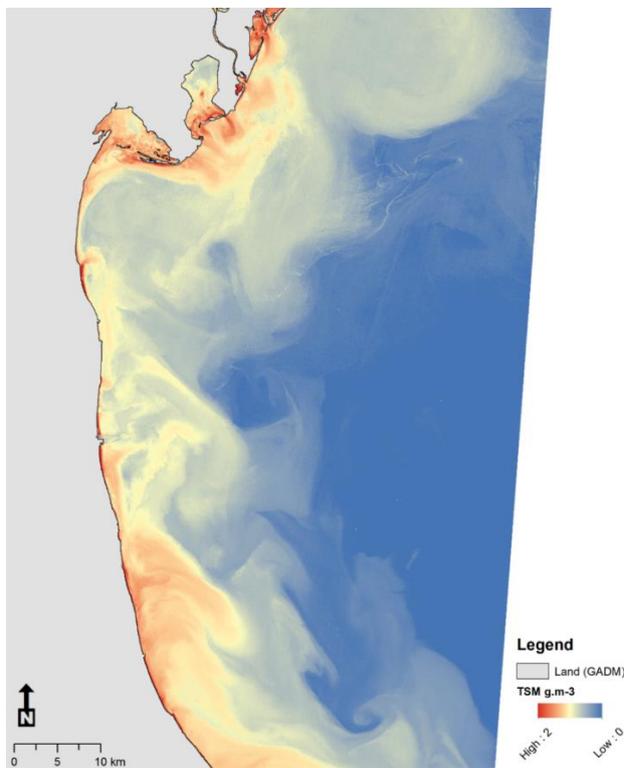


Figure 2: The prototype image using the Sentinel-2 TSM model (10 m). Several features of interest, including convergence areas can be identified in the image. The comparison with Sentinel-3 based TSM data highlighted a strong correlation between both datasets. In addition, a comparison between the Sentinel-2 TSM estimates and the Secchi Disk Depth data measured in-situ at offshore sample stations proved the plausibility of the Sentinel-2 based Total Suspended Matter data.

Very high-resolution satellite data were acquired from the WorldView-2 mission during the main offshore data collection campaign (PoPLAST 2021 cruise). Two object identification approaches were tested, both basing on the combination of an edge-detection approach using the panchromatic band and the spectral reflectance of the multi-spectral bands and one approach basing on a combination of a spectral angle analysis of the multispectral image and an edge detection on the panchromatic image. Objects such as suspected buoys along a fishing line, suspected plastic litter along windrows as well as fishing boats with surrounding fishing equipment could be thus identified in the images.

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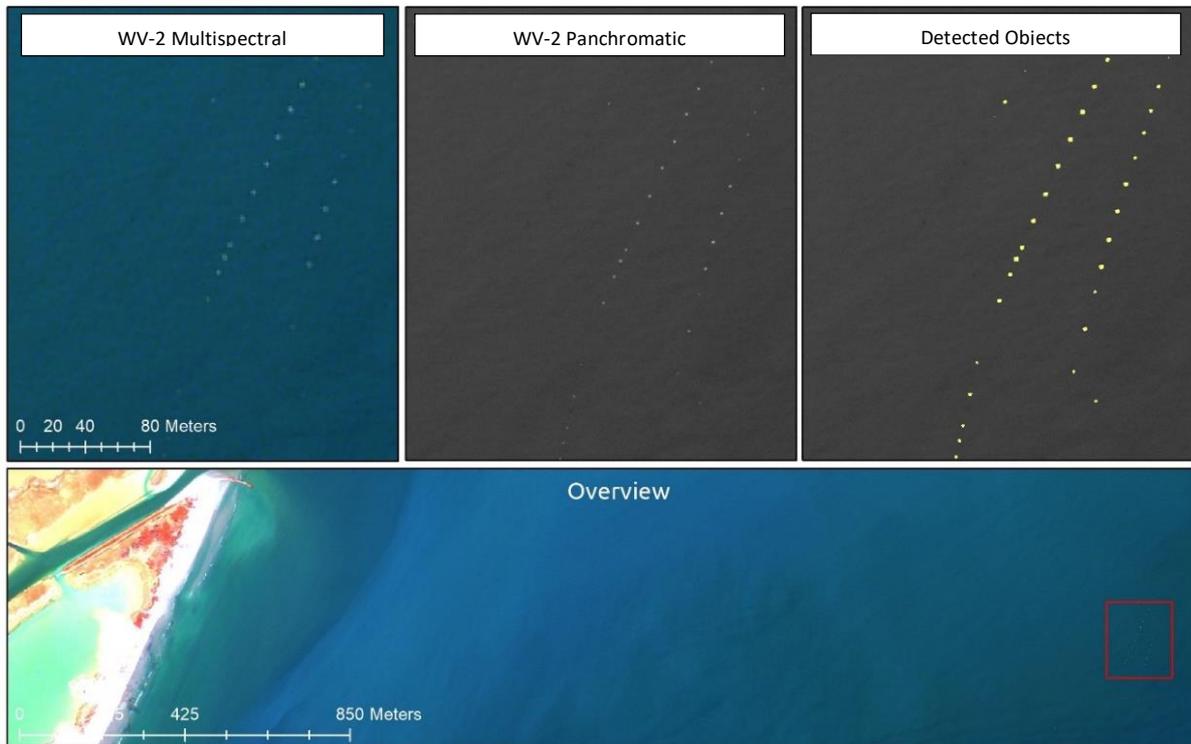


Figure 3: A World View-2 true colour composite (left), panchromatic image (center) and detected objects (right) (suspected fishing line with buoys).

3.3 In-situ microplastic sampling and laboratory analytics

The scope of two field campaigns was to collect in-situ data on various water parameters offshore. Specifically, conductivity, temperature and depth (CTD) data provided the base for the physical validation of the hydrodynamical simulations, while the microplastics samples collected with the manta tow were used to indicate the performance of the microplastic dispersion models. In March 2021, an extensive two-weeks offshore campaign onboard the R/V Dallaporta was conducted (PoPLAST) and one campaign in October 2021 in the Po Delta area. During the PoPLAST cruise, 12 transects and 85 stations were identified for physical sampling. In total, 45 water samples (cyan and green dots in Figure 4) with 20 minutes transects with a 330 μ m net manta tow were collected, 15 zooplankton samples (cyan dots) with the same manta tow and 15 sediments samples (cyan dots in map) with a sediment grab.

Back on land, the samples were pre-processed in the laboratories of CNR-ISMAR and then prepared for shipping to the partner at University of Bayreuth, where state-of-the-art analytical procedures were applied, including a 1. reduction of the amount of degraded organic residues, 2. sorting out putative microplastic particles > 300 μ m under the stereomicroscope, 3. documentation of each sorted particle by photos, 4. determination of the polymer type via FTIR spectroscopy and 5. recording of size, shape and color of each single microplastic particle.

The results showed that Polyethylene (PE), Polypropylene (PP) and Polystyrene (PS) were the dominant polymer types found among the mainly fragmented particles. Stations with much higher microplastic abundances were identified, which suggests that water fronts were covered in the sampling, at which high concentrations of plastics accumulate. These fronts were also visible in the satellite-based total suspended matter maps from the same date.

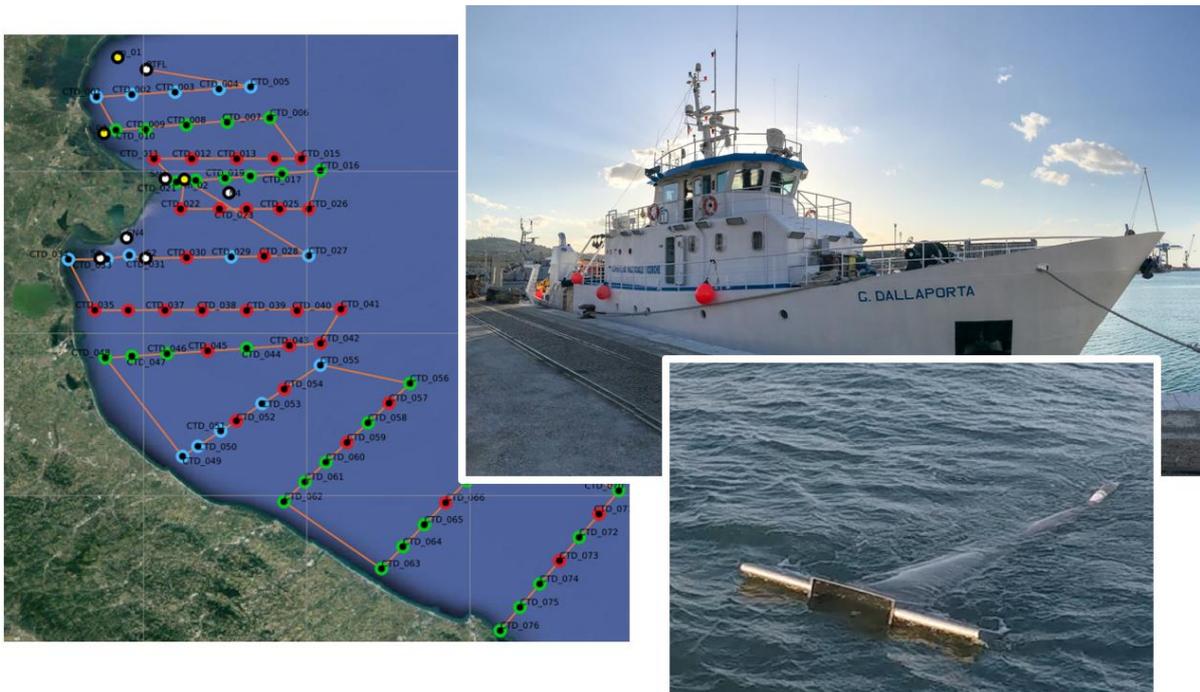


Figure 4: Map of the stations (left) at which various parameters were measured during the PoPLAST cruise in 2021, the ship R/V Dallaporta (upper right) and the manta trawl for microplastic sampling (lower right).

3.4 Hydrodynamic modelling of micro- and macroplastic pathways

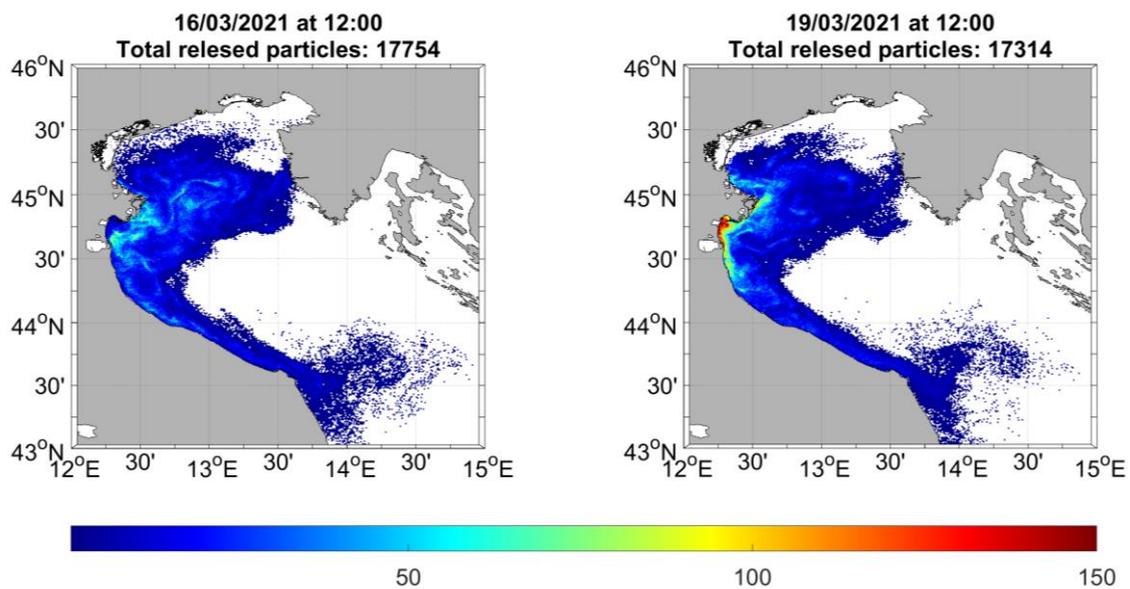


Figure 5: Result of a simulation of microplastics of riverine origin distribution on March 16th and March 19th from the Lagrangian simulations. The colour maps represent the number of particles present on each node of a reference grid. The total number of released particles is shown in titles.

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Another focus of the project was the use of hydrodynamic models to simulate the dispersion pathways of micro- and macroplastics of riverine origin. First, we implemented the Regional Ocean Modelling System (ROMS) hydrodynamical model to simulate the temperature, salinity and current fields. Several adaptations of the model aimed to better represent the delta and coastal dynamics. Second, a Lagrangian model was forced to simulate the dispersion pathways of **microplastics**. A number of drifters was released in the model every two hours in front of each river mouth and followed for the next 20 days. The track of the released particles was used to identify the distribution of particles in the coastal waters (Figure 5).

In addition, **macroplastic** distribution were modelled, both, inside the river branches and delta lagoons (via hydrodynamical model SHYFEM) and in coastal and open waters (via the tracer model HYDROMOD). The results from the tracer model showed that larger objects of macroplastic (>500 mm) are more subject to wind drag than smaller objects and are thus transported differently, depending on the wind speed and direction, which suggests that particles are sorted by size while being transported.

3.5 Detecting beached macroplastics using drones

A field campaign was conducted at selected beaches in the Po Delta where drones were operated with the aim of collecting data for the purposes of verifying the modelling results for macroplastic accumulation along the coastline. Based on an agreed field protocol for drone operations, representative 100 m transects were covered along the pre-defined beach locations. Two UAV platforms were deployed, a MATRIX 600 (with a MICASENSE REEDGE multispectral camera) and a PHANTOM 4 Pro. For each surveyed beach, the hundreds of single pictures taken were then composed into a georeferenced orthomosaic and then further analyzed in the 'LitterDrone' software. The LitterDrone software employs a machine learning algorithm, based on parameters such as the colour and shape of plastic objects and beach background, in order to identify microplastic particles (>2,5cm) in the very high-resolution images. The distribution and type of macroplastic particles could thus be mapped using the very high-resolution drone data.

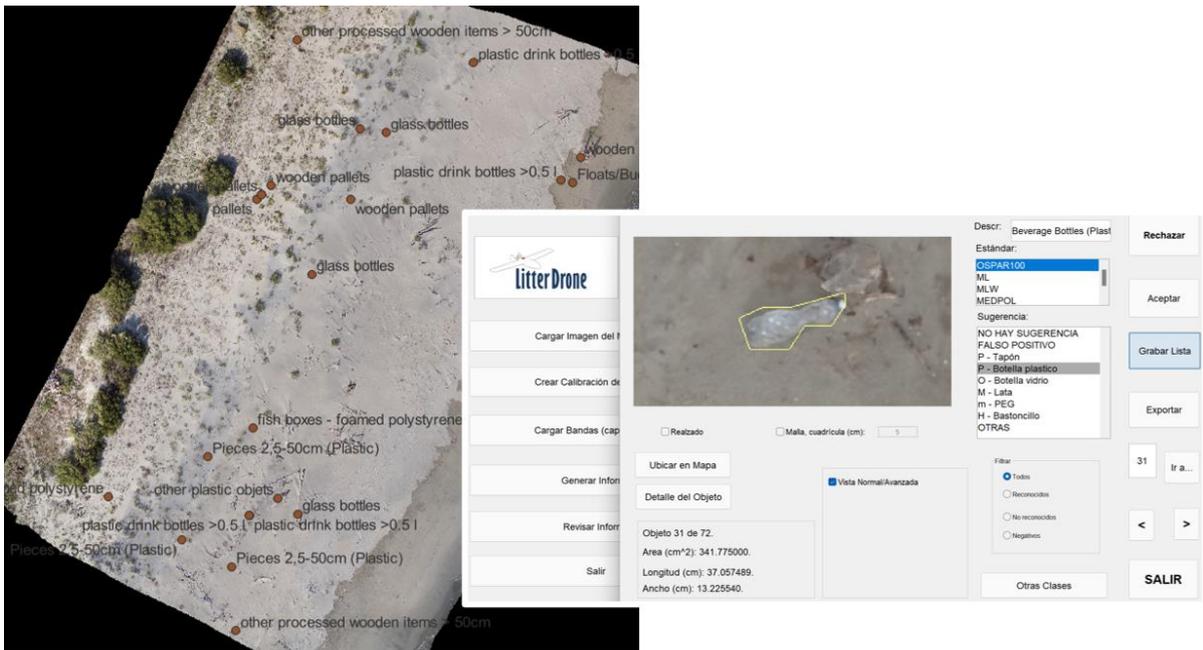


Figure 6: Orthomosaic of Barricata beach with the detected and identified objects (left) by the LitterDrone software (right).

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4 Project Summary and Outlook

The aim of this innovation project was the linking of EO data with multi-source in-situ data for modelling debris pathways from source to sink. The demonstration area for this endeavour was located in the delta of Italy's most polluted river, the Po.

A monitoring system able to predict entry points, dispersal trajectories and accumulation areas can offer an innovative, versatile tool for coordination of both abatement and removal measures. Our project therefore prototyped a modular monitoring system, for the first time bringing a wide range of technologies together that can lead to a holistic source-to-sink monitoring. These technologies included satellite remote sensing, drone technology, near-range cameras, various in-situ plastic sampling techniques, lab analytics and hydrodynamic modelling. Each module was independently developed by the different partners, in order to test the readiness level of the various technologies. The modules were finally linked in order to demonstrate the inter-linkages and the benefits of the technologies as a whole.

This proof-of-concept can lay the groundwork for future concepts. With additional research, development and test activities in the future, this monitoring concept can lead to an operational system that provides continuous spatial information crucial for entities and stakeholders involved in the mitigation and removal of plastics in the environment. Activities to keep shorelines free of waste are quite costly (ca. 1,300 USD/t of waste or 4,000 USD/km of cleaned beach). Such monitoring system could then not only support prevention and counteraction activities, but also spatially target interventions and help to make them more efficient. A functional monitoring system could also provide the opportunity to remove more plastic from the environment in order to recycle certain types of plastic. Monitoring concepts such as demonstrated in this project can act as a significant contribution towards the creation of an urgently needed legal basis for avoiding water system impairment through plastic contamination, since threshold monitoring will require a functioning measurement system.